Reading Emotions: How people with Autism Spectrum Disorders process emotional language

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Chapter 1

General Introduction

1.1 Introduction

Autism Spectrum Disorder (ASD) is a highly complex and clinically and etiologically heterogeneous disorder with a population prevalence of about 1% (Matson and Kozlowski, 2011; Matson and Shoemaker, 2009). Despite thousands of research papers on ASD are being published each year, our knowledge about the clinical phenotype and its neural underpinnings and etiology is fragmentary. This thesis is aimed at advancing our understanding of the recognition and processing of emotions in ASD, with a special focus on emotion language. In the sections below, I will shortly further introduce ASD, emotion symptoms in ASD and the recognition and processing of emotions, language and ASD, and genetics of ASD. Then I will elaborate on the specific aims of the thesis.

1.2 Autism Spectrum Disorder

ASD is a pervasive developmental disorder that manifests in early childhood and persists through the entire life of an individual. The term "autism" to describe a specific mental disorder was first introduced by Kanner in 1943. He described nine patients, all boys, characterized by the same behavioral profile: emotionally cold and retracted, avoiding any kind of social interaction, and obsessed with a specific type of activity or behavior, like arranging toys in a certain order, spinning or hand flapping (Kanner, 1943). Before Kanner's time, these children would often be diagnosed as intellectually disabled. However, as autistic disorder, or autism, became more recognized, it also became clear that children with autism can also have normal or even superior intellectual skills. For long time, in the second half of the past century, autism was considered to be an extremely rare disorder. However, with time clinicians learned to better distinguish autism from intellectual disability and speech and language pathology, and recognize better the more subtle forms and expressions of autism in children, adolescents and adults with normal intellectual skills, which previously went undiagnosed. Hence, the diagnosis increasingly became more common.

Autism is diagnosed according to the algorithm of the DSM (Diagnostic and Statistical Manual of Mental Disorders). The previous version of DSM, DSM-IV-TR, had a category of Pervasive Developmental Disorders which included 5 separate diagnostic categories: Autistic Disorder, Asperger syndrome, Rett's syndrome, Childhood Disintegrative Disorder, and pervasive developmental disorder not otherwise specified (PDDNOS) (APA, DSM-IV-TR, 2000). In 2013, a new version of the DSM was published in which Autistic Disorder, Asperger syndrome and PDDNOS were combined in one broad category of ASD, and Rett's syndrome and Childhood Disintegrative Disorder were removed. Additionally, a new diagnosis of Social

Communication Disorder was added to include people who have persistent problems in social interaction, but do not meet the diagnostic criteria for ASD (APA, DSM-5, 2013).

DSM-5 criteria for the diagnosis of ASD differ from the DSM-IV-TR in several aspects. First, DSM-5 combines the symptoms in two domains instead of three. The first domain includes impairments in social interaction and communication, which were described as two separate domains in the previous version of DSM. It includes behaviors such as reduced eye contact, failure to initiate or respond to social interaction, deficits in maintaining social relationships. The second domain includes repetitive and restricted behaviors and activities.

DSM-IV	
Autistic Disorder	• Qualitative impairment in social interaction; • Qualitative impairments in communication; • Restricted repetitive and stereotyped patterns of behavior, interests, and activities; • Delays or abnormal functioning in at least one of the following areas, with onset prior to age 3 years: (1) social interaction, (2) language as used in social communication, or (3) symbolic or imaginative play.
Asperger Syndrome	• Qualitative impairment in social interaction; • Restricted repetitive and stereotyped patterns of behavior, interests, and activities • The disturbance causes clinically significant impairment in social, occupational, or other important areas of functioning • No clinically significant general delay in language development • No clinically significant delay in cognitive development
PDDNOS	• A severe and pervasive impairment in the development of reciprocal social interaction, verbal and nonverbal communication skills, or presence of stereotyped behavior, interests, and activities • Not meeting diagnostic criteria for a specific Pervasive Developmental Disorder, Schizophrenia, Schizotypal Personality Disorder, or Avoidant Personality Disorder
Rett Syndrome	• All of the following: – apparently normal prenatal and perinatal development – apparently normal psychomotor development through the first 5 months after birth – normal head circumference at birth • Onset of all of the following after the period of normal development: – deceleration of head growth between ages 5 and 48 months – loss of previously acquired purposeful hand skills between ages 5 and 30 months with the subsequent development of stereotyped hand movements (e.g., hand-wringing or hand washing) – loss of social engagement early in the course (although often social interaction develops later) – appearance of poorly coordinated gait or trunk movements – severely impaired expressive and receptive language development with severe psychomotor retardation

Childhood Disintegrative Disorder	• Apparently normal development for at least the first 2 years after birth; • Clinically significant loss of previously acquired skills (before age 10 years) in at least two of the following areas: – expressive or receptive language – social skills or adaptive behavior – bowel or bladder control – play – motor skills • Abnormalities of functioning in at least two of the following areas: – qualitative impairment in social interaction; – qualitative impairments in communication; – restricted, repetitive, and stereotyped patterns of behavior, interests, and activities; • The disturbance is not better accounted for by another specific Pervasive Developmental Disorder or by Schizophrenia
DSM-5	
Autism Spectrum Disorder	• Persistent deficits in social communication and social interaction across multiple contexts; • Restricted, repetitive patterns of behavior, interests, or activities; • Symptoms must be present in the early developmental period; • Symptoms cause clinically significant impairment in social, occupational, or other important areas of current functioning; • These disturbances are not better explained by intellectual disability or global developmental delay; • having a DSM-IV diagnosis of Autistic Disorder, Asperger syndrome, or PDD-NOS.
Social Communication Disorder	• Persistent difficulties in the social use of verbal and nonverbal communication; • The deficits result in functional limitations in effective communication, social participation, social relationships, academic achievement, or occupational performance; • The onset of the symptoms is in the early developmental period; • The symptoms are not attributable to another mental disorder.

Table 1. Summary of diagnostic criteria for autism-related disorders in DSM-IV-TR and DSM-5.

In the DSM-IV-TR, this domain included behaviors such as stereotyped movement, rigid daily routines, unusually intense and restricted interests. In the new version of the DSM, this domain was extended to include sensory symptoms, such as hypersensitivity or hyposensitivity to certain types of input such as sounds or textures (APA, DSM-5, 2013). Finally, DSM-5 allows for comorbidity of ASD and ADHD, which was not possible in the previous version.

1.3 Emotions and emotional symptoms in ASD

The diagnostic criteria for ASD also include emotional symptoms: a lack of emotional reciprocity, reduced sharing of affect and enjoyment (DSM-5, 2013). A number of studies shows that individuals with ASD are impaired in recognizing and processing of emotions (Smith, Montagne, Perrett, Gill, and Gallagher, 2010; J. B. Grossman, Klin, Carter, and Volkmar, 2000). People with ASD have problems recognizing and reacting appropriately to emotions of others (Scambler, Hepburn, Rutherford, Wehner, and Rogers, 2007), and identifying facial and prosodic expressions of emotions (Wolf et al., 2008; Peppé, McCann, Gibbon, O'Hare, and Rutherford, 2007).

However, with studies of emotions in social context it becomes difficult to disentangle possible contributions of social and emotional impairments. It could be that the neural networks underlying emotion processing in ASD are functioning normally, and atypical performance in facial emotion recognition tasks comes from participants with ASD having less interest in faces and social scenes, and less experience with observing facial expressions of others. Additionally, a number of studies failed to find a significant deficit in facial emotion recognition in the ASD group, even when a more difficult task was used (Tracy, Robins, Schriber, and Solomon, 2011) or the cognitive ability was taken into account (Loveland et al., 1997). One possible explanation for these negative results is that emotional impairments are secondary to the problems with social skills, therefore participants with better social skills from a high-functioning end of the spectrum would not show a significant emotional impairment. An alternative explanation is that participants with ASD could use learned strategies to correctly label the photos, therefore we need to look at brain activity and implicit measures of emotion processing where participants could not apply learned strategies.

To resolve the question whether emotional impairments in ASD are secondary to the problems of social interaction or reflect a more general deficit it is important to study emotion processing in a variety of different tasks and using different types of stimuli, such as language. A few studies investigated how people with ASD process emotion in other types of stimuli, such as images and words. One finding that has been replicated is the atypical emotional memory effect in ASD (Deruelle, Hubert, Santos, and Wicker, 2008; Beversdorf et al., 1998; Gaigg and Bowler, 2008, 2009b). Normally, people remember emotional information better than neutral. Emotional words and images are perceived by the brain as motivationally salient, and they recruit more processing resources, which results in a better encoding.

However, this emotional memory advantage seems to be absent in autism. One study asked people with ASD and matched controls to memorize and recall spoken sentences. They found that people with ASD recalled the same number of emotional and neutral sentences, while the comparison group recalled emotional sentences significantly better (Beversdorf et al., 1998). Another study presented participants with a set of positive, negative and neutral images, and later asked them to recognize those images in a recognition memory test. ASD and control group showed a significantly different pattern of results: typical participants recognized emotionally negative images significantly more accurately than positive or neutral, while participants with ASD did not show a difference in memory accuracy for positive, negative or neutral images (Deruelle et al., 2008). A similar result was obtained using emotion words. In another study, participants were asked to memorize emotional and neutral words and recall them at 3 different time intervals (immediately, after 1 day and after 1 week). Typically developing participants recalled emotional words better at each of the time points. Participants with ASD also demonstrated an emotional memory advantage at immediate recall. However, in the ASD group this advantage was gone at the two later time points, when they recalled emotional words at an equal rate as the neutral words (Gaigg and Bowler, 2008). Finally, typically developing participants were better at correctly rejecting words that were not presented at the memorizing stage when those words were emotional. But participants with ASD were equally likely to falsely recall emotional and neutral words (Gaigg and Bowler, 2009b). These results suggest that emotionally valenced stimuli may in general be less salient for people with ASD, resulting in a less efficient encoding. However, another study using stories presented in picture slide sequence or in video clips found enhanced memory for emotionally arousing stories in both ASD and control groups (Maras, Gaigg, and Bowler, 2012).

Two more studies investigated stimulus detection for emotional and neutral words (Gaigg and Bowler, 2009a; Corden, Chilvers, and Skuse, 2008). Participants watched words appearing on the screen in a rapid serial visual presentation stream, and were asked to detect target words that were presented in a certain font. Normally this task is relatively easy. However, when two target words appear very fast one after another, people usually detect only the first word, and miss the second word. the reason for this is because people's attention is still engaged with the processing of the first word, and when the second word appears, there is not enough processing resources left to detect it. This phenomena is called attention blink.

In typical people, attention blink is attenuated for highly arousing emotional words: because of high emotional salience of these words, they are detected very well regardless of whether there was another target word presented right before them. However, two studies that investigated attention blink in ASD sample found that people with ASD missed emotional and neutral words equally likely in such an attention blink paradigm (Corden et al., 2008; Gaigg and Bowler, 2009a). These results further argue for atypical processing of emotional information in participants with ASD, and for a widespread emotional deficit which is not restricted to the context of social interaction.

In all, there is some evidence for impairments of emotion processing outside of the context of social interaction, but because of a small number of studies and a limited range of paradigms so far it is difficult to draw definite conclusions. For example, the two attention blink studies mentioned above used taboo and sexually explicit words as their emotional stimuli. These words form a very specific subset of emotional stimuli, so it is not clear whether those findings would generalize to other types of emotional words. Also, sometimes individuals with ASD demonstrate a typical emotional memory advantage for emotionally arousing stimuli (Maras et al., 2012; Gaigg and Bowler, 2008; South et al., 2008), suggesting that other factors may come into play, such as task requirements, timing of the experiment and level of engagement of participants in the task. Recent reviews in this field have pointed out that while there is evidence for atypical emotional processing in ASD, the underlying cognitive mechanisms and interaction with other cognitive domains are not well understood (Gaigg, 2012; Nuske, Vivanti, and Dissanayake, 2013; Uljarevic and Hamilton, 2013; Lartseva, Dijkstra, and Buitelaar, 2015).

1.4 Language in ASD

While language impairment is not on the list of diagnostic criteria anymore, a delay in linguistic development is a common symptom in ASD. There is a lot of variability in the severity level of language problems (Groen, Zwiers, Gaag, and Buitelaar, 2008; Eigsti, de Marchena, Schuh, and Kelley, 2011). Most severe impairments, such as complete absence of language, are relatively rare, while subtle deficits in semantic and pragmatics and problems with understanding non-literal meaning, irony or humour are almost universal in ASD (Pijnacker, Hagoort, Buitelaar, Teunisse, and Geurts, 2009; Loukusa et al., 2007; Pexman et al., 2011).

1.5 Genetics of ASD and Broad Autism Phenotype

ASD is a disorder with substantial heritability (Abrahams and Geschwind, 2008), although more recent studies tend to report lower heritability estimates (Hallmayer, Cleveland, Torres, and et al., 2011). The genetics of ASD is highly heterogeneous, and there are probably thousands of genetic variants that can contribute to a risk of developing ASD. Some of those variants are rare de novo mutations that lead to monogenic disorders with symptoms of autism, such as Fragile X syndrome or tuberous sclerosis. Other genetic variants raise the risk of developing ASD only by a small fraction, and a child must inherit a combination of those risk variants to develop a disorder. It is thought that most cases of autism are caused by a combined effect of multiple genes (Abrahams and Geschwind, 2008). In this case, other family members (parents and siblings) would also share some of those risk variants, but in a combination that is not sufficient for developing a disorder.

Studies investigating ASD traits in parents and siblings also confirm this: first-degree relatives without a diagnosis of ASD also have more ASD traits than the general population. Researchers use the term "broad autism phenotype" (BAP) to describe people with ASD traits that do not reach the severity level required for the diagnosis.

Many features previously associated with ASD have also been found in people with BAP, such as (write something here)

1.6 Aims of the thesis

It is not well understood how people with ASD process emotional (positive and negative) words compared to neutral words. Only a few behavioral effects (such as emotional memory effect and attention blink) have been investigated. Few studies investigated brain systems involved in emotion language processing using fMRI (Kennedy and Courchesne, 2008; Han, Yoo, Kim, McMahon, and Renshaw, 2014; Mason, Williams, Kana, Minshew, and Just, 2008), and these studies reported that ASD group recruited additional brain regions (such as right-hemisphere homologs) during emotion word processing. These results suggest that individuals with ASD have some problems with processing of emotion at the neural level. However, so far no studies looked at the time course of emotion word processing using electrophysiological brain activity. Thus, it is not clear whether participants with ASD are slower at detecting emotional valence of the stimuli, in which case the effects would be

delayed, or they are slower at processing it, in which case the effects will be extended in time. Furthermore, the studies looking at emotional language processing often did not compare processing of emotional aspects of the word to other non-emotional lexical or semantic aspects. Therefore, it remains an open question whether the differences between ASD and control groups that were found in these studies were specific to emotion or they were a consequence of a general difficulty of ASD participants with verbal stimuli.

The overall aim of my thesis was to extend our understanding of the processing of emotion language in ASD. The following research questions were addressed:

1. How do people with ASD process emotion words in a non-emotional task which does not require extensive processing of the meaning of the word or affective valence? What are the neural (event-related potential) correlates of processing emotion words? And if they process emotion words in an atypical way, is this specific to emotion, or is it also present for a different word characteristic, namely lexical frequency?
2. How do people with ASD process emotion words in an evaluation judgment task which requires an explicit evaluation as emotionally positive or negative? And how does presenting an emotion word affect the processing of a following word?
3. Are people with ASD able to integrate emotion words into sentence context? What are the neural correlates of emotion word processing when those words are encountered during passive reading of sentences?
4. People with ASD have previously been shown to have difficulty to match emotion words to facial expressions. Is this an endophenotypic feature of ASD? Would unaffected first-degree relatives of individuals with ASD show an atypical pattern of behavioral responses and eye movements when matching emotion words to facial expressions?

1.7 Methods used in this thesis

In this thesis I make use of two methods: electroencephalography (EEG) and eye-tracking. Below we provide the background on these methods. EEG is a method to record electrical brain activity. Our brain consists of billions of brain cells, or neurons. When a neuron is active, there is an electrical current running along the cell membrane. The current generated by one neuron is very small and it is impossible to detect without doing invasive measurements. However, simultaneous activity of several thousand neurons can generate enough electrical current so that can be detected with EEG sensors on the surface of the

head. In order for currents generated by individual cells to add up, the cells have to be aligned. Additionally, the signal strength rapidly decreases with the distance between the source of the signal and the sensor. Because of that, the EEG mostly reflects the activity of the pyramidal neurons in the neocortex, which are both aligned with each other and are located close to the skull (as opposed to the subcortical structures, such as the amygdala or striatum, which are located deep inside the brain, and where the spatial organization of the cells is more complex).

The EEG sensors measure the electric potential on the surface of the head. The electric potentials at different locations can be influenced by currents generated by the brain. However, the absolute value of the electric potential at a given location is meaningless by itself. It can only be interpreted as being smaller or bigger compared to the neighbouring sensors. Therefore what EEG activity measured by a given electrode actually represents is voltage relative to a reference, or in other words a difference in electric potential between the current electrode and a reference electrode which is chosen as an arbitrary zero level. One reference which is commonly used in language studies is a mastoid reference. Mastoid is located behind the ear, and it is a place where the skull is thicker than at other places, therefore the electric potential measured at mastoid is relatively less affected by brain activity. Another possibility is to use average reference, i.e. to take the sum of all electrodes as zero. By definition, the sum of voltages measured around a sphere is always zero. Therefore, if we could cover the entire head with electrodes, then average reference would actually give us the true magnitude of the signal. However, most EEG systems (including the one we used) do not cover the face. Therefore, average reference is not always optimal.

One common way to analyze EEG activity is to look at so called event-related potentials (ERP). Whenever a participant has to perform a particular task (for example, to read a word on the screen), the same sequence of brain areas is activated. The evoked synchronized activity of thousands of neurons which were involved in performing this task produces the ERP. In the raw EEG signal, the ERP is obscured by other ongoing brain activity (staying awake, sitting upright, maintaining the task schema, and so on), as well as physiological activity outside the brain (electric potentials generated by heart, muscles, eye movements). However, if we average the segments of EEG activity and time-lock them to the events of interest, the ERPs from individual trials will be added together, and all other activity will be averaged out, resulting in an average ERP for a given task and condition. The ERP can be

further segmented in different ERP components. Each ERP component roughly corresponds to a particular cognitive operation, or processing stage. Notable ERP components include the P1 and N1, which reflect early stimulus detection, the N400, which reflects processes involved in semantic analysis, and Late Positive Component (LPC), which includes several processes such as stimulus reappraisal, evaluation, and memory encoding.

The second method used in this thesis is eye-tracking. Eye-tracking can also inform us about the time course of processing a stimulus, and also of features of the stimulus that were relevant for the processing. In our experimental setup, the eye was continuously recorded with a camera, and the eye position was determined by comparing the location of the darkest spot (the pupil) and the brightest spot (the light reflection from the cornea). In addition to eye position, the camera simultaneously recorded pupil size, which is a measure of physiological arousal.

Eye-tracking provides a continuous measure of attention and information processing (Hermans, Vansteenwegen, and Eelen, 1999; Kellough, Beevers, Ellis, and Wells, 2008). The duration and order of fixations on different parts of the visual scene can reveal automatic orienting biases to certain stimuli or features as well as more conscious elaborative processing. Typically the eye gaze always follows where attention is focused, and although in laboratory conditions people are able to voluntarily focus their attention at a different location from where their eyes are fixated, this doesn't happen in normal viewing conditions (Jonides, 1981).

One of the experimental paradigms that has been widely used in cognitive psychology is the visual world paradigm (which has been reviewed extensively in Huettig, Rommers, and Meyer, 2011). In this paradigm, participants are simultaneously presented with a visual display and an auditorily presented utterance. The visual display can contain different stimuli such as simple schematic drawings or a complex realistic scene with multiple objects. The utterance can also consist of one word or of a longer piece of speech. Participants can be instructed to perform a task, such as click on the mentioned object, or to merely passively listen. The outcome variable in those types of experiments is usually the probability of fixation within a certain region of the image at a specific time point (Huettig et al., 2011). Normally this class of paradigms has been used to study language processing: for example, at the time course of phonological word processing (Mitterer and McQueen, 2009) or

at predictive understanding in sentence processing (Altmann and Kamide, 1999). However, this paradigm is also suitable for investigating visual processing in different groups of participants.

1.8 Structure of this thesis

This thesis aims to bridge this gap by investigating behavioral and neural correlates of emotion word processing in the ASD population by using a number of different experimental paradigms. In **chapter 2** we conducted a systematic review of the empirical literature on the processing of emotion language in ASD and discussed the findings in light of the current theories of ASD. In **chapter 3** we studied processing of emotion words presented in isolation in a lexical decision task which does not require an in-depth processing of word meaning. In **chapter 4** we used an evaluative judgment task to investigate explicit processing of emotion. Furthermore, we employed a word priming paradigm to look at two different effects: affective word priming, which operates through the salience detection network and involves a fast and bottom-up evaluation process, and semantic priming which operates through the semantic network in the mental lexicon and relies on the in-depth analysis of the word meaning. In **chapter 5** we studied the ERP correlates of processing of emotion and neutral words in sentence context in a passive reading task. In **chapter 6** we investigated matching of emotion words to facial expressions in a visual world paradigm by unaffected relatives of people with ASD. Finally, in **chapter 7** we provide a general discussion of the findings, the implications for the current understanding of ASD, as well as the directions for the future research.

Chapter 2

Emotional Language in Autism: a Systematic Review

Abstract

In his first description of Autism Spectrum Disorders (ASD), Kanner emphasized emotional impairments by characterizing children with ASD as indifferent to other people, self-absorbed, emotionally cold, distanced, and retracted. Thereafter, emotional impairments became regarded as part of the social impairments of ASD, and research mostly focused on understanding how individuals with ASD recognize visual expressions of emotions from faces and body postures. However, it still remains unclear how emotions are processed outside of the visual domain. This systematic review aims to fill this gap by focusing on impairments of emotional language processing in ASD. We systematically searched PubMed for papers published between 1990 and 2013 using standardized search terms. Studies show that people with ASD are able to correctly classify emotional language stimuli as emotionally positive or negative. However, processing of emotional language stimuli in ASD is associated with atypical patterns of attention and memory performance, as well as abnormal physiological and neural activity. Particularly, younger children with ASD have difficulties in acquiring and developing emotional concepts, and avoid using these in discourse. These emotional language impairments were not consistently associated with age, IQ, or level of development of language skills. We discuss how emotional language impairments fit with existing cognitive theories of ASD, such as central coherence, executive dysfunction, and weak Theory of Mind. We conclude that emotional impairments in ASD may be broader than just a mere consequence of social impairments, and should receive more attention in future research.

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2.1 Introduction

Autism spectrum disorder (ASD) is characterized by persistent impairments in social communication and interaction, restricted and repetitive behavior, and an onset of the disorder in early childhood (APA, 2013). While ASD was divided into subtypes in previous versions of the diagnostic and statistical manual of mental disorders (DSM), different forms of ASD are now combined in one broad category in the new DSM-5 (APA, 2013).

Clinically important diagnostic characteristics of ASD include lack of spontaneous seeking to share enjoyment, emotions, affect, interests, or achievements with other people, and a lack of emotional reciprocity. In his original description of autism, Kanner (1943) already emphasized the presence of emotional impairments, and characterized the patients as indifferent to other people, self-absorbed, emotionally cold, distanced, and retracted. However in the later years these emotional impairments were shifted to the background and were considered to be just a part of the core social deficits (Ritvo and Freeman, 1977; Rutter, 1978; Denckla, 1986; Fein, Pennington, Markowitz, Braverman, and Waterhouse, 1986). Most studies of emotion processing in ASD focused on facial emotion recognition (Harms, Martin, and Wallace, 2010; Jemel, Mottron, and Dawson, 2006; Uljarevic and Hamilton, 2013). A recent meta-analysis concluded that facial emotion recognition is indeed impaired in the ASD population, although there is considerable variability between studies and the true effect size is probably much smaller due to publication bias (Uljarevic and Hamilton, 2013). However, the evidence from studies with facial stimuli alone is not sufficient to draw conclusions about the severity and extent of emotional impairments in ASD. The reason is that individuals with ASD have problems with processing faces in general, not restricted to only emotional faces (Jemel et al., 2006; Harms et al., 2010). In contrast to typical individuals, individuals with ASD do not spontaneously pay attention to faces, ignore the eye region and focus on less significant parts of the face (Jemel et al., 2006; Wolf et al., 2008; Senju and Johnson, 2009). So, even in studies that do report main group effects in facial emotion recognition, it is unclear whether the differences should be explained by a more specific emotional impairment, or by more general problems in face processing.

Comparatively little attention has been paid in research in ASD to processing of other types of emotional stimuli, such as emotional language (understanding of emotion-laden words, sentences and text; talking about emotions; perception and production of emotional intonation in speech). In fact, a lack of research on emotion processing in non-social tasks has been

pointed out in earlier reviews (Gaigg, 2012; Nuske et al., 2013). If more generic emotional impairments exist in people with ASD that cause facial emotion processing deficits, we would expect to observe emotional impairments in language as well. The aim of this article is to provide a systematic review of the empirical literature with respect to emotional language in ASD, discuss the implications for our understanding of ASD, and give recommendations for future research.

In discussing emotional language in ASD it is important to keep in mind that many people with ASD have problems in language development and impairment in verbal and nonverbal communication. Phenotypically, most people with ASD have semantic, syntactic and pragmatic deficits, and a smaller number are known to have phonological deficits (Groen et al., 2008). On the most high-functioning end of the autism spectrum, people have no apparent language delay and normal to high verbal IQ with only minor difficulties with respect to pragmatic language use. In contrast, individuals on the most low-functioning end never develop any language at all. The majority of people with ASD range between these two extremes. This variation in verbal ability can be a major confound. Possible ways to deal with it include: (1) comparing high-functioning people with ASD to healthy controls matched on verbal IQ; (2) comparing people with ASD to other clinical groups with a similar level of language problems (for example, suffering from dyslexia or specific language impairment); and (3) including participants with a wide range of verbal abilities and testing if correcting for verbal IQ causes the effect of emotion to disappear.

2.2 Aim

There is an evident lack of knowledge on how individuals with ASD process non-facial emotional stimuli, such as language. This paper aims to fill this gap by providing a systematic review of emotional impairments in ASD with a primary focus on emotional language. We will address the following questions:

1. Is there evidence for emotional impairments in the language domain? Is it present in different experimental paradigms? Does it depend on modality, such as visual (i.e., reading words and texts) or auditory channel (i.e., listening to words and sentences), and/or on complexity of information: simple (single words) vs. complex (sentences and discourse)? Does it affect primarily implicit measures (which the participant is not aware of or is not able to exert conscious control: difference in memory performance,

error rates, physiological responses) or explicit processing of emotion (valence rating, verbal report)?

2. Does the degree of emotional language impairments in ASD individuals correlate with their clinical characteristics, such as the severity of cognitive and clinical linguistic impairments? If emotional impairments are caused by a linguistic or cognitive impairment, one would expect emotional impairments to be present more often and with greater severity in individuals with lower verbal or nonverbal IQ and a history of intellectual and language delay. In addition, IQ then would be negatively correlated with the severity of emotional impairments.
3. How do emotional language impairments fit within existing cognitive theories of ASD, such as the central coherence impairment, executive dysfunction, Theory of Mind account, and impairment of the mirror neuron system (MNS)? We will also explore whether the concept of alexithymia and motivational factors related to reward and punishment learning provide useful theoretical accounts of emotional language impairments in subjects with ASD.

2.3 Methods

To identify relevant articles, we systematically searched PubMed and Google Scholar for papers published from 1980 onwards using the following search terms: (1) autism OR autistic OR Asperger OR ASD; (2) emotion* OR affect OR feeling; (3) (1) AND (2). We selected all original studies that compared the performance of a group of people diagnosed with ASD with controls on an emotion-related measure. Additionally, we manually searched the reference lists of these papers, and checked (using Google Scholar) all articles that were cited in the articles we selected.

Articles were included in our systematic review if they satisfied the following criteria:

- inclusion of participants with ASD diagnosed according to the official DSM or international classification of diseases (ICD) criteria;
- inclusion of at least one control group without ASD;
- the groups were compared with respect to their performance on an emotion-related measure, and either considered emotionally laden stimuli as an independent variable (such as emotional words, sentences or prosody) or studied the spontaneous production

of emotionally loaded reactions (such as referring to one's own or another person's emotional state).

We excluded studies focusing on the processing of facial expressions of emotions, because these have been extensively reviewed elsewhere (Jemel et al., 2006; Harms et al., 2010), as well as intervention and drug studies. If the study measured multiple variables, performance on facial emotion recognition was not reviewed but other relevant outcomes were reported in the review. Thus, in contrast to other reviews, we focused exclusively on studies of relatively abstract emotional representations. At the end, we retrieved 33 studies with verbal/linguistic stimuli to be discussed in this review. A summary of all papers can be found in Table 1 including details on the ASD and control groups and the tasks administered. The studies retrieved vary with 8 reporting on emotional processing in children, 15 in adolescents, and 10 in adults with ASD. Nineteen/thirty three (57 percent) of the studies used formal research instruments autism diagnostic interview (ADI) or autism diagnostic observation schedule (ADOS) to confirm clinical diagnosis. Other diagnostic instruments included Autism Behavior Checklist (Volkmar et al., 1988), Asperger syndrome diagnostic scale (Goldstein, 2002), childhood autism rating scale (Schopler, Reichler, DeVellis, and Daly, 1980; Rellini, Tortolani, Trillo, Carbone, and Montecchi, 2004), social communication questionnaire (Chandler et al., 2007), and others. Sample sizes for most studies were rather small (on average 18 participants in the ASD group, ranging from 6–37 participants) with only 12 (1/3) studies reporting about sample sizes larger than 20. Twenty-five studies included higher functioning subjects with ASD, whereas 8 studies investigated lower functioning participants. Seventeen studies did match ASD and control group on age and verbal/nonverbal IQ, but in 5 studies the groups significantly differed on IQ scores, 6 studies did not provide IQ scores for the control group, and 5 studies included multiple control groups partially matched on chronological age, mental age and IQ.

2.4 Is There Evidence for Emotional Impairment in Emotional Language?

First, we addressed the question of whether abnormalities in emotional language processing are specific to particular cognitive domains, or are more general, i.e., independent of the type

of information involved. In the next section, we group all articles in terms of the cognitive task used.

2.4.1 Comparison of Different Tasks

Emotional language has been investigated in a variety of tasks including recognition and recall, stimulus detection, and discourse and reasoning.

Typically developing people remember emotion laden words and sentences better than neutral stimuli (Dolcos, LaBar, and Cabeza, 2004). Some reports indicate that this is not the case for subjects with ASD. In one study, participants listened to and had to memorize neutral and emotional sentences, among other conditions (Beversdorf et al., 1998). Memory performance did not differ between ASD and control participants on scrambled word lists, neutral sentences, sentences which made a coherent story together with other sentences from the list, and sentences describing other people's mental states and perspectives. The only difference between the two groups was on recall of emotional sentences where typical participants showed better performance compared to other conditions, while ASD subjects did not (Beversdorf et al., 1998). A similar finding was obtained in studies with visually presented single words (Kennedy, Redcay, and Courchesne, 2006; Gaigg and Bowler, 2008, 2009b). Control participants showed better recognition memory for emotional words compared to neutral words, had better recall rates for emotion words over a 24 h period, and were less likely to falsely recall them in an illusory memory paradigm. In ASD subjects, however, those effects were significantly diminished. The current view is that typical people remember emotional stimuli better because they perceive these stimuli as potentially motivationally significant and allocate additional processing resources. This process is subserved by medial temporal lobe structures and results in better encoding and retrieval (Dolcos et al., 2004). Lack of emotional memory effect in the ASD participants can mean that they either did not perceive the emotional words or sentences as more salient and motivationally relevant, or failed to efficiently encode them because of an impairment at a later processing stage. In contrast, another study did not find a difference in memory performance for emotion words between ASD and typical participants (South et al., 2008). In this study participants read word lists and were then immediately tested for recognition memory. This result suggests that the differences between the ASD and typical groups on emotional memory could be dependent on time and could be less prominent at immediate recall/recognition.

Subjects with ASD also display abnormalities in their automatic attentional reaction to emotionally salient stimuli. In an attentional blink paradigm, subjects were asked to read words in a rapid serial visual presentation (RSVP) stream and detect target words printed in a red color (Gaigg and Bowler, 2009a). Normally, the probability of successfully detecting a target word depends on the time interval between the presentation of the preceding target word (T1) and the current target word (T2). If the T1 was presented just before the T2, then at the time the T2 is presented most of the attention resources are still engaged in processing the T1, and therefore the probability of successfully detecting T2 significantly drops ("attentional blink" effect). However, this attentional blink phenomenon does not occur with emotional words, which are detected with high accuracy irrespective of the timing. This emotional modulation of attentional blink is thought to be a result of emotion words being perceived as more salient and motivationally relevant and thus receiving more attentional resources, primarily because if the involvement of the amygdala in detecting of emotional words (A. K. Anderson and Phelps, 2001). In two studies, the predicted modulation of attentional blink by T2 valence was found in controls, but not in ASD. In the ASD group, the detection rates of neutral and emotional T2s were not statistically different (Corden et al., 2008; Gaigg and Bowler, 2009a). This result suggests that individuals with ASD do not perceive emotional words as more salient, suggesting an impairment in the amygdala functioning or in the connectivity between the amygdala, cingulate cortex and frontal cortical areas in the ASD group (Gaigg and Bowler, 2009a).

Studies of reasoning about emotions expressed in discourse also showed differences between ASD and control individuals. One study investigated children's responses in a structured conversation. This study found that children with Asperger syndrome more frequently gave inadequate or no response when talking about an emotional topic compared to a neutral one (Adams, Green, Gilchrist, and Cox, 2002). Two more studies investigated emotion word use during telling a story about a fictional or real event. They found that children with ASD talked significantly less about emotions, desires and beliefs compared to typically developing control children. Children with ASD also less frequently referred to emotional states as a cause of one's action (compared to TD group), although both groups talked equally often about causes for physical events (Capps, Losh, and Thurber, 2000; Losh and Capps, 2006). Similar results were obtained in a study which asked adult participants to watch a film clip displaying interactions between people. Adults with ASD were less likely than controls to

include the characters' emotional state in the description or explanation of their behavior (Barnes, Lombardo, Wheelwright, and Baron-Cohen, 2009). Overall these findings show that individuals with ASD have problems with processing and handling emotional language in memory paradigms, automatic information processing, and in discourse and reasoning.

2.4.2 Comprehension vs. Production Tasks

There is debate on whether or not subjects with ASD have abnormal profiles of production and comprehension of language. Some studies find better production than comprehension in children with ASD for language in general (Hudry et al., 2010; Miniscalco, Fränberg, Schachinger-Lorentzon, and Gillberg, 2012) while other studies report a more uniform profile of language development (Jarrold, Boucher, and Russell, 1997). Three of the studies reviewed here used the PEPS-C prosody test which consists of perception and production subtests, including affective prosody; all of these studies showed deficits in both perception and production subtests (Peppé et al., 2007; Järvinen-Pasley, Peppé, King-Smith, and Heaton, 2008; Hesling et al., 2010). In spontaneous dialog or interview, participants from the ASD group were less likely to mention emotions, describe emotional states (Tager-Flusberg, 1992; Adams et al., 2002; Müller and Schuler, 2006), or use emotional state for a causal explanation of characters' actions (Capps et al., 2000; Pearlman-Avnion and Eviatar, 2002; Brown, Morris, Nida, and Baker-Ward, 2012). In some studies, this neglect was specific to emotions and not present when talking about other types of events (Losh and Capps, 2006); however, one study found no group differences between ASD and typically developing children (Bang, Burns, and Nadig, 2013).

In all, the data suggest that emotion language impairments are present in both production and comprehension modes. There is no evidence for an imbalance between production and comprehension emotion language skills in ASD.

2.4.3 Modality: Visual vs. Auditory

Auditorily presented speech unfolds over time, so participants need to continuously pay attention; it is also not possible to go back and listen to parts of it again if something was missed or misheard. Analysis of auditory stimuli also starts earlier, with semantic analysis being made on the basis of partial information before the presentation of the word ends,

which results in an earlier onset of semantic ERP effects (Holcomb and Neville, 1990). Previous studies have reported that auditory stimuli compared to visual also elicit stronger behavioral effects: larger and more robust effects of semantic priming and semantic expectancy on reaction times and accuracy (Holcomb and Neville, 1990; Holcomb, Coffey, and Neville, 1992), as well as greater amplitude and earlier onset of electrophysiological brain responses (Holcomb et al., 1992; Niznikiewicz et al., 1997). This means that visual tasks can be potentially less sensitive and require larger samples to have sufficient power to detect a difference between ASD and control groups. Processing of auditory stimuli compared to visual is also affected by timing of word presentation to a much greater degree (J. E. Anderson and Holcomb, 1995), and follows a different developmental trajectory (Holcomb et al., 1992).

From the studies that investigated perception of emotional language, 8 studies presented the stimuli visually (Kennedy et al., 2006; Corden et al., 2008; Gaigg and Bowler, 2008; Mason et al., 2008; South et al., 2008; Gaigg and Bowler, 2009a, 2009b; Han et al., 2014) and 11 studies auditorily (Beversdorf et al., 1998; Boucher, Lewis, and Collis, 2000; Lindner and Rosén, 2006; Korpilahti et al., 2007; Peppé et al., 2007; Järvinen-Pasley et al., 2008; Volden and Sorenson, 2009; R. B. Grossman, Bemis, Skwerer, and Tager-Flusberg, 2010; Hesling et al., 2010; Kuchinke, Schneider, Kotz, and Jacobs, 2011; Eigsti, Schuh, Mencl, Schultz, and Paul, 2012). In the 11 studies that used auditory modality, 8 studies used explicit measures (participants were asked to identify the expressed emotion), and only one study investigated implicit behavioral measures (memory performance, Beversdorf et al., 1998). In contrast, 7 out of 8 studies using visually presented stimuli looked at implicit measures: reaction time, stimulus detection rate, memory performance, while only three used explicit measures: rating emotional arousal of words on a scale (Corden et al., 2008; Gaigg and Bowler, 2008) or detecting emotionally negative words among neutral (Han et al., 2014). The fact that visual and auditory stimuli were used in different paradigms makes it difficult to assess whether the modality in which the stimulus is presented makes a difference. Explicit measures in studies with auditorily presented stimuli were more likely to show a group difference compared to studies with visual stimuli, suggesting that the transient nature of the auditory signal may indeed make the task more difficult for the ASD group. However, because of the small number of studies we can't draw a definite conclusion. Future studies could address this issue by using visual and auditory language stimuli in the same participants and the same

task.

2.4.4 Complexity of Information: Words vs Sentences

Understanding single words for people with ASD is less problematic than understanding complete sentences and natural speech (Tager-Flusberg, Paul, and Lord, 2005; Williams, Botting, and Boucher, 2008).

As indicated in the previous section, many studies on the processing of emotion language have focused on discourse, such as talking about emotional topics and making inferences about emotional states (Adams et al., 2002; Losh and Capps, 2006; Barnes et al., 2009). An alternative explanation could be that the individuals with autism have difficulties expressing complex thoughts in general and that problems in reasoning on emotional topics are not very emotion specific. Therefore, it is important to note that several studies also found impaired performance in the ASD group on tasks that involved detecting or remembering single emotional words. The ASD group performed significantly worse than non-ASD subjects specifically on memory for emotional words (Kennedy et al., 2006; Gaigg and Bowler, 2008, 2009b), although the overall memory performance was similar for ASD and non-ASD subjects. Participants with ASD had less understanding of emotion-related words, but this was not the case for abstract non-emotional words (Hobson and Lee, 1989). In another study where participants had to memorize sentences, participants with ASD showed impaired performance on emotional sentences, but were just as good as controls in remembering neutral sentences with social and Theory of Mind content (Beversdorf et al., 1998). Thus, it was not the case that emotional sentences were more difficult for subjects with ASD because of their relation to social context with which ASD participants would be less familiar. In all, it is unlikely that the deficient performance in processing emotional verbal stimuli in the studies reviewed above is due to a general effect of stimulus complexity.

2.4.5 Explicit vs. Implicit Measures

Some studies used explicit emotion measures to investigate emotion processing in ASD: in those studies participants were asked to assign the stimuli to a particular category (happy or sad) or to rate it as positive or negative, or as more or less emotionally arousing. Other studies applied indirect measures of emotional processing, such as the effect of emotion on

attention or memory, physiological responses, brain activity, and spontaneous talk about emotion.

Indirect and implicit measures are problematic, because the absence of an emotion effect could be due to a deficit outside the emotional domain, for example, in attention or motivation. Thus, the absence of an emotion effect in the ASD group should be interpreted with caution. On the other hand, explicit measures can also be problematic, especially in subjects with high IQ. Even though these individuals may have impairments in emotion processing, they can use their analytic abilities to design alternative strategies to label stimuli as positive or negative. For example, emotional intonation differs from neutral on a number of acoustic characteristics such as pitch height and variation (Bänziger and Scherer, 2005). If individuals with ASD would focus on isolated features in a prosody perception task, they would be able to correctly classify stimuli as emotional or neutral, but the way they process the stimuli still may be fundamentally different from typical controls, who use a more holistic strategy. Similarly, in facial emotion recognition studies, distinguishing between positive and negative emotion can be done based on single feature, such as upturned or downturned mouth corners, which fits with some of the studies finding atypical gaze patterns in ASD (Neumann, Spezio, Piven, and Adolphs, 2006). Thus, rather normal explicit responses in the ASD group can only be interpreted in combination with other measures.

Approximately half of the studies using explicit measures report differences between ASD and controls. It is important to consider the difficulty of the applied task. For instance, when participants were asked to classify the auditorily presented sentences as sad and happy, both groups performed in a similar way (R. B. Grossman et al., 2010). In more difficult tasks, on the other hand, participants with ASD made more errors than controls: for example, when they had to choose between four response options in a task that required identifying emotion in intonation, (Lindner and Rosén, 2006), or when they had to identify complex emotions of social nature such as embarrassment or jealousy (Hillier and Allinson, 2002; Bauminger, 2004; Rieffe, Meerum Terwogt, and Kotronopoulou, 2007). However, some studies also found lower performance in the ASD group in a simple 2-alternative choice task between sad and happy intonation (Peppé et al., 2007; Hesling et al., 2010), suggesting that the task difficulty should be considered in combination with age and functioning level of the participants. To conclude, in certain circumstances participants with ASD have trouble with fine differentiation between various emotions and perform worse than control subjects.

Unfortunately, all of the studies either provided participants with response options, or asked to rate them on one single scale. Potentially, naming the emotion in a free response task, or rating the stimuli on several scales at once (for example, valence and arousal) and having to distinguish between these different aspects, would be more challenging, and this kind of task should be more likely to uncover group differences.

Studies that use implicit measures report strongly variable findings. Behavioral results are very much dependent on the task used, and with respect to some tasks, the results are still preliminary. For example, only 2 studies so far report attenuated attention blink effect (Corden et al., 2008; Gaigg and Bowler, 2009a), and 4 studies find a weaker effect of emotion on memory in ASD compared to non-ASD subjects (Beversdorf et al., 1998; Kennedy et al., 2006; Gaigg and Bowler, 2008, 2009b) but another study does not (South et al., 2008).

With respect to activity of the autonomic nervous system, the studies measuring skin conductance response (SCR) modulation found typical responses during reading emotion words compared to neutral ones in the ASD group (Corden et al., 2008; Gaigg and Bowler, 2008). These studies used highly arousing emotional words, such as profanities, taboo words and sexually explicit words, and the highly arousing nature of these stimuli could be the reason why they elicited an autonomic response not only in typical but also in ASD group. Another study measuring pupillary response to the stimuli with an intermediate level of emotional arousal (sentences spoken with positive and negative intonation) showed increased response to negative stimuli and decreased response to positive (Kuchinke et al., 2011). This is in agreement with yet other studies showing absent or reversed responses of the autonomous nervous system in an anxiety-provoking situation in people with ASD (Kushki et al., 2013). Due to the small number of studies and differences in autonomic measures and design, it is not yet possible to reach a conclusion with respect to physiological correlates of emotions in ASD, but the preliminary evidence suggests that participants with ASD may be less sensitive to subtle variations in emotional valence, while stimuli with high emotional arousal are equally likely to elicit an autonomic response in ASD and typical population. More research in this field is needed.

Moving now to the studies of brain activity, our selection included 5 fMRI studies and one EEG study (Korpilahti et al., 2007). All of them report significant between-group differences with respect to processing of emotion language at the neural level. Studies report less deactivation of the default-mode network regions for visual or auditory emotional stimuli

compared to neutral stimuli or rest in the ASD group (Kennedy et al., 2006; Hesling et al., 2010), suggesting that individuals with ASD may have trouble suppressing task-irrelevant regions and focusing on the relevant stimuli characteristics. The medial prefrontal cortex (MPFC) was more active during rest than during task performance in the typical group, and during task it was more active in response to emotional compared to neutral words (Kennedy et al., 2006). However, the ASD group failed to show any modulation of activity in this region in either of the comparisons. Medial prefrontal regions have been previously implicated in evaluation of stimuli as pleasant or unpleasant (Maddock, Garrett, and Buonocore, 2003) and in silent generation of emotionally positive or negative words (Cato et al., 2004). A lack of modulation of activity in this area in the ASD group suggests an impairment in the processes of evaluation, but it also indicates that people with ASD may engage in different kinds of cognitive processing during resting state, as indicated by higher activity in MPFC at rest in typical group compared to ASD group. Participants with ASD also showed greater activation in the left supramarginal gyrus (implicated in phonological processing) during an auditory task (Hesling et al., 2010), suggesting that the ASD group focused more on phonological rather than conceptual features of the input. Furthermore, studies with verbal stimuli find more activity outside of the language network in the ASD group: fusiform gyrus (Han et al., 2014), right hemisphere homologs (Mason et al., 2008; Eigsti et al., 2012), and brain areas typically involved in memory and control, such as parahippocampal gyrus and globus pallidus (Eigsti et al., 2012). These results suggest that individuals with ASD recruit a different network of brain areas during emotional language tasks, which results in less efficient processing and requires additional involvement of the homologous regions from the right hemisphere. The EEG study comparing electrophysiological responses to auditorily presented neutral and angry sentences found increased mismatch negativity (MMN) amplitude in the ASD group compared to the control group, suggesting that participants with ASD focused more on the low-level acoustic characteristics of the utterances, in contrast to typical group which was processing the stimuli in a more global way. Additionally, there were differences between group in terms of lateralization of the components. Typical children showed larger N1 amplitudes over the right hemisphere and larger late MMN amplitudes over the left hemisphere, but the ASD group showed less lateralization for MMN and N1, with greatest differences between groups over the right hemisphere (Korpilahti et al., 2007). However, this study did not have a behavioral measure, thus it is difficult to make direct

inferences from differences in electrophysiological responses to the corresponding cognitive processes.

In sum, the studies reviewed here demonstrate that subjects with ASD have widespread impairments in processing emotional language, and these impairments are present in tasks tapping into different cognitive domains, in comprehension as well as production tasks, and tasks of varying levels of complexity. These impairments are also reflected in abnormal concomitant physiological and neural responses.

2.4.6 Summary

To summarize, individuals with ASD are able to correctly identify words, sentences or stories as emotionally positive or negative (Volden and Sorenson, 2009; R. B. Grossman et al., 2010; Brown et al., 2012), but have difficulty with providing an in-depth explanation (Bauminger, 2004; Rieffe et al., 2007). Implicit behavioral measures show more robust and consistent between-group differences (compared to studies that use explicit behavioral measures). The overall tendency is that subjects with ASD have a poorer memory for emotional events (Gaigg and Bowler, 2008, 2009b), are less inclined to direct attentional resources to emotional stimuli (Korpilahti et al., 2007; Corden et al., 2008; Gaigg and Bowler, 2009a) and mention emotions in spontaneous conversations (Capps et al., 2000; Barnes et al., 2009) than typically developing participants. Studies of autonomic activity are very few in number and show mixed results. In contrast, neuroimaging studies report consistently diminished brain activation in response to emotional stimuli in subjects with ASD compared to typical participants. At least in studies using auditory stimuli, the brain activity results suggest that participants with ASD are more likely to focus on phonological features of the input rather than process it in the holistic manner, as we hypothesized in Section Explicit vs. Implicit Measures (Korpilahti et al., 2007; Hesling et al., 2010). However, only a small number of studies investigated brain activity (1 study with EEG and 5 studies with fMRI), therefore more studies are required before we can draw more firm conclusions.

It was shown that high-functioning subjects with ASD are able to interpret others' emotional behavior correctly and react with an appropriate emotional response if they are provided with explicit cues, in spite of their problems with spontaneous emotional interactions (Begeer, Koot, Rieffe, Meerum Terwogt, and Stegge, 2008). There are two alternative explanations for the discrepancy between absent spontaneously applied and relatively intact cue-related

emotional skills and responses in ASD. One option is that individuals with ASD have adequate and typical conceptual representations of emotions, but have trouble applying them in real life. The alternative explanation is that the emotion concepts of ASD individuals are actually different from typical individuals and are more similar to neutral concepts. The evidence from the behavioral studies of attention and memory (Beversdorf et al., 1998; Corden et al., 2008; Gaigg and Bowler, 2008, 2009a, 2009b) points towards the latter alternative, and the few available neuroimaging studies suggest that individuals with ASD largely recruit the same neural networks for processing emotional and neutral language (Kennedy et al., 2006; Hesling et al., 2010). However, this is only a preliminary conclusion that needs to be backed up by more research, particularly on autonomic activity and electrophysiology.

2.5 Emotional Language Impairment and General Intelligence

About half to two-third of people with ASD also have some form of intellectual disability (Matson and Shoemaker, 2009). Language impairment in ASD has a more complex pattern. Higher order linguistic functions, such as semantics and pragmatics (understanding contextual and non-literal meaning, inferring speaker intentions) are almost universally impaired in ASD, while phonology, lexicon and syntax are affected to varying degrees in different subgroups (Groen et al., 2008; Eigsti et al., 2011). Some researchers also report more deficits in language comprehension than in production (Hudry et al., 2010). In the following part we will discuss the link between impairment in emotional language processing and (1) history of language delay; (2) presence of intellectual disability; and (3) individual differences in verbal and nonverbal IQ within normal range.

2.5.1 Are Impairments in Emotional Language Related to Language Delay?

By the definition of the DSM-IV criteria, subjects with Asperger have normal milestones for language acquisition in the first years after birth (APA, 2000). If emotional impairments in ASD are in part due to a delay in language acquisition, we would expect that studies including subjects with Asperger syndrome would more often report negative results, in other words find less of even no differences between the control and patient group on emotional

language measures. However, this appears not to be the case. Individuals with Asperger syndrome have serious problems in talking about social-emotional topics (Adams et al., 2002). Furthermore, they have an abnormal Event-Related Potentials (ERP) pattern when hearing angry intonation (Korpilahti et al., 2007), fail to show modulation of attention blink effect by emotional content of the words (Corden et al., 2008), and show a different pattern of pupillary response when hearing emotional sentences (Kuchinke et al., 2011). In all these aspects of emotion processing, subjects with Asperger syndrome differ from controls, despite their rather intact early language skills and absence of language delay. Therefore, their impairment in emotional language cannot be explained by developmental delay in language and communication. However, none of the studies compared a group of participants with Asperger syndrome to a group with autism and language delay within the same paradigm. Therefore, the question remains whether individuals with classic autism who frequently have early language delays, would demonstrate a greater degree of emotion language impairment under the same task conditions.

If the overall level of language development is a decisive factor for the normal development of emotional competence and processing of emotional stimuli, emotional language impairments should also diminish or even disappear when people with ASD catch up in their language development with their peers. However, this does not appear to be the case, since the emotional impairments do not disappear when the participants become older and acquire better language skills. The participants in the studies ranged from 3-year-old children to adolescents and adults, and differences in emotional language processing occurred in subjects with ASD in all age groups. Furthermore, although high-functioning individuals with ASD, and thus without language delay, from various age groups were able to provide adequate explicit evaluations of emotional stimuli, they showed atypical performance compared to control subjects on measures of memory performance, attention, and autonomic activity in relation to the processing of emotional language stimuli. The cause of the absence of behavioral differences in some tasks remains an open question, but one likely explanation is that high-functioning ASD subjects develop compensatory strategies by explicitly learning the relation between a situation and an emotional label (Begeer et al., 2008; see also Hobson, 1991).

Comparison of the results to a non-emotional task of similar difficulty can also help to address the issue of whether or not emotional language difficulties in ASD are a consequence of more

general language delay. Several studies have used such control tasks. They found that the atypical performance in the ASD participants was relatively specific to emotional stimuli, and did not extend to other semantic features of the verbal materials: namely semantic relatedness (Gaigg and Bowler, 2008), distinctiveness of individual words (Corden et al., 2008; Gaigg and Bowler, 2009a), or the conceptual content of sentences (Beversdorf et al., 1998).

2.5.2 Are Impairments in Emotional Language Related to the Presence of Intellectual Disability?

The next question is whether the emotional impairments are related to the presence of general intellectual disability. If so, emotional impairments should show a different degree of severity in individuals with ASD with high and low IQ. One possibility is that individuals with ASD and intellectual disability would show a greater degree of emotional impairment. Most of the studies we identified tested individuals with normal or above normal intelligence, and only 8 studies included a sample of low-functioning subjects (Hobson and Lee, 1989; Boucher et al., 2000; Capps et al., 2000; Hillier and Allinson, 2002; Pearlman-Avnion and Eviatar, 2002; Williams and Happe, 2010). It is difficult and even problematic to estimate whether and how emotional language stimuli are processed in low-functioning subjects with ASD, because more complex tasks can't be administered in this population. Further, the problems specific to emotional information add up with problems in understanding the instruction and performing the task in general. Thus, in more difficult tasks specific difficulties with emotion processing may be obscured, for instance, by the effects of shorter attention span, poor understanding of the task, tendency for impulsivity, or response perseveration. Simpler tasks, on the other hand, may lead to ceiling effects in both groups.

Notwithstanding these methodological problems, some studies reported that low-functioning individuals with ASD performed worse on emotion language task than mental age-matched healthy controls (Rieffe et al., 2007). In contrast, other studies found that low functioning ASD subjects performed equally (Capps et al., 2000; Williams and Happe, 2010) or even better Boucher et al., 2000) than children with a linguistic or intellectual impairment. These discrepant findings could reflect differences in emotional skills between the groups, but could also be due to the task demands being too high, particularly for the children with an intellectual disability. This confound makes it difficult to determine whether the emotional

language impairment is due to a specific emotional deficit or to suboptimal general cognitive skills.

Additionally, it is also possible that individuals with ASD with extremely high IQ would also show greater degree of emotional impairment compared to people with average IQ. Other domains, such as restricted and repetitive behaviors, were previously shown to have such complex association with IQ (Bishop, Richler, and Lord, 2006). None of the studies included in our review specifically looked at a subgroup of people with ASD with extremely high IQ, although the reported variance of IQ scores suggests that at least a few of their participants had IQ scores in the extremely high range.

So far, the issue of whether emotional language impairments are present to a similar degree in individuals with ASD with varying levels of IQ has not been fully explored. A possible design is to include three groups of subjects with ASD (functioning in the low, middle and superior range of intelligence) and three age and IQ matched non-ASD control groups, and examine whether any discrepancies on emotional language tasks between ASD and matched controls would vary systematically as a function of IQ.

2.5.3 Are Impairments in Emotional Language Related to Variation in General Intelligence?

Another way to explore the dependance of emotional impairments on IQ differences is to directly calculate the within-group correlation between the performance in the experiment and IQ. If the variation in IQ would matter and would be causally linked to the task performance, we would expect the verbal or nonverbal IQ to negatively correlate with the degree of emotional language impairment within the ASD group. This was examined in seven studies. Three studies found a positive correlation between performance on emotional task and verbal IQ (Gaigg and Bowler, 2009a; Williams and Happe, 2010; Siller, Swanson, Serlin, and Teachworth, 2014), and in three studies the correlation was not significant (Hillier and Allinson, 2002; Lindner and Rosén, 2006; Losh and Capps, 2006). Two studies reported correlations with nonverbal abilities; one study found a significant positive correlation (Hillier and Allinson, 2002), while the other study reported a nonsignificant relationship (Losh and Capps, 2006). Finally, two studies did not look separately at verbal and nonverbal components: one study found a significant positive relationship with mental age (Bauminger, 2004), while the other study found no association with IQ (Han et al., 2014). Because of

the small number of studies, it is hard to reach a definite conclusion on whether IQ plays a significant role in performance. However, the fact that only half of the studies found an effect of IQ while the other half found no effect suggests that even if the effect is there, it must be rather weak. Finally, in case of the studies that do not report any data on association between IQ and their measures of interest, it is not clear whether those studies did not investigate the effect of IQ, or whether they found a statistically nonsignificant effect and decided not to report it. A general recommendation for future studies would be to report the relationship between IQ and the outcome of interest, even if this relationship is not statistically significant.

In summary, from these data we can conclude that language delay, presence of intellectual disability or variation in general intelligence cannot fully explain impairments in the processing of emotional language in subjects with ASD. In fact, there is more evidence for impairments of emotion language in high-functioning subjects with ASD and in subjects with Asperger, when compared to appropriate matched control subjects, than in low-functioning subjects with ASD. Nonetheless, variation in general intelligence still plays a role to some degree, although not in all types of tasks, and not with all types of stimuli. The extent to which IQ differences influence emotional language processing remains an open issue that merits further study.

2.6 Consequences of Emotional Language Impairments for Our Understanding of ASD

So far we have concluded that emotional language impairments in ASD are widespread and not restricted to any particular cognitive domain or stimulus type; they are even more pronounced in subjects with high-functioning autism and Asperger syndrome than in individuals with intellectual disability, language problems or language delay; and they persist through all age groups. These emotional language impairments complement the emotional impairments for the recognition, processing, understanding and production of facial and visual displays of emotions, which have been reviewed extensively by others (Jemel et al., 2006; Harms et al., 2010). In this next section, we will discuss whether and how these widespread and rather general emotional impairments can be accounted for by existing cognitive theories of autism.

2.6.1 Emotions and Global vs. Local Processing

The central coherence account proposes that autism is characterized by a particular cognitive style of information processing, which can be described as detail-oriented, with particular attention paid to separate parts or aspects of an object (Happé, 2005; Happé and Frith, 2006). In contrast, typical individuals have a strong preference for global processing and integration, also known as central coherence. The evidence supporting the deficit in central coherence in ASD comes from a wide range of studies, including different kinds of visual and semantic tasks (Happé, 2005). However, this theory was developed primarily to explain the pattern of cognitive strengths and weaknesses in autism, and it was not intended to explain the emotional and social-communicative impairments of subjects with ASD.

Weak central coherence seems to explain only part of the evidence with regard to emotional impairments reviewed above. The emotional meaning of an image, a musical piece, or a text may not be evident from the details and only apparent when the stimulus is processed as a whole and/or put into context. If individuals with ASD indeed would miss the emotional meaning of a stimulus because of weak central coherence skills, this would be evident in their explicit evaluation of the stimuli. However, this is not the case; in fact, several studies demonstrated that subjects with ASD could correctly classify spoken sentences as emotionally positive or negative (Volden and Sorenson, 2009; R. B. Grossman et al., 2010; Kuchinke et al., 2011), and also provided similar rating of emotional arousal of emotion words as the control group (Corden et al., 2008; Gaigg and Bowler, 2008). Additionally, according to the central coherence account, more complex stimuli (text, stories) would be problematic to subjects with ASD while more simple stimuli such as single words would not be. However, a number of studies found group differences when using single words (Corden et al., 2008; Gaigg and Bowler, 2008, 2009a, 2009b). Finally, if individuals with ASD would be unable to quickly grasp the emotional meaning of a stimulus, we would expect that the neural or autonomic responses to emotional stimuli would not differ from neutral stimuli. However, several studies found that startle potentiation in ASD subjects differs not between positive and negative stimuli, but between these and neutral stimuli, which means that the emotional stimuli do have an effect, but are processed in an atypical way (Wilbarger, McIntosh, and Winkielman, 2009; Dichter, Benning, Holtzclaw, and Bodfish, 2010).

There have also been attempts to integrate social-communicative impairments into the central coherence account, by arguing that integrative and holistic processing is essential for

social cognition and Theory of Mind skills (Happé, 1997; Jarrold, Butler, Cottington, and Jimenez, 2000). However, some studies reported that individuals with ASD who pass the Theory of Mind task and those who fail have a similar lack of central coherence performance. This supports the notion that central coherence and theory of mind deficits are independent (Happé, 1997, 2000). Additionally, it is still debated whether central coherence in ASD is weak or deficient, or just unused, because under some task conditions subjects with ASD are able to display holistic processing (Happé and Frith, 2006).

An alternative to the Weak Central Coherence account is the Enhanced Perceptual Functioning (EPF) model (Mottron and Burack, 2001; Mottron, Dawson, Soulières, Hubert, and Burack, 2006). This model proposes that individuals with ASD are not impaired at global processing, but they are better at processing details. As a consequence, spontaneously they choose a more detail-oriented processing style, even though they are able to focus on the global picture when they are explicitly instructed to do so. According to the EPF model, focusing on the perceptual aspects and ignoring the conceptual aspects of the stimuli could lead to a relative lack of processing emotional information. This would explain why participants with ASD would utilize emotional information in some tasks but not in others (Gaigg and Bowler, 2008; South et al., 2008). Future studies need to address this issue, for example, by considering whether a focus on different levels of processing (e.g., superficial perceptual feature analysis or deep semantic analysis) may explain the difference in processing emotion by ASD and typical groups.

2.6.2 Emotions and Executive Dysfunction

Another influential theory proposes that the executive dysfunction is at the core of ASD (Ozonoff, South, and Provencal, 2005). Executive function is a broad term that refers to a group of cognitive functions that include monitoring of one's own behavior, cognitive control, flexibility, inhibition, planning and working memory (Eslinger, 1996). Deficits in various aspects of executive function are observed not only in ASD, but also in many other psychiatric disorders, such as ADHD (Willcutt, Doyle, Nigg, Faraone, and Pennington, 2005). Problems in executive function in ASD are especially evident for cognitive flexibility, with inhibitory control and working memory being less affected (Ozonoff et al., 2005).

Research has suggested a link between executive functioning and the processing of emotions

(Pessoa, 2009). Research in other clinical populations found that executive control measures correlate with performance in tasks tapping into emotional and motivational systems in schizophrenia (S. J. Lee, Lee, Kweon, Lee, and Lee, 2009), measures of cognitive control correlate with mood in patients with traumatic brain injury (McDonald, Hunt, Henry, Dimoska, and Bornhofen, 2010), and cognitive flexibility and response inhibition correlate with empathy measures in depressed patients (Thoma et al., 2011). However, emotions and executive functions are thought to be rather separate systems that rely on different brain networks (Seeley et al., 2007). Furthermore, while mood state and emotional significance of the stimuli can certainly have an effect on executive function (Pessoa, 2009; Mueller, 2011), there is no evidence that executive functioning by itself has major effects on emotion processing, in particular on fast stimulus-driven responses (Corden et al., 2008; Gaigg and Bowler, 2009a) and autonomic activity (Kuchinke et al., 2011). Therefore, deficits in executive functioning are not a sufficient explanation for the emotional impairments in ASD.

2.6.3 Emotions and Theory of Mind

The development of emotion understanding is tightly linked to the development of social relationships and the accumulation of experience in interaction with others. One of the influential cognitive models of ASD is the Theory of Mind account. It assumes that people normally develop an ability to attribute mental states to themselves and to other people (Leudar, Costall, and Francis, 2004; Sodian and Kristen, 2010). This ability is also called Theory of Mind reasoning or mentalizing. Mentalizing is required to reason about thoughts and desires of people, infer their feelings and beliefs, and predict their actions. People with ASD have problems in attributing mental states to themselves or to other people (Yirmiya, Sigman, Kasari, and Mundy, 1992; Lombardo, Barnes, Wheelwright, and Baron-Cohen, 2007; Jones, Happe, Gilbert, Burnett, and Viding, 2010; Schulte-Rüther et al., 2011). Reasoning about other people's emotions is also a part of Theory of Mind abilities. Therefore, problems in deriving emotional meaning from text, describing one's emotional state, and explaining why one should feel sad or happy might rely on general Theory of Mind ability.

However, differences in emotional awareness in subjects with ASD were found to be independent from impairments in self-reflecting and mentalizing skills (Buitelaar, van der Gaag,

Klin, and Volkmar, 1999; Silani et al., 2008). Furthermore, while emotions play an important role in social interactions, they are not limited to social phenomena and fulfill important additional psychological functions. For example, emotions play a role in detecting potentially important threatening or pleasant stimuli and triggering an appropriate approach or avoidance behavioral response. Some of the studies dealing with fast automatic responses to motivationally relevant stimuli (angry voice, scary, or pleasant pictures) tapped into this aspect of emotions (Dichter et al., 2010; Kuchinke et al., 2011). Those responses are very fast and bottom-up in nature, and involve a person's own affective reaction rather than an explicit reflection on his or her own mental state. Those abnormal automatic emotional reactions thus cannot be readily and completely explained by a Theory of Mind deficit.

2.6.4 Emotions and Alexithymia

Recent studies suggest a link between ASD and alexithymia (Silani et al., 2008; Bird, Press, and Richardson, 2011). Alexithymia is defined as a difficulty in identifying and describing one's own feelings and difficulty in distinguishing one's feelings from bodily sensations of emotional arousal (Nemiah, 1977). Alexithymia is thought to characterize about 10% of the general population (Linden, Wen, and Paulhus, 1995; Salminen, Saarijärvi, Äärelä, Toikka, and Kauhanen, 1999). Although alexithymia is neither a necessary nor a sufficient feature of ASD, it is present in approximately 50% of individuals with ASD (Hill, Berthoz, and Frith, 2004; Berthoz and Hill, 2005; Lombardo et al., 2007). Alexithymia is typically assessed based on self-report questionnaires such as TAS-20 (Bagby, Taylor, and Parker, 1994). The key question here is whether the emotional deficits of subjects with ASD described above are linked to alexithymia (Silani et al., 2008; Bird et al., 2010).

There is evidence that the empathy deficits reported in ASD are indeed related to alexithymia. Subjects with ASD who were not alexithymic demonstrated normal empathic responses, but individuals with ASD and alexithymia showed clear empathy deficits (Bird et al., 2011). The alexithymia account fits with the problems in understanding emotions in text, images, and music. Some studies report that subjects with ASD were able to adequately rate the stimuli on their emotional valence (Corden et al., 2008), which at first glance seems to be contradicting the findings from alexithymia studies. However, the scale used in these studies was rather simple and asked only for a differentiation of positive and negative valence.

Introspection into one's own inner state is a rather complex skill that only develops in childhood (Flavell, Green, and Flavell, 2000), but the first symptoms of autism are often apparent before that. Therefore, it is likely that instead of being a cause, both alexithymia and a lack of empathy in ASD arise as a consequence of impaired emotional processing. For example, some studies report that automatic reflexive responses in ASD do not differentiate between positive and negative valence (Wilbarger et al., 2009; Dichter et al., 2010). These low-level processing abnormalities may give rise to a general problem with identifying and categorizing emotional states in other persons and in oneself. Further studies are needed to examine whether alexithymia is a useful construct to subtype subjects with ASD and to examine the underlying physiological and neural mechanisms of impaired emotion processing and empathy deficits.

2.6.5 Emotions and Motivation: Reward and Punishment Learning

As described earlier, emotions are linked to evaluation of the motivational significance of an object or event and to the motivational system in general (Frijda, 2010; Mesquita and Frijda, 2011). Altered sensitivity to reward would lead to a difficulty in estimating the motivational saliency of the stimuli and hence their emotional meaning. Studies of motivation and processing of reward and punishment in ASD are scarce; however, available data suggest deficits in the processing of reward (Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack, and Bookheimer, 2010; Kohls et al., 2011). For example, children with ASD performed abnormally on a delayed non-match to sample task. In this task, a stimulus which is not associated with reward in the current trial will be the one associated with reward in the next trial. Children with ASD had trouble learning stimulus-reward associations and flexibly adjusting them in the course of the task (Dawson, Osterling, Rinaldi, Carver, and McPartland, 2001). Several neuroimaging studies investigating social (smiling face) and nonsocial (monetary) rewards in subjects with ASD found diminished activations in neural networks associated with processing of reward and punishment: nucleus accumbens (NA; Dichter, Richey, Rittenberg, Sabatino, and Bodfish, 2012; Kohls et al., 2013), ACC (Scott-Van Zeeland et al., 2010; Kohls et al., 2013) and striatum (Scott-Van Zeeland et al., 2010). Additionally, neural response to reward in the left ACC was found to correlate with measures of social interaction abilities in the ASD group (Schmitz et al., 2008).

Another fMRI study used two reward conditions, one consisting of monetary reward, and the other consisting of objects that are typically interesting and relevant for ASD individuals: machines, trains, electronic devices. Control group showed significantly greater activation of the NA in the monetary reward condition, while in the ASD group the NA activity was not significantly different in the two conditions, and not significantly different from the control group in the object reward condition (Dichter, Felder, et al., 2012). This result suggests an impairment in the reward processing system in the ASD group, including a diminished anticipation of reward and a lower salience of reward in general. An impairment in reward processing was also found in an ERP study using a different paradigm, where subjects with ASD demonstrated an attenuated P3 component during reward anticipation in response to cues associated with both social and monetary reward (Kohls et al., 2011), suggesting hyporesponsivity to reward in the ASD group and reduced attention allocation to incentive stimuli. However, another EEG study examined a different ERP component (namely, feedback related negativity) and reported no difference between ASD and control groups for positive compared to negative feedback (Larson, South, Krauskopf, Clawson, and Crowley, 2011). This suggests that the dysfunction in the motivational system affects early stages (anticipation of the outcome) to a greater degree compared to later stages (post-feedback processing), and processing of rewards to a greater degree compared to losses.
In all, these data indicate that subjects with ASD are less sensitive to social and nonsocial rewards, as reflected in lower activations of the reward areas of the brain, and even may react with distress to reward given increased activity of the amygdala and insular cortex (Dichter, Richey, et al., 2012). The question of whether problems in motivation and sensitivity to reward cause problems in emotions, or, instead, deficient emotional responses lead to problems in motivation, is not fully clear yet. The link between motivational processes and processing of emotional stimuli in ASD needs to be studied further.

2.6.6 Emotion, Simulation, and the Mirror Neuron System

Embodied simulation theory states that people understand other people's actions by directly simulating them (instead of logically inferring their intentions through metacognitive reasoning; Gallese, 2007; Gallese and Sinigaglia, 2011). They do so by activating the same brain networks which would also be activated if the observer would be performing the same action. For example, when one observes other people's actions, a pattern of motor activity

is activated that corresponds to the neural pattern of when the observer would perform the same action. According to the simulation theory, this MNS plays an important role in understanding and predicting actions of other people in a rather direct way and without necessarily involving more indirect mentalizing skills. Recently, it has been proposed that our brain simulates not only actions, but also emotions of others (Decety and Jackson, 2004; Keysers and Gazzola, 2006) and in this way facilitates understanding others' inner emotional states (Perry, Troje, and Bentin, 2010; Sinigaglia and Sparaci, 2010). Observing other people's facial expressions is associated with increased activity in regions of the inferior precentral and inferior frontal gyri that are also involved in producing similar expressions (Carr, Iacoboni, Dubeau, Mazziotta, and Lenzi, 2003). This activity is thought to trigger congruent activity in emotional brain regions such as the insula and the amygdala (Carr et al., 2003; Jabbi and Keysers, 2008). Activity in the frontal parts of the MNS was found to be associated with the tendency to empathize with other individuals (Gazzola, Aziz-Zadeh, and Keysers, 2006; Jabbi, Swart, and Keysers, 2007; Saarela et al., 2007; Pfeifer, Iacoboni, Mazziotta, and Dapretto, 2008). On the reverse, lesions of this area were associated with deficits in empathy and emotion recognition (Shamay-Tsoory, Aharon-Peretz, and Perry, 2009).

A "broken MNS" hypothesis could explain both the social and emotional impairments in ASD (Iacoboni and Dapretto, 2006). This hypothesis is supported by data from behavioral studies and a variety of structural and functional abnormalities found in the MNS region (Dapretto et al., 2005; Hadjikhani, Joseph, Snyder, and Tager-Flusberg, 2006). However, recent evidence shows that under different task conditions MNS in autism seems to be intact (Hamilton, Brindley, and Frith, 2007). Overall, the empirical evidence for the broken mirror hypothesis of ASD is rather mixed and includes a number of studies yielding disconfirming evidence (Hamilton et al., 2007).

It is possible that the abnormal functioning of the MNS observed in the early studies is caused by a deficit outside the MNS. Some authors suggested that the MNS is not dysfunctional on its own, but that motivational abnormalities draw the child's attention away from social and towards idiosyncratic stimuli. As a result, the MNS does not receive a proper input and therefore does not develop fully (Esser, Sutera, and Fein, 2010). In a recent review, it was further suggested that other neural systems besides MNS, such as networks involved in attention and control, may be responsible for the inconsistent findings with regard to

imitation in ASD (Kana, Wadsworth, and Travers, 2011).

2.7 Conclusions and Perspectives

The results of our systematic review allow us to draw several conclusions. First, the data supports the existence of impairments in the processing of emotional language in individuals with ASD that are relatively independent of the complexity of stimuli (single words, sentences or discourse), task (production or comprehension, recognition, recall or detection), and of the sensory modality (visual or auditory). These impairments were found in different tasks tapping in reasoning, memory, or attention to emotional stimuli. The evidence for atypical physiological or neural responses is limited due to a small number of studies.

Second, these emotional impairments have been documented in ASD participants with average or even above average cognitive abilities and appear to be rather independent of the level of language development. Studies in low-functioning subjects with ASD, however, are less well suited to differentiate specific problems in handling emotional stimuli from more general emotional deficits due to cognitive problems.

Third, the existence of impairments in emotional language processing has implications for our understanding of the relationship between emotional and social deficits in ASD. In contrast to more concrete stimuli such as faces, linguistic representations of emotion are more abstract, and proficient understanding of them is dependent on verbal ability and develops later compared to reading expressions from faces or body postures (McClure, 2000; Adolphs, 2002). Emotional language can be used in a context that does not involve interaction with another persons. A person could know a word for a specific emotion without having a good understanding of this emotion. For example, people with amygdala lesion become impaired in the ability to understand and recognize fear (Broks et al., 1998), but they do not forget the word "fear" itself. Conversely, it's also possible to understand another person's inner state without having a verbal label to describe this state. It seems reasonable to hypothesize that a common emotional impairment may underlie the impairments in both facial emotion processing and in emotional language.

Fourth, we explored how well cognitive accounts of ASD may explain the emotional impairments in ASD. Classic cognitive theories of ASD, namely Theory of Mind, Executive Dysfunction and Weak Central Coherence, have limited power to explain emotional impairments in ASD. On the other hand, findings from studies on reward and punishment learning

offer a more promising account of the emotional impairments. More work in this area is warranted. Finally, alexithymia appears to be a useful construct to subtype subjects with ASD, to examine its underlying physiological and neural mechanisms and to link it to broader aspects of emotional functioning in social interaction.

On a broader level, this review indicates that emotional impairments in ASD should receive more attention from both researchers and clinicians. Emotional impairments in ASD were brought forward by Kanner already in his seminal description in 1943, but since then have shifted to the background. In the current classification systems DSM-5 and ICD-10, emotional symptoms are regarded as part of, or as secondary to, problems in social interaction and communication. Bringing emotional symptoms in ASD to the attention of researchers may inform our understanding of ASD in several ways. We can then establish whether emotional impairments are present across the whole autism spectrum, are specific for ASD, or resemble the deficits observed in other disorders such as schizophrenia or anxiety disorders. Further, this will allow us to provide a more detailed and accurate description of the clinical manifestations of ASD. This would facilitate identification of more homogeneous subgroups and stimulate the study of emotional competence of subjects with ASD within and outside the social context and across various levels of structure of social contexts. Finally, this would increase investments in developing and testing therapeutic interventions for emotional deficits in ASD.

Emotional and social development are tightly linked to each other. Many emotions, such as shame or embarrassment, are social in nature, and displays of emotion are important elements of everyday social interactions. Trouble understanding the emotions of other people can lead to great difficulties in social functioning. The emotional aspects of social interaction received considerable attention from researchers (Begeer et al., 2008). However, 'emotional' and 'social' are not the same. Emotions do not only have social, but also psychological and biological components, are tightly related to the system of motivations and needs (Frijda, 2008; Larsen, Berntson, Poehlmann, Ito, and Cacioppo, 2008; Mesquita and Frijda, 2011), and are responses to unconditional stimuli such as pain. In turn, social interaction cannot be reduced to purely emotional aspects. Various models of social interaction include cognitive components, such as overt encoding and interpretation of behavioral cues and selecting an appropriate response (Crick and Dodge, 1994, 1996), and implicit cognition such as implicit judgment biases and memory (Greenwald and Banaji, 1995; Amodio and Ratner, 2011).

Some authors suggest that simulation is a crucial component of social cognition (Barsalou, 2008), and that the MNS is the neural mechanism of simulation (Wolpert, Doya, and Kawato, 2003; Uddin, Iacoboni, Lange, and Keenan, 2007). Proponents of this view claim that the motor system is essential for social cognition (Gallese, 2007).

Social and emotional development are intertwined; social interactions with other people and observation of their emotional reactions are of the utmost importance for the development and maturation of emotional competence. An impoverished pattern of social experiences as in ASD will have its consequences for the emotional development of an individual.

Are the observed emotional deficits in subjects with ASD only a consequence of limited normal social experiences, or are they present from the very start and do they contribute to the abnormalities in social interaction? Recent reviews in this field have already suggested that impairments of emotion processing in ASD should not be viewed as a mere consequence of core social deficits, but instead as a result of an interplay between emotion and various cognitive processes as well as social development (Gaigg, 2012; Nuske et al., 2013). The data on emotional deficits in adolescents and adults with ASD indicate that these are not limited to the context of social interaction, but also found in tasks that do not directly rely on social interaction or communication skills, such as memory and attention tasks. However, there is still a possibility that these emotional deficits have been ultimately caused by social deficits that affect the development of the emotional competence and emotion understanding: Because a child with ASD is not able to establish normal social contact, his/her knowledge and experience related to emotions are also limited. One way to clarify this issue is to investigate the development of reciprocal social interaction and the amount of social experience along with the development of emotional competence using a longitudinal design. Such a study design would allow a disentanglement of the mutual influence of social and emotional development. Unfortunately, so far not enough developmental studies are available, and the developmental course of this impairment needs further study. Another approach is to compare the processing of emotion in language to other language aspects that would equally rely on social interaction and social understanding, and to test if emotional language processing is impaired above and beyond general semantic or pragmatic language processing. The stimuli in the studies reviewed here are difficult to separate into social vs. nonsocial types. One can rather speak about the degree to which a task has a social component. For example, having a structured interview or having to explain the meaning of

a word to the experimenter can be viewed as a more social task, while listening to recorded speech is less social, and hearing or reading word lists is even less social. None of the studies included in this review manipulated social and emotional aspects of the task independently, although several studies attempted to compare social and emotional aspects of the stimuli (Hobson and Lee, 1989; Beversdorf et al., 1998).

The consideration of social and emotional functioning as rather distinct but closely interacting domains during development has implications for designing and performing longitudinal studies of subjects with ASD. These studies should assess both social and emotional functioning and examine whether and how social problems aggravate problems of emotional functioning, and vice versa in healthy and ASD subjects. Furthermore, research should address whether subjects with ASD try to compensate for their deficit in the processing of social or emotional stimuli by using learned cognitive strategies. In addition, it is important to disentangle the contributions of specific cognitive functions to the problems in the emotional domain and in the social domain to better understand the nature of the disorder and to develop appropriate intervention strategies.

There is also an urgent need for translational cognitive and neuroscience studies in ASD. These should bridge the gap between sophisticated research into cognitive and neural mechanisms in selected and rather small samples of ASD subjects, and observing and analyzing social and emotional functioning in daily life in larger and more representative groups of subjects with ASD. The final test of prospective cognitive and neural markers of ASD is their potential to improve our understanding of day-to-day functioning and adaptation, and to form a basis for clinical intervention and management.

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Chapter 3

Emotion Word Processing: an EEG Study

Abstract

This study investigated processing of emotion words in autism spectrum disorders (ASD) using reaction times and event-related potentials (ERP). Adults with ($n = 21$) and without ($n = 20$) ASD performed a lexical decision task on emotion and neutral words while their brain activity was recorded. Both groups showed faster responses to emotion words compared to neutral, suggesting intact early processing of emotion in ASD. In the ERPs, the control group showed a typical late positive component (LPC) at 400–600 ms for emotion words compared to neutral, while the ASD group showed no LPC. The between-group difference in LPC amplitude was significant, suggesting that emotion words were processed differently by individuals with ASD, although their behavioral performance was similar to that of typical individuals.

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3.1 Introduction

Autism spectrum disorders (ASD) are characterized by problems in reciprocal social interaction, verbal and nonverbal communication, as well as by rigid and stereotypical behavioral patterns (APA 2000). At present, a precise understanding of emotion processing in ASD is lacking. We used reaction time measures to investigate whether adult individuals with ASD process emotion words differently from non-ASD controls, and we obtained EEG measures to examine whether any observed differences occur at an early or late stage of processing.

Most studies of emotion processing in ASD focused on facial expressions of emotion (Harms et al., 2010; Jemel et al., 2006). However, in recent years, the processing of emotion in non-facial stimuli in ASD became an increasingly important topic. The traditional position is that emotional impairments are foremost linked to and due to the well-known social deficits in ASD. Many researchers also linked problems in emotion understanding to Theory of Mind deficits (Simon Baron-Cohen, Wheelwright, Hill, Raste, and Plumb, 2001; Heerey, Keltner, and Capps, 2003; Hillier and Allinson, 2002). In contrast, other scholars argued that emotional impairments are more widespread and extend beyond the social domain (e.g., Gaigg, 2012). Yet other authors argue that emotional impairments are not universal in ASD, which means that there is a lot of heterogeneity in the results across different groups of ASD participants and across different tasks, and that the impairments are not specific to emotion (Nuske et al., 2013). This implies that many of the findings can be accounted for in terms of differences in attention/motivation/baseline physiological activity between ASD and comparison groups.

For typical participants, the processing of emotion words and images has been well-studied. First of all, both emotionally positive and negative words are more salient and automatically recruit attentional resources: they are remembered better than neutral words (Kensinger and Corkin, 2003), and when participants are asked to perform a lexical decision task (in which they decide as quickly as possible whether a letter string is an existing word or not), they respond faster (Kousta, Vinson, and Vigliocco, 2009; Kuchinke, Võ, Hofmann, and Jacobs, 2007), and more accurately (Zohar Eviatar and Zaidel, 1991) if the word is emotional. However, a difference arises not only between emotional and neutral words, but also between emotionally positive and emotionally negative words. For example, emotionally negative words produce interference effects in the color naming Stroop task, but this effect has not been obtained with emotionally positive words (Mackay et al., 2004). In a detection

task, emotionally negative words are generally detected faster and more accurately than positive words (Nasrallah, Carmel, and Lavie, 2009), but in a classification task people take longer to classify emotionally negative words (Dahl, 2001). In the lexical decision task, the effect for negative words is generally weaker (Kissler and Koessler, 2011) and negative words with lower emotional arousal ratings are in fact recognized slower, while positive words are recognized faster irrespective of arousal (Hofmann, Kuchinke, Tamm, Võ, and Jacobs, 2009). One possible explanation for this response difference to positive and negative emotion words is that positive emotion additionally triggers an approach tendency and facilitates responses, while negative emotion triggers avoidance, thus causing a slowdown. In other words, for positive emotion, the two effects are in line and add up, but for negative words they work in opposite direction; the observed outcome depends on which effect dominates in this specific task (Kousta et al., 2009). Another possibility is that emotionally negative words recruit more cognitive resources, thus interfering with the task (Dahl, 2001).

Event-related potential (ERP) studies show that the earliest effects of emotion are visible as early as 100 ms after word onset (Hofmann et al., 2009). Two ERP correlates of emotion processing are the early posterior negativity (EPN) and the late positive component (LPC). The EPN peaks between 250 and 300 ms with a posterior distribution; it is associated with early detection of emotionally salient stimuli (Schacht and Sommer, 2009; Kissler, Herbert, Winkler, and Junghöfer, 2009; Herbert, Junghöfer, and Kissler, 2008). However, some studies do not find an EPN effect (Hofmann et al., 2009; Dillon, Cooper, Grent-'t-Jong, Woldorff, and LaBar, 2006), and other studies report an enhanced P200/P300 amplitude for emotional stimuli, an effect in the opposite direction compared to EPN (Herbert, Kissler, Junghöfer, Peyk, and Rockstroh, 2006; Kanske and Kotz, 2007).

The LPC typically starts around 400 ms after stimulus onset, and lasts for several hundred milliseconds (Dillon et al., 2006; Schacht and Sommer, 2009). Some studies observe similar LPC effects for positive and negative words (Schacht), while other studies find bigger LPC for positive words (Herbert et al., 2006), and yet other studies find a more negative ERP for emotionally negative words (Herbert et al., 2008). A similar LPC effect has been found not only for single words, but also for emotion words embedded in sentence context (Bayer, Sommer, and Schacht, 2010; Holt, Lynn, and Kuperberg, 2008) and for emotional images (Schupp et al., 2000). The LPC has been associated with motivational engagement (Schupp et al., 2000), enhanced attention, and deeper stimulus encoding (Herbert et al., 2006). For

example, a study with images found that increased LPC amplitudes for emotional items correlated with better memory performance on those items (Dolcos and Cabeza, 2002).

To date, only a few studies have investigated emotional processing in ASD outside the domain of facial emotion recognition. Studies on memory performance found that emotional valence had little or no effect in the ASD group, in contrast to the typical population when participants were asked to remember and subsequently recall emotional sentences (Beversdorf et al., 1998), images (Wilbarger et al., 2009; Deruelle et al., 2008), and single words (Gaigg and Bowler, 2008, 2009b). However, other studies failed to replicate this finding (South et al., 2008). In a sequence of rapidly presented stimuli, typical participants detected emotional words more accurately than neutral words, but this was not the case in the ASD group (Corden et al., 2008; Gaigg and Bowler, 2009a). Finally, two more studies reported that individuals with ASD display an abnormal pattern of automatic reflexes such as startle reflex and postauricular reflex in response to emotional stimuli (Dichter et al., 2010; Wilbarger et al., 2009). It is not clear whether there are differential effects of negative valence in ASD group. Several of the studies mentioned above only used negative emotional stimuli (Beversdorf et al., 1998; Corden et al., 2008). One study using emotionally positive and negative items found an effect for negative, but not for positive emotion (Deruelle et al., 2008).

In the current study, we investigated for the first time the emotion facilitation effect in the ASD population in a lexical decision task. In the comparison group with typical participants, we expected to find the often observed emotion facilitation effect (cf Kousta et al., 2009) and the LPC component for emotion words in the EEG. In line with previous research, we expected that in the ASD sample, word valence would have little or no effect on reaction times and ERP amplitudes.

Failure to find ERP effects of emotion in the ASD group could be due to other reasons than just issues of valence. For example, it could be that participants in our sample do not show a reliable ERP response, or that they have a general impairment in lexical-semantic processing which is not specific to emotion per se, but affects all aspects of word processing. Response times and ERP amplitudes to words in general are not only influenced by emotional valence, but also by word frequency (Grainger, 1990; Rugg, 1990; Hauk and Pulvermüller, 2004; Holcomb and Grainger, 2006). Specifically, word frequency modulates the N400 ERP component in the time window between 300 and 500 ms (Halgren et al., 2002; Hauk and

Pulvermüller, 2004), with low-frequency words eliciting more negative amplitudes compared to high-frequency words. The use of the word frequency as an additional control variable provides a safeguard that any absence of a valence effect is not due to an insensitivity of the experimental procedure. Absence of the effect of frequency in addition to an effect of valence would point to a more general impairment in language processing, while the presence of frequency effects in the absence of valence effects would indicate that findings are really valence-specific.

3.2 Materials and Methods

3.2.1 Participants

Participants included 21 high-functioning adults with ASD and 20 matched typical individuals (15 males), aged 18-36 years. All participants with ASD met the DSM-IV (APA, 2000) criteria for autistic disorder or Asperger syndrome as established by an independent clinician. The clinical diagnosis was established based on all information collected during a psychiatric interview, developmental history, an interview with the parents, if available, and a review of prior clinical records. In ten subjects, the Autism Diagnostic Interview-Revised (ADI-R) (Lord, Rutter, and Couteur, 1994) could be administered, the results of which confirmed the clinical diagnosis. In all cases, the clinical diagnosis of ASD was beyond doubt. People with a PDD-NOS diagnosis or severe comorbid axis-I conditions (schizophrenia, bipolar disorder, or depression) were excluded.

	Typical (N = 20)	ASD EEG sample (N = 19)	ASD behavioural sample (N = 21)
Females/males	5/15	5/14	7/14
Age	24.3 (4.3)	26.7 (5.8)	26.9 (5.6)
Verbal IQ (PPVT)	103.8 (9.3)	102.7(14.2)	103.6 (13.9)
Raven (raw score)	23.1 (7.7)	24.4 (7.8)	24.5 (7.4)
Raven (IQ score)	107.9 (15.8)	108.6 (14.4)	108.8 (13.7)

Table 3.1: Participant characteristics

The ASD group was recruited from referrals to the Department of Psychiatry at the UMC and from participants from previous studies (Groen et al., 2009; Poljac et al., 2009; Visser

et al., 2013). People from the comparison group were recruited through advertisements in the local community. Prior to inclusion, typical subjects were asked whether they had any history of psychiatric or neurological disorders; subjects diagnosed with any of these disorders were excluded. All participants were native speakers of Dutch and had no known history of neurological disorder, head injury or reading problems. All participants had normal or corrected-to-normal vision. Two participants with ASD had used psychostimulant medication due to comorbid ADHD prior to the current experiment. All participants gave informed consent to participate in the study and were reimbursed for participation at the rate of 8 euros per hour and travel expenses. The study was formally approved by the local medical ethics committee.

IQ was assessed with the adult version of the Peabody Picture Vocabulary test (Manschot and Bonnema, 1974) and Raven Progressive Matrices test (Raven, Raven, and Court, 1998) in all participants. The groups did not significantly differ on age, verbal intelligence, and nonverbal intelligence ($p > .1$ for all variables). To control for possible differences in mood, participants were asked to fill out the profile of mood states (POMS) questionnaire (Wald and Mellenbergh, 1990) immediately after the experiment. The participant characteristics are summarized in Table 1.

3.2.2 Materials

The stimulus set consisted of 180 Dutch words and 180 pseudowords. Words consisted of 60 neutral, 60 positive, and 60 negative Dutch nouns. Before the study, we collected ratings on their valence (emotionally positive or negative), arousal (relaxing or arousing), and concreteness (concrete or abstract) by means of an online survey. Each word was rated by at least 25 people who did not participate in the main experiment. All ratings were collected on a 7-point Likert scale.

Positive and negative words were matched on perceived arousal ability, and differed significantly from neutral words with respect to both valence and arousal. All three word groups were matched on concreteness, frequency collected from the CELEX database (at http://celex.mpi.nl, Baayen, Piepenbrock, and Gulikers, 1995), and length. The nonwords consisted of legitimate Dutch letter combinations. They were matched to the words with respect to length in number of letters.

Additionally, we controlled the stimuli on lexical frequency per million [number of occurrences of a word in the CELEX text corpus per million words, Baayen et al., 1995). To investigate the effect of frequency, we divided the stimuli into a high-frequency and a low-frequency condition, making sure that frequency and emotion were manipulated orthogonally. Table 2 summarizes the word characteristics: ratings of valence, arousal and concreteness, length in letters, and CELEX frequency per million.

	Positive	Neutral	Negative
	High-frequency		
Valence[a]	5.76	4.08	1.90
Arousal[a]	5.20	3.25	5.04
Concreteness[a]	4.69	4.48	4.56
Frequency[b]	55.9	56.7	55.9
Length	6.37	6.17	6.27
	Low-frequency		
Valence[a]	5.72	4.02	1.87
Arousal[a]	5.1	3.15	4.96
Concreteness[a]	4.81	4.63	4.76
Frequency	8.5	8.7	8.4
Length	6.47	6.53	6.6

[a]Rated on a 1–7 scale

[b]Per million tokens in the CELEX text corpus

TABLE 3.2: Stimuli characteristics

3.2.3 Procedure

Participants were seated in a dimly lit, sound-attenuated room in front of a computer screen. The monitor was approximately 60 cm away, and the participants were allowed to adjust it to a comfortable distance. All stimuli were presented in white capital letters in Arial font against dark gray background at the center of the screen. Each trial began with a fixation cross for 300 ms, after which a letter string was presented for 350 ms, followed by a blank screen. The participants were instructed to read the letter string and respond whether it was an existing Dutch word or not by pressing a "yes" or "no" button on a buttonbox. The response interval lasted for maximally 2,000 ms and ended with a button press. The intertrial interval between response/timeout and the next trial lasted for 2,000 ms.

3.2.4 EEG Data Recording

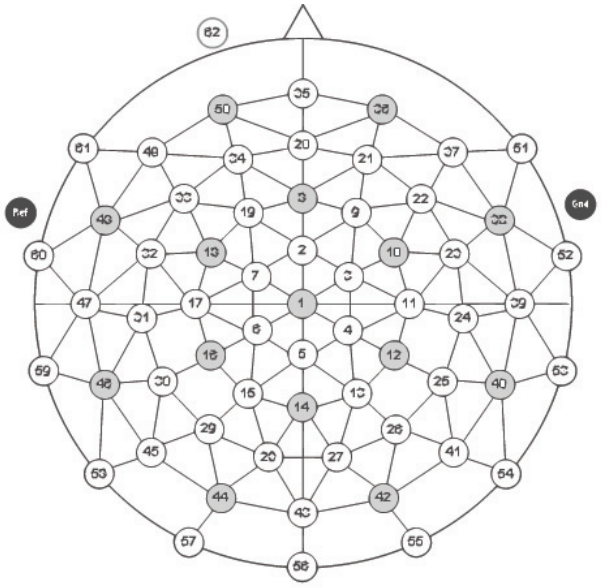

FIGURE 3.1: Electrode positions in the M10 equidistant montage

The EEG was recorded from 64 ActiCap active electrodes (Brain Products GMBH). The signal was amplified with two BrainAmp EEG amplifiers, powered by BrainVision Powerpack LiOn rechargeable batteries. Sixty test and reference electrodes were placed in the Easycap EEG recording cap in an equidistant montage (M10 Equidistant 61-Channel-Arrangement), and four electrodes were placed above and below left eye and at the outer side of each eye to record eye movement. The ground was placed at the nasion and the reference was placed at the left mastoid. The impedance was kept below 20 kOhm. We used the Brain Vision Recorder Professional software (Brain Products GmbH) for the recording. The signal was sampled at 500 Hz, and then band-pass amplified with upper limit at 200 Hz, using a time constant of 10 s.

3.3 Data analysis

3.3.1 Behavioral Data Analysis

The error rate was below 10% in all participants, with the exception of one participant who produced an error rate of 18% (3% of responses were false rejections of word trials and 15% were false "yes" responses to nonwords). Removing the data of this participant did not change the pattern of results; therefore in the final analysis we report the results from all participants. For 5 words out of 120, more than 10 participants (25%) gave an incorrect response. These words were excluded from further analysis. Additionally, we excluded all trials with very slow or very fast responses. The cutoff point for slow responses was set at 2.5 standard deviations of the subject mean (this is a common cutoff threshold in psycholinguistic studies, see for example Yap, Balota, and Tan, 2013; Chwilla, Kolk, and Mulder, 2000; van Hell and Dijkstra, 2002), and was calculated for every participant

separately. The cutoff point for the fast responses was set at 100 ms after stimulus onset. The preprocessing was done using Matlab R2009b (The MathWorks, Inc., Natic, MA) software. To make sure that the results were not driven by the slow responses, we repeated the same analysis for the non-preprocessed data (with only nonwords and false responses removed). We found the same pattern of results as in the preprocessed data. As an estimate of effect size in repeated-measures ANOVA we report the generalized eta squared (η^2_G) in addition to partial eta squared (η^2_p). The first measure is proposed as a preferred effect size measure for within-subject designs, which provides comparability for within- and between-subjects designs (Bakeman, 2005).

3.3.2 EEG Data Analysis: Whole Surface

Because of technical problems during registration, the EEG data from two participants with ASD could not be analyzed. The EEG data were analyzed with Fieldtrip software (Oostenveld, Fries, Maris, and Schoffelen, 2011). The segments were defined from 200 ms before word onset until 1,000 ms after word onset. Trials with muscle artifacts were detected based on power in 110-140 Hz frequency band and rejected completely. Eyeblink artifacts were removed with the Independent Component Analysis (ICA) method implemented in Fieldtrip. After that, the data were low-pass filtered at 35 Hz, preprocessed to remove the linear trend, baseline corrected using a 200 ms interval before word onset as a baseline, and then converted to an average reference. Next, all trials were manually reviewed and remaining artifacts were removed. Finally, the data were distinguished into different conditions and a grand average was calculated for each condition separately.

For the EEG data analysis, we used permutation-based statistics. A conventional ERP analysis is based on a specific time interval and location of interest selection. However, the selection has to be done prior to the analysis, otherwise it leads to biased effect reporting and inflated statistical significance, which is a serious concern (Kilner, 2013). For typical individuals, previous studies allow us to make a definite prediction about where and when the effect of interest will appear. However, for the ASD group no such studies have been done, and if the effect appears earlier or later or has a different spatial distribution, we might entirely miss it. Permutation-based statistics based on a whole-surface whole-time interval analysis avoids this problem by looking at the entire data set while correcting for multiple comparisons.

Instead of averaging the data over a given time interval and channel group, we calculated a t test for every channel and every time point, and looked for clusters of data points exceeding an uncorrected significance threshold of $p = .05$. The cluster statistic was defined as the sum of individual t-values. The significance threshold for the cluster statistic was determined using Monte Carlo simulations by randomly permuting the original data and calculating the probability distribution for the cluster statistic over 1,000 simulations. The cluster statistic was considered as significant if its value was exceeded in no more than 5% cases in the permuted data. This method was developed specifically for EEG/MEG data, and it is similar to a Monte Carlo simulation-based approach used for fMRI data analysis. (For further details and the application of this method to EEG/MEG data, see (Maris and Oostenveld, 2007; van Ede, de Lange, Jensen, and Maris, 2011; Moratti, Saugar, and Strange, 2011).

3.3.3 EEG Data Analysis: Regions of Interest

In addition to the whole brain analysis, we also ran a region of interest (ROI) analysis. We analyzed the data by region and time of interest as follows. From the literature we know that the effect of lexical frequency is most commonly found in the N400 time window (between 300 and 500 ms), and the effect of emotion (LPC) is present between 400 and 900 ms with some variation between the studies. Therefore, we defined two time intervals of interest: the N400 window (300–500 ms) and the LPC time window (500–700 ms). Previous studies have found that the effects of frequency and emotion show a centro-parietal distribution. Therefore, a ROI midline analysis would be most adequate to investigate the effects. We defined three ROIs: the Fz group (electrodes 2,8,9,19,20), the Cz group (electrodes 1,3,4,6,7), and the Pz group (electrodes 13,14,15,27,28) (See Fig. 1).

We expect to find a significant effect of frequency in the N400 time window with no differences between group, and we plan to find an effect of valence in the N400 and the LPC time windows and a significant between-group difference.

3.4 Results

3.4.1 Behavioral Results

The repeated measures ANOVA with reaction time as dependent variable, and Group (ASD, typical) and Emotion (positive, neutral, negative) as independent variables yielded a significant main effect of group ($F(1, 39) = 9.47, p < .005, \eta_p^2 = .20; \eta_G^2 = .19$) and a significant main effect of Emotion ($F(2, 78) = 23.60, p < .001, \eta_p^2 = .38, \eta_G^2 = .007$). The typical subjects reacted overall faster than the ASD subjects, and reactions to emotion words were overall faster than reactions to neutral words (see Fig. 2). The interaction between the two factors was not significant ($F = .29, p = .74$).

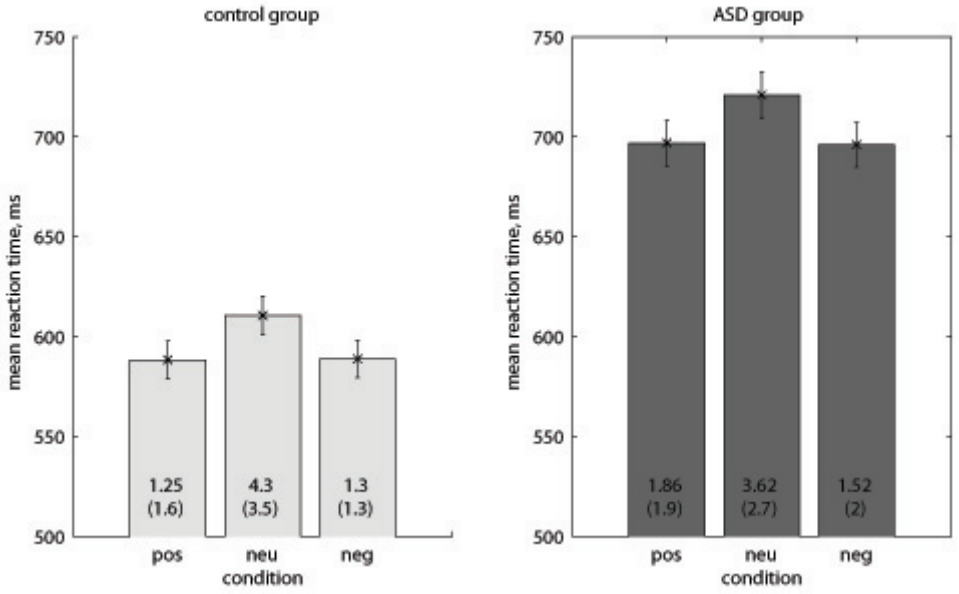

FIGURE 3.2: Mean reaction times for emotional and neutral words in the ASD and typical groups (error bars indicate 95% confidence intervals). The numbers indicate the error rate (in percent) for each condition, standard deviation is in parentheses

Although the two groups did not statistically differ in terms of their IQ, we explored whether the group effect was co-determined by IQ. When verbal IQ measured by PPVT was added as a covariate to the model, the main effects of Group and Emotion remained significant, and the interaction between the two remained nonsignificant. However, the Emotion * Group * PPVT interaction was found to be significant (Greenhouse-Geisser corrected, $F(4, 74) = 2.98, p = .024, \eta_p^2 = .14$). This means that verbal IQ played a different role in the ASD and typical groups. In order to explore the relationship between verbal IQ and the emotion facilitation effect in ASD and typical individuals, we looked at the two groups separately. In the typical group, the emotion facilitation effect (which is the reaction

time difference between emotion and neutral words) was not significantly correlated with the verbal IQ of the participants for either emotionally positive words ($r = -.23, p = .34$), or emotionally negative words ($r = -.03, p = .9$). In the ASD group, the verbal IQ of the participants was uncorrelated with the emotion facilitation effect for positive words ($r = -.38, p = .09$), but significantly correlated with the emotion facilitation effect for negative words ($r = -.56, p = .008$). ASD participants with higher verbal IQ score displayed a smaller reaction time difference between negative and neutral words. In the analysis by items with between-subject factors Group (ASD, typical) and Emotion (positive, negative, neutral), both the factors Group ($F2(1, 344) = 543.0, p < .001, \eta_p^2 = .61, \eta^2 = .059$) and Emotion ($F2(2, 344) = 10.88, p < .001, \eta_p^2 = .06, \eta^2 = .02$) were significant. Adding the effects of frequency, concreteness, and length to the model did not change the significance level of the effect (main effect of Group: $F(1, 341) = 628.83, p < .001$; main effect of Emotion: $F(2, 341) = 12.64, p < .001$; frequency: $F(1, 341) = 40.92, p < .001$; concreteness: $F(1, 341) = 8.04, p = .005$; length: $F(1, 341) = 4.40, p = .04$; for all interactions $p > .2$).
With respect to error rates in the analysis by subjects with factors Group (ASD, typical) and Emotion (positive, neutral, negative), there was no main effect of Group ($F < .01, p = .93$), but there was a main effect of Emotion, with emotional words eliciting more accurate responses compared to neutral words (Greenhouse-Geisser corrected, $F(2, 78) = 33.76, p < .001, \eta_p^2 = .46, \eta_G^2 = .21$). The interaction between group and word valence was not significant ($F(2, 78) = 1.80, p = .18$). The mean percentages of errors in the different conditions are reported in Fig. 2.

3.4.2 EEG Results: Whole Surface Analysis

In the analysis of the EEG data, we adopted the cluster-based statistics approach described above. Although at visual inspection the amplitude of the ERP components in the ASD group appeared to be smaller than in the typical group, between-group differences did not reach significance for any of the conditions (all p values > .1).
Within-group comparisons between conditions yielded several significant results. First, a lexicality effect was found in both groups: nonwords elicited ERPs with more negative amplitudes compared to words. The timing and distribution of the lexicality effect was similar in the two groups (typical group: critical values for 2.5th and 97.5th percentile: -1,377.1 and 1,343.3 respectively, cluster statistic = $19,404.2, p = .002$, 292-692 ms; ASD

group: critical values for 2.5th and 97.5th percentile: -1,068.6 and 995.9 respectively, cluster statistic $= 9,113.2, p = .002$, 302-632 ms). The group by lexicality interaction was not significant.

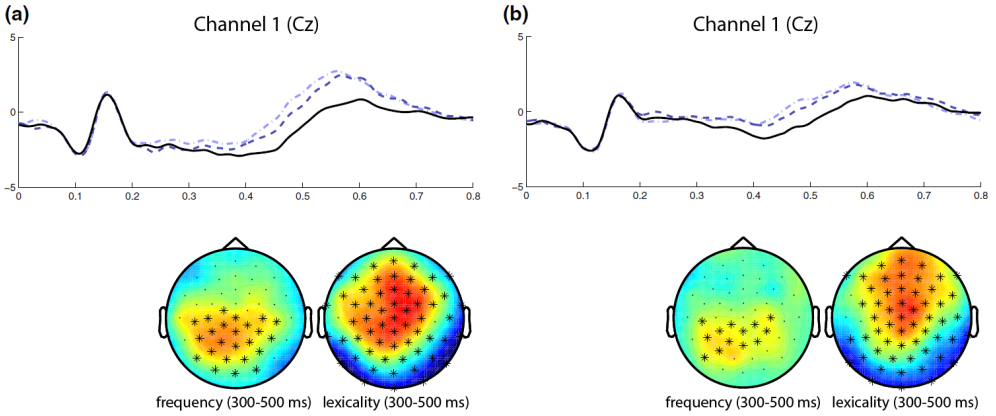

FIGURE 3.3: Lexicality and frequency effect: nonwords (black line), low-frequency words (blue dashed line) and high-frequency words (blue dash-dotted line). (a): typical group, (b): ASD group.

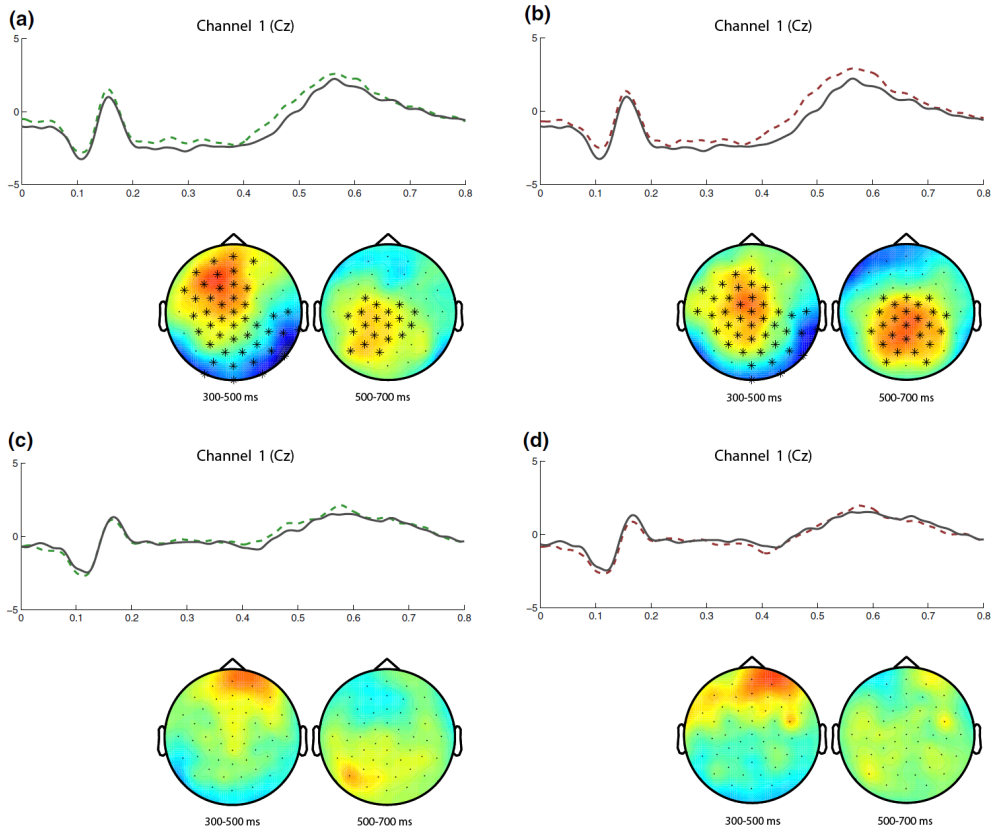

FIGURE 3.4: Effect of emotional valence (asterisks indicate channels showing a significant difference between conditions). Green line = positive, red = negative, gray = neutral words. Typical group: (a): positive vs neutral words, (b): negative vs neutral words. ASD group: (c): positive vs neutral words, (d): negative vs neutral words.

The effect of frequency was also found in both groups (see Fig. 3). High-frequency words elicited more positive-going ERP than low-frequency words (typical group: critical values for 2.5th and 97.5th percentiles: -781.2 and 720.8 respectively, cluster statistic $= 5,568.9, p =$ .002, 394-564 ms; ASD group: critical values for 2.5th and 97.5th percentiles: -640.6 and 616.0 respectively, cluster statistic $= 2,415.0, p = .002$, 440-622 ms). Additionally, there was a marginally significant group by frequency interaction (critical values for 2.5th and 97.5th percentiles: -664.8 and 585.5 respectively, cluster statistic $= 587.2, p = .05$, 204-256 ms). In this time window, the typical group had higher voltage for high-frequency words compared to low-frequency words, while in the ASD group this was reversed.

Turning to our main analyses, in the typical group both emotionally negative versus neutral conditions, and emotionally positive versus neutral conditions, significantly differed from each other. Emotionally positive words elicited a more positive-going ERP amplitude compared to neutral (critical values for 2.5th and 97.5th percentiles: -688.1 and 740.6 respectively, cluster statistic $= 4,430.6, p = .002$, time interval 336-562 ms); the same for emotionally negative versus neutral words (critical values for 2.5th and 97.5th percentiles: -812.5 and 940.8 respectively, cluster statistic $= 5,082.7, p = .002$, time interval 402-618 ms, see Fig. 4). The distribution of the significant clusters included left and central parietal electrodes. In the ASD group, however, the two conditions did not differ: positive versus neutral: critical values for 2.5th and 97.5th percentiles: -600.5 and 534.7 respectively, cluster statistic $= 76.1, p = .9$, negative versus neutral: critical values for 2.5th and 97.5th percentiles: -568.6 and 500.5 respectively, cluster statistic $= 295.8, p = .2$ (Fig. 4).

To test for between-group differences, we compared difference waves for positive versus neutral contrasts, and negative vs neutral contrasts, between groups. With respect to the difference between negative and neutral words, the two groups significantly differed from each other: the magnitude of the difference wave was larger in the typical group (critical values for 2.5th and 97.5th percentiles: -553.1 and 648.2 respectively, cluster statistic $= 1,014.2, p = .014$, time interval 458-526 ms). For the positive versus neutral contrast, the two groups did not differ statistically (critical values for 2.5th and 97.5th percentiles: -597.9 and 603.1 respectively, cluster statistic $= 201.5, p = .5$).

3.4.3 EEG Results: Region of Interest Analysis

To investigate the effect of frequency, we ran a Group (ASD, typical) by Frequency (high, low frequency) by Location (Fz, Cz, Pz) repeated measures ANOVA with Group as between-subject factor, and Frequency and Location as within-subject factors within the N400 time window ($300 - 500$ ms). For the variables with more than three levels, the p values were adjusted with Greenhouse-Geisser correction. The ANOVA yielded a significant main effect of Frequency ($F(1, 37) = 7.7, p = .009, \eta_p^2 = .17, \eta_G^2 = .003$), main effect of Location ($F(2, 74) = 28.1, p < .001, \eta_p^2 = .43, \eta_G^2 = .34$) and a significant Location by Frequency interaction ($F(2, 74) = 7.32, p = .004, \eta_p^2 = .172, \eta_G^2 = .002$). High-frequency words elicited more positive-going ERP amplitudes than low-frequency words, and this difference was significant at Pz (high vs. low: $F(1, 37) = 12.85, p = .001$, mean difference $= .40\mu V, 95\%CI$ for difference: .18 to .63 μV) and Cz locations (high vs. low: $F(1, 37) = 8.63, p = .006$, mean difference $= .34\mu V$, 95%CI for difference: .10 to .57 μV), but not at the Fz location (high vs. low: $F(1, 37) = .19, p = .66$; mean difference $= -.05\mu V, 95\%CI$ for difference: -.26 to -.17 μV). The main effect of Group did not reach significance ($F(1, 37) = 1.02, p = .3$) and neither did any interactions involving Group (frequency by group: $F(1, 37) = 1.6, p = .2$; Location by Group: $F(2, 74) = 2.67, p = .1$; frequency by group by location: $F(2, 74) = .15, p = .8$).

For the effect of valence, we ran a Group (ASD, typical) by Emotion (positive, negative, neutral) by Location (Fz, Cz, Pz) repeated measures ANOVA with Group as between-subject factor, and Emotion and Location as within-subject factors. For the variables with more than three levels the p values were adjusted with Greenhouse-Geisser correction.

Within the N400 time window ($300 - 500$ ms), the ANOVA yielded a significant main effect of Emotion ($F(2, 74) = 8.65, p < .001, \eta_p^2 = .19, \eta_G^2 = .003$), main effect of Location ($F(2, 74) = 28.32, p < .001, \eta_p^2 = .43, \eta_G^2 = .34$), and a Group by Emotion interaction ($F(2, 74) = 5.24, p = .008, \eta_p^2 = .12, \eta_G^2 = .002$). To resolve this interaction, we repeated the ANOVA in each group separately.

Within the typical group, the main effect of Emotion was significant ($F(2, 38) = 11.33, p < .001, \eta_p^2 = .37, \eta_G^2 = .009$). Neutral words elicited less positive-going ERP amplitudes than both emotionally negative words ($F(1, 19) = 20.1, p < .001, \eta_p^2 = .51, \eta_G^2 = .01$; mean difference (neg-neu)$= .49\mu V$, 95%CI for difference: .26 to .72 μV) and emotionally positive words ($F(1, 19) = 12.7, p = .002, \eta_p^2 = .4, \eta_G^2 = .008$; mean difference (pos-neu) $= .40\mu V$, 95%CI for difference: .16 to .63 μV). Within the ASD group, we did not find a significant

effect for either the main effect of Emotion ($F(2, 36) = 1.68, p = .2, \eta_p^2 = .08$), positive versus neutral ($F(1, 18) = 3.82, p = .07, \eta_p^2 = .17$, mean difference .16$\mu V$, 95%CI -.01 to .34 μV); negative versus neutral ($F(1, 18) = .01, p = .9, \eta_p^2 = .001$, mean difference .01$\mu V$, 95%CI -.22 to .24 μV) or Emotion by Location interaction ($F(2, 36) = 1.69, p = .19, \eta_p^2 = .09$).

Within the LPC time window (500 − 700ms), the ANOVA yielded following significant effects: main effect of Emotion ($F(2, 74) = 4.75, p = .01, \eta_p^2 = .11, \eta_G^2 = .002$), main effect of Location ($F(2, 74) = 26.27, p < .001, \eta_p^2 = .42, \eta_G^2 = .29$), Emotion by Location interaction ($F(4, 148) = 3.07, p = .04, \eta_p^2 = .08, \eta_G^2 = .003$), and finally Group by Emotion interaction ($F(2, 74) = 3.38, p = .04, \eta_p^2 = .08, \eta_G^2 = .002$). To resolve this interaction, we repeated the ANOVA in each group separately.

Within the typical group, the main effect of Emotion was significant ($F(2, 38) = 7.76, p = .002, \eta_p^2 = .29, \eta_G^2 = .008$). Emotionally negative words elicited more positive-going ERP compared to neutral words ($F(1, 19) = 16.74, p = .001, \eta_p^2 = .47, \eta_G^2 = .01$; mean difference = .42$\mu V$, 95%CI .21 to .64 μV) but emotionally positive words did not significantly differ from neutral ($F(1, 19) = 2.15, p = .13, \eta_p^2 = .12, \eta_G^2 = .003$; mean difference: .19$\mu V$, 95%CI -.06 to .44 μV). Within the ASD group, we did not find a significant effect for either the main effect of Emotion ($F(2, 36) = .07, p = .9, \eta_p^2 = .004$; positive versus neutral: $F(1, 18) = .06, p = .81, \eta_p^2 = .003$, mean difference: .03$\mu V$, 95%CI -.20 to -.26 μV; negative versus neutral: $F(1, 18) = .11, p = .74, \eta_p^2 = .006$, mean difference: .04$\mu V$, 95%CI -.20 to -.27 μV) or Emotion by Location interaction ($F(2, 36) = 2.23, p = .11, \eta_p^2 = .11$).

To explore whether the group effect was co-determined by IQ, PPVT was added to the model. The Group by Emotion interaction remained significant (in the N400 time window: $F(2, 72) = 5.11, p = .009, \eta_p^2 = .12$; in the LPC time window: $F(2, 72) = 3.39, p = .04, \eta_p^2 = .09$), but the main effect of Emotion became nonsignificant (in the N400 time window: $F(2, 72) = .14, p = .87, \eta_p^2 = .004$; in the LPC time window: $F(2, 72) = .56, p = .57, \eta_p^2 = .01$). Furthermore, the PPVT by Location interaction was significant (in the N400 time window: $F(1.27, 45.7) = 6.3, p = .011, \eta_p^2 = .15$; in the LPC time window: $F(1.3, 47.9) = 10.44, p = .001, \eta_p^2 = .23$). In participants with high PPVT scores, in both time windows the average voltage was more positive at posterior electrodes and more negative at frontal electrodes, but in participants with low PPVT scores the topography was more "flat", with a smaller difference between front and back. This was the case in both ASD and in typical group. The whole surface analysis (which corrects for multiple comparisons and is unbiased

with respect to selecting time windows and electrodes) did not find a significant EPN effect. To make sure that we did not miss the EPN, we tested for the effect of EPN in the time window and location reported by Schacht and Sommer 2009 (200–300 ms, electrodes 42 and 44 which correspond to O1 and O2). We found no significant effect of emotion ($F(2, 74) = 1.9, p = .16$).

We also explored whether the ERP effect (defined as the voltage difference between emotion and neutral words at the Cz location in the 300–500 ms time window, where the LPC was largest) was correlated with the behavioral measure of interest (emotion facilitation effect). The correlation turned out to be not significant (for positive words: $r = -.23, p = .17$; for negative words: $r = .09, p = .6$).

3.5 Discussion

In the present lexical decision study, we compared the performance of high-functioning ASD participants and a typical comparison group on behavioral measures of reaction times and error rates, and on ERP amplitude in various time windows following stimulus onset. In line with previous research, the typical group gave faster and more accurate responses to emotion words compared to neutral words. Contrary to our prediction, we found a similar effect of emotional valence on the reaction times and error rates of the ASD group. This result shows that individuals with ASD are not "blind" or "insensitive" to valence, as we hypothesized.

Our behavioral findings contradict the initial hypothesis that subjects with ASD would process emotion and neutral words in a similar way, as well as previous studies finding no effect of emotion in the ASD group. There may be several explanations for the obtained result pattern. First, the task was different: Previous studies used memory and attention tasks requiring stimulus detection or recall, while our study involved a lexical decision task, which required giving a response on every trial. The two types of tasks tap into different stages of emotion processing: The emotional facilitation effect in the lexical decision is mainly driven by early preconscious bottom-up facilitation that speeds up recognition and response (Kousta et al., 2009), while successful emotional memory formation is associated with increased activity at a later time window during postlexical processing (Dolcos and Cabeza, 2002).

Another explanation for the findings lies in the variation between participant samples. There is a possibility that other parameters, which we did not measure, such as callous-unemotional traits (Dolan and Fullam, 2010; Rogers, Viding, Blair, Frith, and Happe, 2006) or alexithymia (Bird et al., 2010, 2011; Lombardo et al., 2007), are responsible for differences between our sample and samples included in the other studies. As a third option, we should consider that some of the previous studies that found the behavioral reactions to emotion words in ASD and typically developing participants to be different, based their conclusions on finding a significant effect in the typical group in the absence of an effect in the ASD group, while their main effects of group or the group by valence interaction did not reach significance (Gaigg and Bowler, 2008, 2009a; Dichter et al., 2010). This throws some doubt on these studies with respect to their power to assess whether the ASD and control groups were really different or similar in behavioral performance.

With regard to ERP measures, we found an effect of lexicality (words vs. nonwords) and of word frequency (high vs. low) in both participant groups. The effect of frequency reached significance in the late N400 time window (400–500 ms) and had a similar spatial distribution in both groups. ROI analysis confirmed that in the N400 time window (300–500 ms), the ERP amplitude was significantly lower for low-frequency words in both groups with no between-group differences. This finding lends support to the validity of our experimental design and stimulus materials. As predicted, we found a significant effect of stimulus valence in the typical group, which consisted of a positive shift in the ERP at central and anterior electrodes at 350–400 ms, moving towards centroparietal electrodes at 500–600 ms. The distribution and timing of the effect closely resembled the LPC reported previously for emotional words and images (Dolcos and Cabeza, 2002; Kissler and Koessler, 2011). In the ASD group, the LPC effect was absent in both the positive versus neutral contrast and the negative vs neutral contrast. The group by valence interaction analyses confirmed that the negative versus neutral contrast, but not the positive versus neutral contrast, differed significantly by group. The same pattern emerged in the ROI analysis, where we found a significant group by valence interaction in both N400 and LPC time windows, with a significant effect of valence in the typical but not ASD group. We did not find a significant EPN effect in either group; however, previous studies suggest that EPN is more dependent on task and stimuli characteristics (compared to LPC) and is more difficult to replicate (Dillon et al., 2006; Hofmann et al., 2009).

Based on the ERP data, we conclude that individuals with ASD may still process in particular negative emotional valence differently compared to typical participants, while the corresponding behavioral response data do not differ between the groups. The finding that the group by valence interaction only reached significance in the negative condition is consistent with the results of previous research (e.g., Deruelle et al., 2008), where a significant group by valence interaction emerged for negative, but not for positive stimuli. Further, studies of processing of emotion words and images suggest that negative valence is qualitatively different from positive valence, and has a stronger effect on brain activity and behavior (Dahl, 2001; Nasrallah et al., 2009; Ohira, Winton, and Oyama, 1998; Vaish, Grossmann, and Woodward, 2008; Taylor, 1991). In life, it is generally more important to avoid threatening objects than to approach attractive ones. Neural mechanisms affected in the ASD sample may be crucial for the processing of negative valence, but not so much positive valence, in line with the finding that the positive condition differed from neutral, albeit only at trend level, while the negative condition did not.

The absence of the LPC in the participants with ASD suggests that they do not engage in more intensive top-down processing during the comprehension of emotion words. It also suggests that they process valence in a way that differs from the typical population. In principle, the processes underlying the LPC should have no effect of the lexical decision, because the LPC occurs after lexical access. Thus, by the time the LPC reaches its peak (around 500–600 ms), the word has already been identified. On the other hand, LPC has been associated with increased cognitive processing load, and enhanced attention and memory encoding. In other studies, a larger ERP amplitude for emotion words in the 400–600 ms interval predicted better subsequent memory performance (Dolcos and Cabeza, 2002). Therefore, the lack of ERP modulation by valence in the ASD group may explain why previous studies found no emotional memory effect in that group. Furthermore, the absence of an LPC in the ASD group is not likely to be due to general difficulty with language stimuli or lack of reliable ERP response to words. Note that the effect of valence in the typical group lasted even longer than the effect of frequency and also involved a larger cluster of electrodes. In contrast, in the ASD group, the effect of frequency was present, but there was no significant effect of valence. This indicates that it is not the processing of linguistic stimuli per se that makes the difference between ASD and typical participants, but their valence in particular.

To summarize, our study led to a number of innovative findings and conclusions. Firstly, contrary to suggestions from earlier studies, individuals with ASD are not completely insensitive to emotional valence, as is reflected in our behavioral findings. However, and secondly, individuals with ASD process emotional valence in a different way than typical individuals on the neural level, as indicated by our EEG data. Whereas manipulations of lexicality and frequency evoked similar neural responses by the participants from both groups, the effect of valence (as reflected by LPC) was only present in the typical group.

The behavioral emotional facilitation is thought to be an early preconscious effect reflecting enhanced bottom-up processing (Kousta et al., 2009). On the other hand, LPC is generated by the cortical sources and is thought to reflect postlexical processing, allocation of additional resources for information that can be potentially relevant (Schupp et al., 2000, 2006). Our results suggest that the deficit in emotional processing in ASD is specific to late top-down processing, while the early stages of processing are unaffected. Perhaps the participants with ASD have developed an alternative processing strategy for emotional content which results in the atypical ERP response. A limitation of this study is that ADI scores were available only for a subgroup of participants with ASD. Therefore, it might be argued that this limits a potential generalization of the findings to the ASD population as a whole. However, we would like to point out that the clinical diagnosis of ASD was beyond doubt in all participants with ASD.

In all, our results add to the understanding of emotion processing in high-functioning individuals with ASD. The existence and extent of emotional impairments in ASD has become a debated topic. Recent reviews indicate that individuals with ASD indeed have difficulty in processing emotional stimuli, but it is still debated whether those difficulties are secondary to other cognitive domains or constitute an independent problem (Nuske et al., 2013; Gaigg, 2012). Our results support the theoretical position that emotional impairments extend beyond the visual domain to emotional language and are a relatively independent component of ASD. Further study of the neural architecture of abnormal emotion processing in ASD is warranted, and should be complemented with studies on how emotional impairments link with cognitive processes and social behavior in ASD. Already in 1943, Kanner described autistic children as emotionally cold and distanced. However, in the decades following this remark, this topic received relatively little attention, with most emotion-related research in ASD focusing on the perception of emotions in faces. The present study meant to revitalize

the important topic of the relations between emotion, language, and cognition. We hope to have shown that the study of emotion processing by means of linguistic stimuli may contribute significantly to our understanding of ASD.

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Chapter 4

Semantic and Affective Word Priming in Autism Spectrum Disorder

Abstract

Several studies have found atypical processing of emotion words in ASD. While typical participants recognize and recall emotion words more accurately than neutral words, individuals with ASD show a similar performance for emotion and neutral words. An impairment in the amygdala-based salience detection system has been proposed to account for these findings. Here, we investigated the processing of emotion words in a priming task. Participants (22 adults with ASD and 31 controls) evaluated whether a presented target word was emotionally positive or negative, while their EEG was recorded. Each target word was preceded by a briefly presented prime word. When the prime was affectively congruent (i.e., had the same emotional valence as the target), the participants' decision was facilitated, whereas an affectively incongruent prime slowed it down. In typical participants, the affective priming effect was of the same magnitude for emotionally positive and negative target words. In contrast, participants with ASD showed a smaller affective priming effect for emotionally negative targets and a larger effect for emotionally positive words. The pattern of EEG responses was also different between groups, with the typical but not the ASD group showing a posteriorly distributed Late Positive Component. We conclude that participants with ASD are sensitive to emotional valence in words. However, for them negative emotion has a greater salience than positive emotion, and evaluating emotion words is a more conscious and effortful process.

Keywords: autism, ASD, affective priming, semantic priming, EEG, ERP, LPC, N400.

Publication: Lartseva, A., Dijkstra, T., Kan, C., and Buitelaar, J. Semantic and affective word priming in Autism Spectrum Disorder (in preparation).

4.1 Introduction

Diagnostic criteria of Autism Spectrum Disorder (ASD) include a deficit in emotional reciprocity, and a lack of sharing affect and enjoyment (APA 2000, 2013). Studies report atypical processing of emotional stimuli in people with ASD in that there is similar memory performance for emotional and neutral stimuli, while typical participants remember emotional information better (Deruelle et al., 2008; Beversdorf et al., 1998). In addition, people with ASD have similar stimulus detection rates for emotion and neutral words, while typical participants detect emotion words better (Corden et al., 2008; Gaigg and Bowler, 2009a). These results argue for an impaired processing of emotional valence. However, a study in which stories were presented in a sequence of picture slides found an emotional memory effect in ASD (Maras et al., 2012). This finding suggests that instead of being generally impaired, the emotion processing system in ASD might just be conditionally impaired, depending on strategic differences in task performance. The studies described earlier involved non-emotional tasks in which the valence of the stimulus words was task-irrelevant and could potentially be ignored. In those cases, it is not clear whether participants with ASD were unable to process emotion words, or if they just selectively blocked the processing of emotional valence because it was task-irrelevant. To resolve this issue, in the present study we investigated affective word priming effects by means of an evaluative judgment task. If an (emotion) word is preceded by another word that has the same emotional valence (for example, both words are emotionally positive), then the second word is recognized faster and with greater accuracy, compared to when the two words have opposite emotional valence. This effect is called "affective priming" (Klauer and Musch, 2003). This effect is usually found in tasks that require explicit attention to the emotional properties of the word, such as judging whether the word means something pleasant or unpleasant (evaluative judgment task). There is some evidence for affective priming effects in naming and lexical decision, but these have not been consistently replicated (Rossell, 2004).

At the neural level, affective priming is mediated by two mechanisms (Spruyt, Hermans, de Houwer, Vandromme, and Eelen, 2007). The first mechanism is response selection: The prime briefly pre-activates a corresponding response ("positive" or "negative"), so when the target is presented, the response preparation for the target is either facilitated (if the prime was congruent), or inhibited (if the prime was incongruent). There is evidence that the amygdala may mediate in this process (Yang, Cao, Xu, and Chen, 2012; Garolera et

al., 2007). One MEG study with emotion words found transient amygdala activation at 150 ms after presentation of the target word for emotionally congruent prime-target pairs (Garolera et al., 2007). Of note, patients with psychopathy, another condition associated with amygdala impairment (R. J. R. Blair, 2008; Mitchell et al., 2006), do not show affective priming (K. S. Blair et al., 2006).

The second affective priming mechanism involves facilitation of target encoding (Spruyt et al., 2007), which acts through spreading activation in the semantic network. At the neural level, it is reflected in the N400 component. Several EEG studies find an attenuated N400 component to affectively congruent prime-target pairs in the 300-500 ms time window after target onset (Kamiyama, Abla, Iwanaga, and Okanoya, 2013; Goerlich et al., 2012; Wu, Athanassiou, Dorjee, Roberts, and Thierry, 2011; Steinbeis and Koelsch, 2009; Zhang, Lawson, Guo, and Jiang, 2006). However, because semantic analysis is slower than amygdala-based response preparation, it is unlikely that this process contributes substantially to the behavioral effect, at least in the valence categorization task (Spruyt et al., 2007).

Lastly, affectively incongruent prime-target pairs elicit a larger Late Positive Component (LPC) between 500 and 800 ms after target word onset (Herring, Taylor, White, and Crites Jr, 2011; Czerwon, Hohlfeld, Wiese, and Werheid, 2013; Méndez-Bértolo, Pozo, and Hinojosa, 2011; Aguado, Dieguez-Risco, Méndez-Bértolo, Pozo, and Hinojosa, 2013; Zhang, Kong, and Jiang, 2012). The LPC is thought to reflect allocation of additional resources towards motivationally relevant stimuli. A larger LPC is typically found for emotional stimuli as compared to neutral ones. Subsequently remembered stimuli also elicit larger LPC than subsequently forgotten stimuli (Dolcos and Cabeza, 2002), suggesting that LPC also reflects memory encoding. Increased LPC amplitude to incongruent pairs reflects difficulties with response conflict resolution and reappraisal processes.

An absence of affective priming in the ASD group might either indicate an impairment of the emotion processing system, or be due to other factors, such as not being able to read the briefly presented prime in time or general difficulties with language processing. To make sure that a possible null finding is not due to a problem with the paradigm, we included a semantic priming condition, in which the prime and the target word are semantically related ("cat-dog" or "pen-write"). Semantically related primes lead to faster and more accurate recognition of the target word (Perea and Rosa, 2002). At the neural level, the semantic

priming effect is reflected in the modulation of the N400 component, with semantically unrelated pairs eliciting greater N400 amplitudes (Holcomb and Neville, 1990).

We made the following predictions:

- If participants with ASD have a general impairment in the rapid processing and integration of semantic information, both semantic and affective priming effects will be absent in the ASD group.
- If emotion, but not language processing, is selectively impaired, we expect to find typical semantic priming effects in the ASD group, but no affective priming effects.
- Finally, if the ASD group shows typical semantic and affective priming effects, that would suggest that emotion processing in ASD is in fact not universally impaired. In this case, the results of previous studies could better be explained in terms of attentional or memory deficits.

4.2 Methods

4.2.1 Participants

Participants included 22 high-functioning adults with ASD and 31 group matched typical individuals, aged 18–36 years. All participants with ASD met the DSM-IV (DSM-IV-TR, 2000) criteria for autistic disorder or Asperger syndrome as established by an independent experienced clinician. The clinical diagnosis was established based on all information collected during a psychiatric interview, developmental history, an interview with the parents, if available, and a review of prior clinical records. People with a PDD-NOS diagnosis or severe comorbid axis-I conditions (schizophrenia, bipolar disorder, or depression) were excluded.

	Typical group (N=36)	ASD group (N=22)	p
age	23.3 (3.6)	24.0 (4.1)	.52
AQ	14.9 (6.6)	32.05 (9.4)	$< .001$
EQ	43.2 (12.4)	23.9 (11.0)	$< .001$
Raven	25.9 (5.3)	23.4 (6.8)	.16
PPVT	102.2 (11.3)	106.0 (11.4)	.22

TABLE 4.1: Participant characteristics

The ASD group was recruited from referrals to the Department of Psychiatry at the UMC Nijmegen, and the Karakter Child and Adolescent Psychiatry University center. People from the comparison group were recruited through advertisements in the local community. None of the control participants reported any history of neurological or psychiatric diseases, head injury, or reading problems. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. All participants gave informed consent to participate in the study and were reimbursed for participation at the rate of 8 euros per hour and for travel expenses. The study was formally approved by the local medical ethics committee.
IQ was assessed with the adult version of the Peabody Picture Vocabulary test (Manschot and Bonnema, 1974) and Raven Progressive Matrices test (Raven et al., 1998) in all participants. Additionally all participants completed the Autism Quotient (AQ) (S. Baron-Cohen et al. 2001) and Empathy Quotient (EQ) (Simon Baron-Cohen and Wheelwright, 2004) to confirm the difference between groups in the degree of self-reported ASD symptoms, as well as to screen the control participants for presence of potential undiagnosed ASD. None of the control participants scored above 30 on the AQ questionnaire (Sasson, Dichter, and Bodfish, 2012). Participant scores are summarized in Table 1.

4.2.2 Stimulus Materials

primes	Valence	Frequency	Length(in letters)	targets	Valence	Concreteness	Frequency	Length(in letters)	N trials
positive (1)	5.87	22.9	7.1	positive (1)	5.82	4.61	22.7	6.66	32
positive (2)	5.82	23.2	7.1	positive (2)	5.95	4.85	23.2	7.2	32
negative (1)	2.06	18.9	7.3	negative (1)	1.87	4.3	21.6	6.8	32
negative (2)	1.95	19.2	6.8	negative (2)	1.91	4.61	21.4	7	32
neutral-pos (1)	4.37	31.4	5.9	neutral-pos (1)	5.81	4.98	45.2	6.8	18
neutral-pos (2)	4.41	31.6	5.5	neutral-pos (2)	5.8	4.9	42.1	7.3	18
neutral-neg (1)	3.59	26.7	6.3	neutral-neg (1)	2.05	4.91	27.9	6.4	18
neutral-neg (2)	3.43	14.9	6.1	neutral-neg (2)	2.0	4.8	25.6	6.3	18

TABLE 4.2: Characteristics of the stimuli in all test conditions. Frequency measured in occurrences per million; valence and concreteness rated on a 1-7 scale

The stimulus set consisted of 200 Dutch word pairs, which included 128 affectively congruent/incongruent pairs and 72 semantically related/unrelated pairs (Table 2). For the affectively congruent/incongruent word pairs, the emotionally positive and negative words were selected from a larger set of Dutch words rated on valence (emotionally positive or negative), arousal (relaxing or arousing), and concreteness (concrete or abstract) by means of an online survey. Each word was rated by at least 25 people who did not participate in the main experiment. All ratings were collected on a 7-point Likert scale. The affectively related word pairs were counterbalanced across participants, so that each prime appeared before a positive target for half of the participants, and before a negative target for the other half. Frequency norms were taken from CELEX database (CELEX, 2001).
The semantically related words pairs were constructed by matching an additional set of 36 emotionally positive and 36 emotionally negative target words with semantically related neutral prime words. The neutral semantically related primes were selected using the Dutch Word Association Database (De Deyne and Storms, 2008), and they were rated on emotional valence by a separate set of typical participants to confirm that they indeed were emotionally neutral words. Semantically unrelated words were obtained by shuffling the semantically related primes for half of the target words. Each neutral word appeared before a semantically related target for half of the experimental participants, and before a semantically unrelated target for the other half.

4.2.3 Procedure

Participants were seated in a dimly lit, sound-attenuated room in front of a computer screen at a distance of approximately 60 cm. All stimuli were presented in white capital letters in Arial font against dark gray background at the center of the screen. Each trial began with a fixation cross for 500 ms, after which the prime was presented for 200 ms, followed by a blank screen for 100 ms, and target word for 300 ms. The participants were instructed to indicate by pressing a button as quickly and accurately as possible whether the second word referred to something emotionally pleasant or unpleasant.

EEG data recording

The EEG was recorded from 61 ActiCap active electrodes (Brain Products GMBH) placed in the Easycap EEG recording cap in an equidistant montage (M10 Equidistant 61-Channel

Arrangement) and 4 additional electrodes to record the EOG.

The signal was amplified with two BrainAmp EEG amplifiers, powered by BrainVision Powerpack LiOn rechargeable batteries. We used the Brain Vision Recorder Professional software (Brain Products GmbH) for the recording. The signal was sampled at 500 Hz and then band-pass amplified with upper limit at 200 Hz, using a time constant of 10 s.

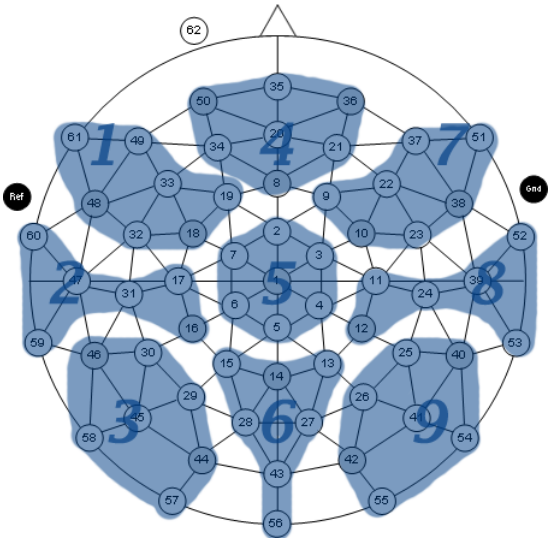

FIGURE 4.1: M10 equidistant electrode layout and electrode groups (1-9) used in the analysis.

4.2.4 Data analysis

Behavioral data analysis

Two participants were excluded because of extremely slow responses falling above the cutoff of 2.5 SD: one participant with ASD (average RT 1.9 seconds, z-score 4.2) and one control participant (average RT 1.7 seconds, z-score 3.5).

Reaction times of the participants in the evaluative judgment task showed an extremely skewed distribution. We analyzed the data using two methods: 1) removing the slowest responses (Ratcliff, 1993): we calculated the mean and SD for the RTs of each subject individually, and removed RTs that fell above 2.5 SD (2.5 SD is commonly used for outlier removal in psycholinguistic studies, see Yap et al., 2013; Chwilla et al., 2000; van Hell and Dijkstra, 2002); 2) calculating log-transformed RTs using base 10 logarithm in milliseconds (Knopman and Nissen, 1991; De Houwer, 2003; Fishbach, Friedman, and Kruglanski, 2003). We report the results as significant if they reached the significance threshold in both analyses. The data were analyzed in a repeated measures ANOVA with Group (ASD, typical) as between-subject factor and Target Emotion (positive, negative) and Relatedness/Congruency (related/congruent, unrelated/incongruent) as within-subjects factors.

EEG data analysis

For the EEG data analysis, we focused on two components: the N400, peaking at 400 ms, and the LPC, peaking at 600 ms. Because the two components go in the opposite directions, we selected more narrow time windows at 350-450 ms (for the N400) and 550-650 ms (for the LPC) to avoid overlap.

We expected to find a significant effect of semantic relatedness in the N400 time window with no differences between groups, and we expected to find an effect of affective congruence in the N400 and the LPC time windows, as well as a significant between-group difference.

To analyze the spatial distribution of the ERP, we divided the electrodes into 9 groups as shown in Figure 1: 3 in Left-Right (LR) direction (Left, Midline, Right) by 3 in Anterior-Posterior (AP) direction (Anterior, Central, Posterior). Although the scalp distributions of the N400 and LPC in the typical group are known, the distribution in the ASD group may be different. Therefore, we chose to include all sensors in the analysis. The EEG data were analyzed using a repeated measures ANOVA with Group (ASD, typical) as between-subject factor, and Relatedness/Congruency (related/congruent, unrelated/incongruent), Location-LR (left, midline, right), and Location-AP (anterior, central, posterior) as within-subjects factors.

4.3 Results

4.3.1 Affective priming effects

Error rates

Participants with ASD on average made the same number of errors as typical participants ($F(1, 54) = 1.17, p = .28$). Overall congruent trials elicited fewer errors than incongruent trials, but the main effect of Congruency did not reach significance ($F(1, 54) = 3.94, p = .052$). The congruency by emotion interaction was significant ($F(1, 54) = 5.89, p = .019$). Negative words elicited a similar number of errors irrespective of prime type, but positive words were more often identified as negative after a negative prime. No interaction involving Group reached significance (Group*Emotion: $F(1, 54) = .16, p = .69$; Group*Congruency: $F(1, 54) = 2.43, p = .12$; Group*Emotion*Congruency: $F(1, 54) = .53, p = .47$).

Reaction times

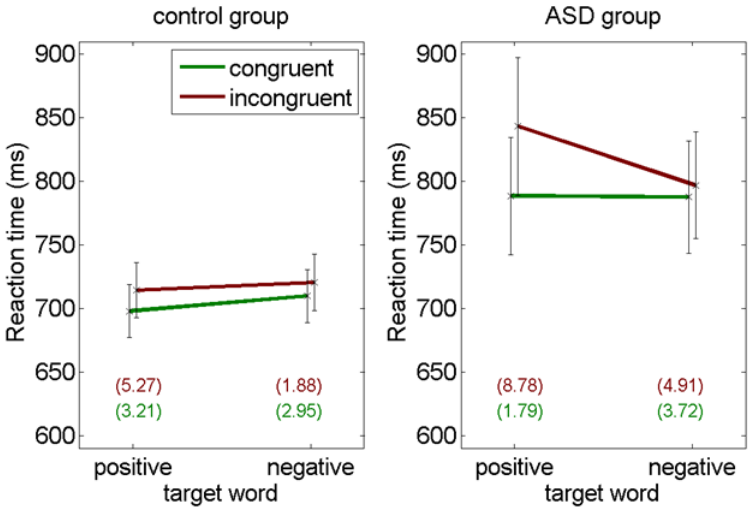

FIGURE 4.2: Affective priming effect in reaction times (plotted) and error rates (in parentheses) for congruent and incongruent conditions in the ASD group (right) and the control group (left). Error bars indicate standard error of the mean.

The main effect of congruency was significant: Target words preceded by an affectively congruent prime elicited shorter reaction times (See Figure 2). The Emotion by Congruency and Group by Emotion by Congruency interactions were also found to be significant (see Table 3). To consider this interaction in more detail, we analyzed each participant group separately.

The typical group showed a main effect of Congruency, but no Emotion * Congruency interaction. The magnitude of the priming effect was the same for positive and negative target words. In the ASD group, however, only the Emotion by Congruency interaction turned out to be significant in both analyses. For positive target words, the congruent condition was significantly faster than incongruent, but this was not the case for negative

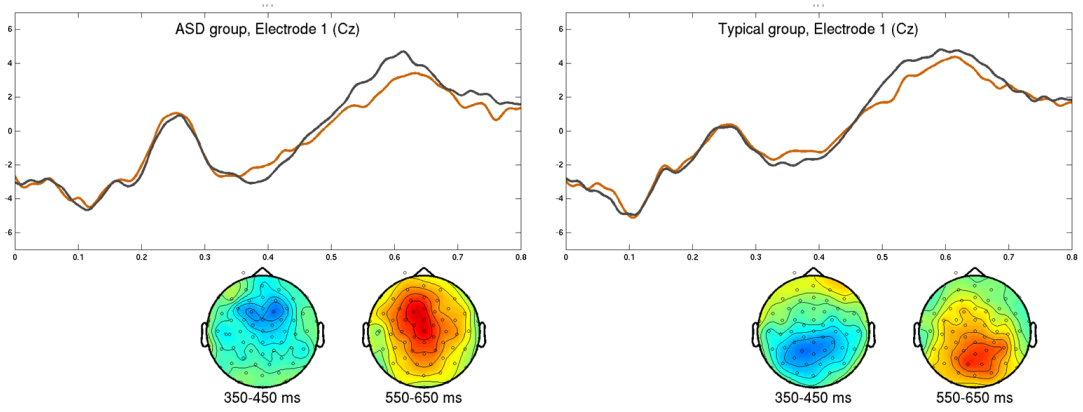

FIGURE 4.3: Affective priming effect in ERPs, ASD group (left) and control group (right)showing the ERP for affectively congruent targets (orange line), affectively incongruent targets (gray line) and the topographic plots for the difference waves.

Effect	Raw RT		Log RT	
Both groups	F (1,54)	p	F (1,54)	p
Group	4.33	.042*	3.73	.059
Emotion	.97	.33	.12	.73
Congruency	**7.75**	**.007***	**11.10**	**.002***
Emotion*Congruency	**7.74**	**.007***	**7.49**	**.008***
Group*Emotion	4.75	.034*	3.54	.065
Group*Congruency	1.28	.26	1.21	.28
Group*Emotion*Congruency	**4.66**	**.035***	**4.39**	**.041***
Typical group	F(1,34)	p	F(1,34)	p
Emotion	1.38	.25	4.35	.045*
Congruency	**4.17**	**.049***	**6.20**	**.018***
Emotion*Congruency	.49	.49	.29	.60
ASD group	F(1,20)	p	F(1,20)	p
Emotion	2.62	.12	.67	.42
Congruency	3.13	.09	4.39	.049*
Emotion*Congruency	**5.44**	**.03***	**8.68**	**.008***

TABLE 4.3: Reaction time results for the affective priming condition in both typical and ASD groups

targets.

In our previous study (see Chapter 3) we found a significant effect of verbal IQ on emotion word processing (Lartseva et al. 2014). We therefore analyzed the data with verbal IQ as a covariate. The results of this analysis are presented in the appendix.

EEG results

In the N400 time window, we observed a main effect of congruency, with incongruent word pairs eliciting more negative-going ERP compared to congruent. No other main effects or interactions reached significance (see Table 4).

In the LPC time window, both groups showed a more positive-going ERP for the incongruent condition compared to congruent (see Table 4). With respect to spatial distribution, the two groups significantly differed: In the typical group, the effect reached maximum over posterior electrodes, while in the ASD group it was distributed over frontal and central scalp regions (see Figure 3).

Effect	N400 time window		LPC time window	
Both groups	F (df)	p	F (df)	p
Congruency	**4.06 (1,54)**	**.049***	**9.62 (1,54)**	**.003***
Congruency*LR	1.01 (2,108)	.36	**3.91 (2,108)**	**.023***
Congruency*AP	.44 (2,108)	.54	.60 (2,108)	.48
Congruency*LR*AP	.54(4,216)	.61	**6.38 (2,216)**	**.002***
Group*Congruency	$< .01(1, 54)$	.98	.51 (1,54)	.47
Group*Congruency*LR	.06 (2,108)	.94	.20 (2,108)	.82
Group*Congruency*AP	1.48 (2,108)	.23	**5.99 (2,108)**	**.010***
Group*Congruency*LR*AP	1.60 (4,216)	.20	.34 (2,216)	.71
Typical group			F (df)	p
Congruency			3.41 (1,34)	.074
Congruency*LR			1.51 (2,68)	.23
Congruency*AP			**6.05 (2,68)**	**.011***
Congruency*LR*AP			**4.75 (4,136)**	**.011***
ASD group			F (df)	p
Congruency			**7.21 (1,20)**	**.014***
Congruency*LR			3.03 (2,40)	.06
Congruency*AP			1.60 (2,40)	.22
Congruency*LR*AP			2.6 (4,80)	.09

TABLE 4.4: ERP results for the affective priming condition in both typical and ASD groups

4.3.2 Semantic priming effects

Error rates

There was no main effect of group, which means that participants with ASD on average made no more errors than typical participants ($F(1, 54) = .59, p = .45$). Participants with ASD made more errors on negative words, while typical participants made more errors in positive words, but the Emotion*Group interaction did not reach significance ($F(1, 54) = 3.78, p = .057$).

The only effect that reached the significance threshold of p=.05 was the main effect of Relatedness: Semantically related targets elicited more correct responses than unrelated targets ($F(1, 54) = 5.19, p = .027$).

No other effect reached significance ($p > .2$ for all other main effects and interactions).

Effect	Raw RT		Log RT	
Both groups	F (1,54)	p	F (1,54)	p
Group	4.55	.037*	3.92	.053
Emotion	**12.97**	**.001***	**15.14**	**<.001***
Relatedness	**12.75**	**.001***	**6.72**	**.012***
Emotion*Relatedness	3.44	.069	3.40	.071
Group*Emotion	.12	.73	.59	.45
Group*Relatedness	2.75	.10	.80	.38
Group*Emotion*Relatedness	2.59	.11	.74	.39

TABLE 4.5: Reaction time results for the semantic priming condition

Effect	N400 time window		LPC time window	
Both groups	F (df)	p	F (df)	p
Relatedness	**31.49 (1,54)**	**<.001***	**4.88 (1,54)**	**.031***
Relatedness*LR	**12.92 (2,108)**	**<.001***	1.61 (2,108)	.21
Relatedness*AP	**8.56 (2,108)**	**.003***	.52 (2,108)	.51
Relatedness*LR*AP	**12.32 (4,216)**	**<.001***	**3.57(4,216)**	**.023***
Group*Relatedness	.04 (1,54)	.84	1.38 (1,54)	.24
Group*Relatedness*LR	.25 (2,108)	.74	.06 (2,108)	.91
Group*Relatedness*AP	1.03 (2,108)	.33	.78 (2,108)	.40
Group*Relatedness*LR*AP	2.22 (4,216)	.097	1.94 (4,216)	.14

TABLE 4.6: ERP results for the semantic priming condition.

Reaction times

The main effect of group was marginally significant: The ASD group tended to be on average slower than the typical group (Figure 4). The main effect of Emotion was significant in both analyses: Participants were faster to evaluate positive targets than negative. The main effect of Relatedness also was significant in both analyses: Targets preceded by a semantically related prime were evaluated faster. None of the interactions reached significance (see Table 5).

In our previous study we found a significant effect of verbal IQ on emotion word processing (Lartseva et al. 2014). Therefore, we analyzed the data with verbal IQ as a covariate. The results of this analysis are presented in the appendix.

EEG results

Both participant groups showed a significant N400 effect, with semantically unrelated targets eliciting more negative ERP waves compared to semantically related targets (Table 6). The effect was most pronounced at the centroparietal electrodes (see Figure 5). No significant differences between the groups emerged.

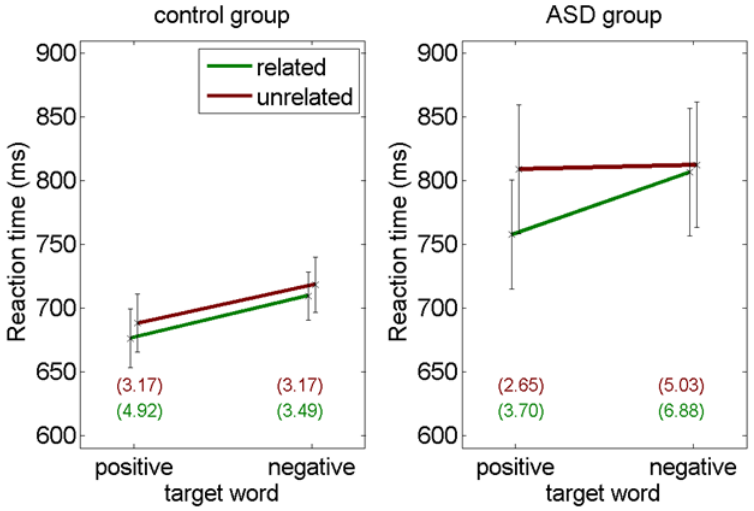

FIGURE 4.4: Semantic priming effect in reaction times (plotted) and error rates (in parentheses) for ASD group (right) and control group (left). Error bars indicate standard error of the mean.

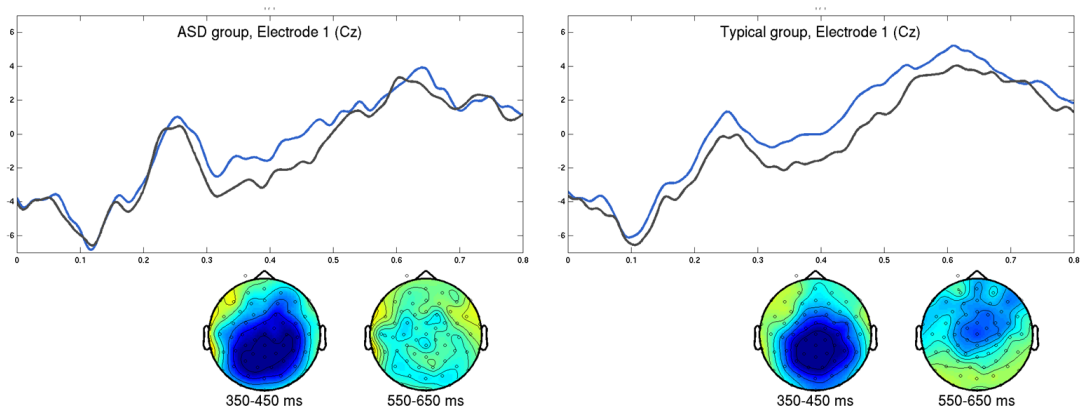

FIGURE 4.5: Affective priming effect in ERPs, ASD group (left) and control group (right)showing the ERP for affectively congruent targets (orange line), affectively incongruent targets (gray line) and the topographic plots for the difference waves.

4.4 Discussion

We investigated whether typical and ASD participants differ in their processing of affective stimuli using the affective priming paradigm. We additionally included semantic priming as a control condition that was not expected to result in differences between the two participant groups.

With respect to affective priming, we found a significant priming effect in both error rates and RTs in each of the participant groups. Target words preceded by an affectively congruent prime elicited more correct responses and were evaluated faster than targets preceded by affectively incongruent primes. The affective priming effect is thought to rely on activity of the amygdala (Garolera et al., 2007; Yang et al., 2012). Thus, this result argues against a universal amygdala impairment, suggesting that some amygdala functions can be less impaired than others. This result is consistent with another study reporting intact amygdala function in ASD participants (South et al., 2008). One possible explanation for the variation in results across studies could be individual differences, with some people with ASD having an impairment in the amygdala function more than others. Another possibility is the superior ability of participants with ASD to focus on isolated features of the stimuli. Previous research has already shown that participants with ASD do not spontaneously focus on the emotional features of verbal stimuli (Lartseva, Dijkstra, Kan, and Buitelaar, 2014).

Additionally, there was a significant difference between the two groups in terms of the magnitude of the priming effects for emotionally positive and emotionally negative targets. The responses of typical participants were faster for both congruent emotionally positive prime-target pairs and emotionally negative pairs, suggesting that emotionally positive and emotionally negative primes had similar effects. However, in the ASD group the responses to emotionally negative target words were not affected by the emotional valence of the prime word. In contrast, the decision about emotionally positive target word was significantly slowed by an incongruent prime.

This result suggests a difference with respect to how participants with ASD process items having positive or negative valence. Such a difference could theoretically be explained in several ways. First, negative emotion could be more salient for ASD participants, leading to fast and accurate responses of ASD participants to emotionally negative words. In contrast, judging positive emotions could be more problematic, and presenting an affectively incongruent prime would disrupt and slow down this process. Other studies have also found

attenuated response to positive stimuli in participants with ASD: atypical processing of positive feedback, and abnormal brain activity in response to reward (Dichter, Felder, et al., 2012; Scott-Van Zeeland et al., 2010; Kohls et al., 2011). Taken together, these data suggest that positive affect in general is less salient for people with ASD.

A second alternative (which does not necessarily exclude the previous possibility) is that processing of positive emotion is delayed compared to negative emotion. In this case, a briefly presented positive prime would not be processed fast enough to generate a response preparation in time the target word is presented. This possibility can be investigated in future studies by manipulating the time interval between the prime and the target. A third possibility is that participants with ASD have a general bias to classify words as emotionally negative. However, in this case one would expect more errors to be made on positive words than on negative, which was not what we found. Therefore, this explanation does not seem likely.

In the ERPs, we found an effect of affective congruence in both the N400 and LPC time windows. The N400 is a marker of semantic encoding and integration (Kutas and Hillyard, 1980). Affectively congruent primes facilitate the semantic encoding of the target by preactivating its semantic representation through spreading activation in the semantic network (Spruyt et al., 2007). The N400 effect was not significantly different between the two groups, which suggests that in our group of high-functioning participants general semantic encoding was not different from controls.

Affectively congruent pairs also elicited an attenuated LPC effect compared to incongruent pairs. The LPC has been associated with sustained attention and increased memory demands and with an allocation of cognitive resources to motivationally relevant stimuli. Affectively congruent primes preactivate memory representations corresponding to its emotional valence, while affectively incongruent primes require inhibiting the processing of the prime and switching to the opposite emotional valence, which requires more cognitive resources (Hinojosa, Carretié, Méndez-Bértolo, Míguez, and Pozo, 2009). A significant LPC effect to incongruent pairs was found in both groups. However, the spatial distribution of the LPC significantly differed in the ASD compared to the typical group. In typical participants, the LPC had a posterior distribution and was similar to the effect found in a previous study for single words in a lexical decision task (Lartseva et al., 2014). A lexical decision task does not require overt attention to emotional aspects of the word, while the evaluation

judgment task which was used in the current study does. The similarity in the ERP patterns between the two studies suggests that typical participants process the emotional valence of words in a similar manner regardless of the task.

In contrast, in the ASD group the LPC effect was mostly present at fronto-central electrodes. This suggests that participants with ASD recruited a different network of cortical regions. Additionally, in a previous study LPC in response to single words in ASD group was completely absent (Lartseva et al., 2014). This suggests that participants with ASD do not spontaneously pay attention to the emotional aspects of the word when the task does not require it. Additionally, processing the emotional valence may be a more effortful and recruit additional networks, particularly prefrontal regions involved in attention and control, resulting in a more frontal shift of the LPC.

As predicted, both groups showed the effect of semantic priming in RTs and error rates. Presenting a semantically related prime led to more correct responses and speeded up the evaluative judgment in both groups. When the results of the two groups were analyzed with verbal IQ (VIQ) added as a covariate, a difference between the two groups emerged. In the typical group, the magnitude of the effect was not moderated by verbal IQ of the participants. In contrast, ASD participants with lower VIQ showed a significantly stronger priming effect for emotionally positive words, while the effect in participants with higher VIQ was more similar to controls. A possible explanation is that ASD participants with lower verbal IQ may evaluate the emotional valence of the words in a more top-down and conscious way, and semantically related primes speeded up the processing of the meaning to a greater degree, while ASD participants with higher VIQ (as well as controls) evaluated those words in a more automatic manner, before the full semantic analysis was complete.

In the ERPs, we found an expected N400 effect for semantically unrelated compared to related words. This effect was present in both groups, with no significant differences in timing or scalp distribution. Several previous studies found that the N400 response was absent or attenuated in ASD participants, suggesting that the neural networks responsible for semantic processing and integration may be impaired even in individuals with good verbal abilities (McCleery et al., 2010; Pijnacker, Geurts, van Lambalgen, Buitelaar, and Hagoort, 2010; Fishman, Yam, Bellugi, Lincoln, and Mills, 2011). There are are several possible explanations for the absent or weak N400 effect in previous studies. Two important factors to consider are the task difficulty and the verbal ability of the participants. In our task,

we used pairs of words while some other studies required participants to read sentences or pieces of text. Detecting a semantic association between two words can arguably be easier than detecting that one word in the sentence is unexpected or violates world knowledge. Another possible factor is the instruction together with the strategy needed to accomplish the task. In our experiment, participants had to evaluate the word and give a response as fast as possible, thus they had to use all available information to quickly process the word and respond. In other paradigms, such as passive reading, participants could potentially stop paying close attention to semantics once they notice that half of the sentences do not make sense. A detailed-focused processing style of ASD participants and their ability to better focus on isolated features of the stimulus could have helped them to adopt a different processing strategy that is less focused on the semantic features of the words. A potential way to resolve this issue would be to use a control task that explicitly asks participants to evaluate the plausibility of the sentences, focusing their attention on the semantics.

4.5 Conclusions

In sum, our study led to the following conclusions. First, participants with ASD are sensitive to both semantic relatedness and affective congruence between stimuli. Second, positive affect is less salient for participants with ASD than for typical participants, while we did not observe any difference in the processing of negative affect. Third, the neural mechanisms of processing of semantic relatedness in ASD appear to be intact. Processing affective congruence in ASD, however, was found to be atypical and recruits additional neural mechanisms compared to the typical group. These processing difficulties could follow from the relative inexperience of people with ASD in the processing of emotional valence, and spontaneously paying attention to the emotional salience of the stimuli.

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Chapter 5

Neural Correlates of Emotion and Semantic Expectancy During Sentence Processing in Autism Spectrum Disorders

Abstract

ASD is characterized by impairments in social interaction and communication, and rigid and repetitive behavior. Some studies report impaired emotion processing in ASD. It is not known, however, whether this impairment is present for emotional language, and if so, what its neural correlates are.

We recruited 24 high-functioning adults with ASD and 32 typical control participants, and recorded their electrophysiological brain activity while they silently read sentences in which a critical word was emotional or neutral in experiment 1, and semantically expected or unexpected in experiment 2.

We analyzed event-related potentials (ERPs) in three time windows: 325-425 ms (the N400), 500-700 ms (the Late Positive Component, or LPC), and 700-1000 ms (the Positive Slow Wave, or PSW). Controls showed a significant effect of emotion in the ERP in the first two time windows. A similar effect was also found in the ASD group. However, the ERP effect for emotional words in the ASD group was longer lasting compared to controls and also extended in the PSW time window. Furthermore, both groups showed a significant N400 effect for semantic expectancy.

In contrast to previous studies, we obtained an LPC effect not only for negative, but also for positive words in a passive reading task. Furthermore, contrary to our prediction, participants with ASD showed differential brain activity for emotional and neutral words in sentences. We conclude that processing of emotional meaning and cognitive semantics in sentence context is not impaired in high-functioning participants with ASD. However, processing of emotional valence is a more extended process in ASD participants.

Keywords: ASD, language, emotion, ERP, LPC, N400.

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5.1 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by impairments in social interaction and communication, and by repetitive patterns of behavior. The diagnostic criteria of ASD also include deficits in social-emotional reciprocity, and a lack of sharing emotions and affect (APA 2013). Nevertheless, it has been debated for a long time whether processing of emotion is really impaired in ASD, and, if so, to which extent (Gaigg, 2012; Nuske et al., 2013). In fact, some researchers have argued that emotional impairments in ASD are not observed in all tasks or in all subjects with ASD, and that they are secondary to problems in other cognitive domains such as attention, cognitive control, or motivation (Nuske et al., 2013). For example, in the domain of facial emotion recognition, early studies found a deficit in recognizing facial expressions of basic emotions in people with ASD (Hobson, 1986b, 1986a; Hobson, Ouston, and Lee, 1988). However, lower performance of ASD participants can often be explained by other factors, such as avoiding looking at the eye region of the face (Harms et al., 2010; Jemel et al., 2006). Overall, reviews suggest that problems in facial emotion recognition are much milder than previously thought (Harms et al., 2010; Jemel et al., 2006; Uljarevic and Hamilton, 2013). With respect to other types of stimuli, the ratings of participants with ASD and of the typical population were not different when they explicitly classified words or sentences as emotionally positive or negative (Corden et al., 2008; Wilbarger et al., 2009; Dichter et al., 2010; Mathersul, McDonald, and Rushby, 2013; Caria, Venuti, and Falco, 2011). Similarly, people with ASD can recognize affect in music as well as control participants (Heaton, Hermelin, and Pring, 1999; Quintin, Bhatara, Poissant, Fombonne, and Levitin, 2011).

In contrast, other researchers have argued in favor of an impairment in emotion processing (Gaigg, 2012). Studies using more indirect tasks that do not explicitly direct participants' attention to the emotional content of the stimuli indicate that individuals with ASD do process emotion in language differently. For example, when participants had to detect words during rapid serial visual presentation (RSVP), a typical participant group performed better with emotional words than neutral words, but participants with ASD did not detect emotional words any better than neutral words (Corden et al., 2008; Gaigg and Bowler, 2009a). Furthermore, in a recall task, ASD participants were more likely to falsely remember emotional lure items than typical participants (Gaigg and Bowler, 2009b). ASD participants also differed from typical controls when the recall of words was not immediate. During

delayed recall, ASD participants recalled an equal number of emotional and neutral words (Gaigg and Bowler, 2008). Likewise, ASD participants recalled an equal number of emotional and neutral sentences as a whole (Beversdorf et al., 1998). In sum, these past studies indicate that people with ASD are able to detect emotion and apply a correct label to the detected emotion when a given experimental task explicitly requires them to do so. However, it is not clear whether people with ASD really process emotion in the same way as typical controls do. Differences in emotion processing could be due to different mechanisms. First, it might be the case that individuals with ASD process emotion differently from typical individuals, and in the behavioral rating tasks they use different cognitive strategies to achieve the same performance. Second, individuals with ASD might have difficulty with lexical or general semantic language processing that is not specific to emotion. This may then lead to a difference in performance in tasks requiring detection and recall of words and sentences. Finally, individuals with ASD might in principle be able to process emotion in a similar manner to typical individuals, but might not pay attention to the emotional aspects of the words under certain tasks conditions.

The present study aimed to clarify these issues by investigating neural correlates of emotional and conceptual-semantic language processing in people with ASD and in neurotypical controls. Many studies have investigated the processing of emotion words in typical populations by means of event-related potentials (ERP). The general finding is that both pleasant and unpleasant words elicit an early ERP response (early posterior negativity, or EPN) relative to neutral words, which is followed by a later component (LPC, late positive component, or LPP, late positive potential) (Herbert et al., 2008, 2006; Schacht and Sommer, 2009; Inaba, Nomura, and Ohira, 2005; Kanske and Kotz, 2007; Kissler et al., 2009; Scott, O'Donnell, Leuthold, and Sereno, 2009). The EPN is usually defined to occur between 200 and 300 ms, and it reflects initial enhanced processing associated with identification of motivationally relevant stimuli (Herbert et al., 2008; Kissler, Herbert, Peyk, and Junghöfer, 2007). The LPC occurs between 500 and 700 ms and is maximal over posterior electrodes (Wang, Bastiaansen, Yang, and Hagoort, 2013). In some studies the LPC was found to continue into the Positive Slow Wave (PSW) lasting until 1000 ms (Citron, Weekes, and Ferstl, 2013). This was mostly observed in more demanding tasks, such as emotionality rating (Schacht and Sommer, 2009; Dillon et al., 2006), or reading words in sentences (Bayer et al. 2010). The LPC and PSW have been hypothesized to reflect an increased processing load associated

with sustained attention and the allocation of additional cognitive resources (Herbert et al., 2008; Hinojosa, Méndez-Bértolo, and Pozo, 2010; Schupp et al., 2006).

Most studies found identical effects for emotionally positive (pleasant) and emotionally negative (unpleasant) items (Dillon et al., 2006; Hinojosa et al., 2010; Hofmann et al., 2009; Kissler et al., 2007). However, sometimes the reported effects were stronger for positive words (Herbert et al. 2008; Kissler et al. 2009) or for negative words (Inaba et al., 2005).

When preceded with sentence context, emotional words were found to elicit an enhanced LPC relative to neutral words peaking around 600 ms after word onset (Bayer et al., 2010; Holt et al., 2008). The LPC effect for negative relative to neutral words was observed both in passive reading and emotion evaluation tasks (Holt et al., 2008) and in the semantic correctness judgment task (Bayer et al., 2010). In contrast, the LPC effect for positive words was found only in the emotion evaluation task, but not in a passive reading task (Holt et al., 2008). This could either be due to a genuine processing difference between positive and negative stimuli, or because the positive sentences were closer to the neutral in terms of their valence and arousal ratings than the negative stimuli were.

In contrast, the exact ERP correlates of emotion word processing in the ASD population are still unclear. One study has investigated this issue using a lexical decision task (Lartseva et al., 2014). Even though individuals with ASD showed a typical emotion facilitation effect in the behavioral responses, there was no LPC effect for emotional relative to neutral words. However, an absence of the LPC effect in the ASD group does not imply that participants with ASD are insensitive to emotional valence of the words. The lexical decision task can in principle be executed without processing the meaning or the affective properties of the presented word, because it only requires a decision about whether a letter string exists as a word in the language or not. Thus, an absence of the LPC in the ASD group could indicate one of two alternatives. First, participants with ASD could generally be unable to allocate additional cognitive resources to the processing of emotion words compared to neutral words. Alternatively, the absence of the LPC could be due to the task used in the study which required processing of the word form but not the meaning. If the latter is the case, a more demanding task that requires participants to pay attention to the meaning of the words would elicit an LPC in the ASD population. To disentangle the processing of emotion from that of conceptual-semantic content, we included a manipulation of semantic expectancy in our study. If participants with ASD in general process the meaning of words

more slowly or with more difficulty, then the emotional valence of the word also might not be processed, because it is part of word meaning. Therefore, it is important to ascertain that any observed between-group difference is specific to emotion and not due to general language processing difficulties.

Conceptual-semantic processing has previously been investigated in ASD, but the ERP results are inconsistent. Semantic processing is typically reflected by the N400 component, a negative wave peaking at 400 ms after onset of the target stimuli. This component has a more negative amplitude for semantically incongruent items than for semantically congruent items (Kutas and Hillyard, 1980). Several studies in ASD participants reported a less negative N400 for incongruent words relative to congruent words in auditorily presented sentences (Fishman et al., 2011), a lack of N400 effect to mismatching picture-word pairs (McCleery et al., 2010), a lack of N400 to semantic violations in visually presented sentences (Pijnacker et al., 2010), and a reduced hemodynamic response in the language network in response to world knowledge violations (Tesink et al., 2011). In contrast, two fMRI experiments using semantically anomalous sentences found normal brain responses in ASD participants (Groen et al., 2010; Tesink et al., 2011). This variation in results is probably due to differences in the samples: Some studies tested high-functioning individuals matched in verbal IQ, while in other studies verbal IQ of ASD participants was lower than in the control group.

The current study used EEG recordings to examine whether individuals with ASD process the emotional content and conceptual-semantic content in language differently from neurotypical controls. In Experiment 1, participants with ASD and typically developing controls passively read positive, neutral, and negative words in sentences. In Experiment 2, they read sentences with semantically expected and unexpected items.

In the typical group, we expected LPC effects for positive and negative words relative to neutral words, and N400 effects for semantically unexpected relative to expected words. We made the following predictions:

1. If participants with ASD are specifically impaired in the emotion processing in language but not in general cognitive-semantic processing, a difference relative to a group of typical controls should arise in the LPC effects for emotionally positive and negative words relative to neutral items. There would be no difference between participant groups with respect to processing of semantically expected compared to unexpected words.

2. If the ASD group has a more general conceptual-semantic language processing deficit, we expect to find differences between groups with respect to the effect of emotion as well as an effect of semantic expectancy relative to a control group.
3. If the ASD group processes the emotional content in language in a similar way as the typical population does, we expect to find the same LPC effect for emotion words in the ASD group and in the control group.

5.2 Experiment 1: Processing emotional words in sentences.

5.2.1 Methods

Participants

	ASD (N=24)	Typical individuals (N=32)	p-value
Age	24.9 (4.7)	24.3 (4.0)	0.6
Gender	16 male, 8 female	19 male, 13 female	0.8
Vocabulary size (PPVT)	106.7 (11.6)	107.0 (10.1)	0.9
Verbal IQ (WAIS)	111.5 (11.4)	116.9 (7.3)	0.1
Nonverbal IQ (WAIS)	118.5 (15.5)	116.8 (16.5)	0.7

TABLE 5.1: Participant characteristics in Experiment 1. Standard deviations are given in parentheses

Participants were 24 high-functioning adults with ASD and 32 control participants recruited from the local community, all aged 18-36 years (see Table 1). The ASD group was recruited from referrals to the Department of Psychiatry at the local medical centre, from the Adult Autism Clinic of Dimence in Deventer, and from participants of previous studies of the same research group. All participants with ASD met the DSM-IV (APA 2000) criteria for ASD as established by an independent clinician. The clinical diagnosis was based on all information collected during a psychiatric interview, developmental history, an interview with the parents, if available, and a review of prior clinical records. In five participants, the clinical diagnosis was confirmed by the Autism Diagnostic Interview-Revised (ADI-R, Lord et al. 1994). In all cases, the clinical diagnosis of ASD was beyond doubt. People

Characteristics of sentence pairs and critical words	positive	neutral	negative	p-values
Pre-test emotional valence rating of the sentence pairs	5.45 (0.31)	4.21 (0.44)	2.32 (0.36)	all $p < .001$
Cloze probability of the critical word	4.76 (13.28)	1.28 (8.53)	3.35 (10.22)	pos-neg: .37 pos-neu: .02 neg-neu: .11
Frequency of the critical word (number of occurrences per mln)	28.54 (43.59)	25.78 (39.49)	21.46 (30.56)	pos-neg: .15 pos-neu: .61 neg-neu: .34
Length of the critical word	8.08 (2.46)	7.96 (1.92)	7.73 (1.99)	pos-neg: .23 pos-neu: .68 neg-neu: .36
Examples				
Mary walked along the beach. She saw a ... lying in the sand.	pearl	shoe	corpse	
There is an old park in the city. The park is ... and has a pond.	beautiful	small	littered	
Robert was a politician. After the election, he was described as a ... in a newspaper.	winner	democrat	traitor	

TABLE 5.2: Example sentences (translated into English) for Experiment 1, and stimulus characteristics.

with severe comorbid axis-I conditions (schizophrenia, bipolar disorder, or depression) were excluded.

The IQ of all participants was assessed by means of the adult version of the Peabody Picture Vocabulary test (Manschot and Bonnema, 1974) and four subscales from the WAIS (vocabulary, similarities, block design, matrix reasoning) in all participants. The groups did not significantly differ with respect to their age, verbal intelligence, and nonverbal intelligence. Typical individuals were recruited through advertisements in the local community. All participants were native speakers of Dutch and had no known history of neurological disorder, head injury, or reading problems. All participants had normal or corrected-to-normal vision. The study was formally approved of by the medical ethics committee of the Radboud UMC. All participants gave informed consent to participate in the study and were reimbursed for participation at the rate of 8 euros per hour and for travel expenses.

Stimuli

We constructed a total of 220 sentence pairs with reference to Holt et al. (2008), such that the second sentence of the pair contained a target word that would make the sentence positive, neutral, or negative. To avoid wrap-up effects in the EEG, the target word was never the final word in the sentence.

The emotional valence of the sentence pairs was confirmed by means of an online questionnaire. The raters were students recruited through the Radboud University Participant Database. Participants were asked to rate each pair of sentences on a scale from 1 to 7 where 1 was "very emotionally negative", 4 was "emotionally neutral", and 7 was "very emotionally positive". Based on the ratings, we made a final selection of sentence pairs to be used in the experiment. The stimuli were included in the final list if all of the following criteria were satisfied: The positive version of the sentence received an average rating of 5 or higher, the neutral version received a rating between 3 and 5, and the negative version received a rating of 3 or less.

Cloze probability measures were collected using an online questionnaire. The raters were 21 university students who participated for course credit. The average cloze probability of the sentences was 27.2%.

The final selection included 120 sentence pairs. The stimuli characteristics are summarized in Table 2. The items significantly differed in terms of average valence of the sentence, and were matched in terms of the length and the lexical frequency of the critical word taken from CELEX database (CELEX, 2001).

The sentences were distributed over 3 lists (40 positive, 40 neutral, and 40 negative sentence pairs in each list) via Latin Square rotation. From the discarded sentences, we selected 9 sentences for the practice session. Simple yes-no comprehension questions followed 10% of the trials to stimulate active processing and attention.

Procedure

Participants sat in a dimly lit, sound-attenuated room at a comfortable distance of approximately 60 cm from the computer screen. They were instructed to carefully read the presented sentences. and answer the occasional comprehension questions as accurately as possible. The experiment started with a practice set, followed by 4 experimental blocks of 30 trials. The total duration of the EEG experiment was about 35 minutes.

Each trial started with a fixation cross presented for 1000 ms. Then the first sentence of the pair was presented for 4 seconds. After that the second sentence of the pair was presented word by word, with each word presented for 350 ms in the center of the screen followed by a blank screen of 350 ms. When there was a comprehension question, the question appeared on the screen 1000 ms after the offset of the last word of the sentence, and stayed on the screen until participant responded by pressing a button.

After the experiment, participants filled in a rating questionnaire on the computer. The questionnaire contained the list of the same 120 sentences that participants have just seen in the EEG experiment (in a different order), and the task was to rate each sentence on a 1-7 scale, where 1 was "very emotionally negative", 4 was "emotionally neutral", and 7 was "very emotionally positive".

EEG acquisition and preprocessing

EEG was recorded using Brain Vision Easycap with 64 active electrodes and amplified using BrainAmp EEG amplifiers (Brain Products GMBH). Of these, 61 electrodes were placed in the recording cap in an equidistant montage, 2 electrodes were placed above and below the left eye for recording vertical eye movements, and another 2 electrodes were at the outer side of each eye for recording horizontal eye movements.

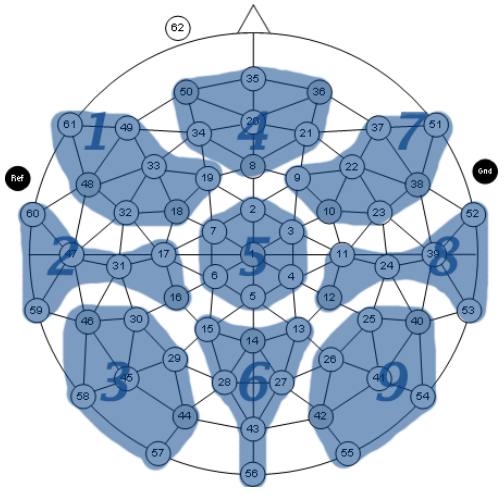

FIGURE 5.1: Electrode positions in the M10 equidistant electrode arrangement and the electrode groups used in the analysis.

The impedance was kept below 20 kOhm. Signals were sampled at 500 Hz and band-pass amplified with upper limit at 200 Hz, using a time constant of 10 s.

EEG data were preprocessed with Fieldtrip software (Oostenveld et al., 2011). First, the data were filtered with a 0.3 Hz high-pass filter to remove the effects of slow drift and artifacts from slow head movement. Next, the data were segmented into trials from 500 ms before word onset until 1500 ms after word onset. Trials with muscle artifacts

were detected based on the power in the 110-140 Hz frequency band (Muthukumaraswamy, 2013) and were rejected. Artifacts associated with excessive head movement were rejected and trials with channel jumps were corrected on a trial-by-trial basis by replacing the affected channel with the average of its neighbouring electrodes. Eyeblink artifacts were removed with an Independent Component Analysis (ICA) method (Oostenveld et al., 2011), with the ICA components corresponding to eye movements identified based on correlations with EOG electrodes and spatial distributions. Next, the data were low-pass filtered at 40 Hz, baseline corrected using a 200 ms interval before word onset, and re-referenced to the average of the electrodes on top of left and right mastoids (electrode 59 and 53 on Figure 1). Finally, the grand averages of amplitudes for each condition was calculated.

ERP Analysis

Based on Holt et al. (2008) and Bayer et al. (2010), the ERP time windows selected for statistical analysis were: 325-425 ms (N400), 500-700 ms (LPC), and 700-1000 ms (PSW). 61 electrodes covering most of the scalp surface were selected and grouped into 9 locations (Left Anterior, Midline Anterior, Right Anterior, Left Central, Midline Central, Right Central, Left Posterior, Midline Posterior, Right Posterior, as shown in Figure 1).

The mean amplitudes were entered in repeated-measures ANOVAs of 2 Group (ASD, typical) x 3 Emotion (positive, negative, neutral) * 3 Location-LR (Left, Midline, Right) * 3 Location-AP (Anterior, Central, Posterior) for each of the time windows. Greenhouse-Geisser corrections were applied where appropriate.

There were two behavioral measures: The accuracy of the comprehension questions, and the average emotional ratings for each sentence. The ratings were entered in a repeated-measures ANOVA of 2 Group * 3 Emotion.

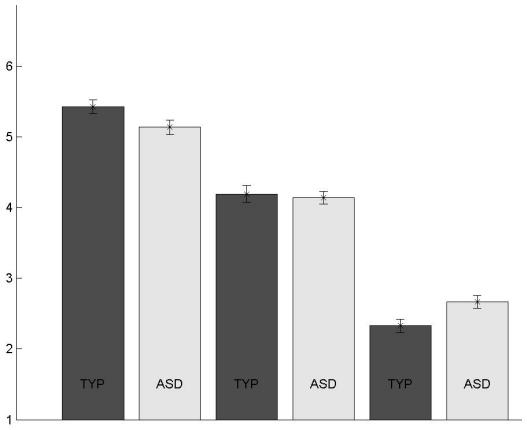

FIGURE 5.2: Average subjective ratings of the sentences (1 = most negative, 4 = neutral, 7 = most positive). Vertical bars indicate 95% confidence intervals.

5.2.2 Results

Behavioral results

The average accuracy of the comprehension questions was 93.06%(SD = 1.08%) for the ASD group and 95.96%(SD = .93%) for the control group, $F(1, 54) = 4.18, p = .046$.

The averaged emotional ratings for the ASD and control groups are summarized in Figure 2. The analysis revealed that there are a main effect of emotion ($F(2, 238) = 1074.7, p <$ .001) and a significant group by emotion interaction effect ($F(2, 238) = 59.4, p <$ .001). ASD participants rated emotional sentences in a significantly less extreme way compared to control group (see Figure 2).

	Positive-negative-neutral			Negative-neutral			Positive-neutral		
	F	df	p	F	df	p	F	df	p
Emotion	**6.60**	**2,108**	**.003***	.55	1,54	.46	**8.39**	**1,54**	**.005***
Emotion*LR	**3.04**	**4,216**	**.025***	.02	2,108	.9	**4.48**	**2,108**	**.018***
Emotion*AP	**9.08**	**4,216**	**<.001***	**16.71**	**2,108**	**<.001***	1.83	2,108	.18
Emotion*AP*LR	**7.70**	**8,432**	**<.001***	**4.89**	**4,216**	**.004***	**4.13**	**4,216**	**.008***
Group	.72	1,54	.4 .42	1,54	.52	.89	1,54	.35	
Group*Emotion	.18	2,108	.8	.01	1,54	.9	.39	1,54	.5
Group*Emotion*LR	.1	4,216	.9	.07	2,108	.9	.03	2,108	.95
Group*Emotion*AP	2.10	4,216	.12	3.36	2,108	.06	3.05	2,108	.08
Group*Emotion*AP*LR	.92	8,432	.47	.73	4,216	.5	.92	4,216	.43

TABLE 5.3: Effect of Emotion in the N400 time window (325-425 ms). Effects significant at $p < .05$ are highlighted

ERP results

N400 time window (325-425 ms): The results are summarized in Table 3. There was a significant main effect of Emotion, as well as significant interactions between Emotion, Location-AP and Location-LR (see Table 3). Pairwise ANOVAs comparing positive vs. neutral and negative vs. neutral conditions separately revealed that the positive words elicited more positive-going ERPs than the neutral words. This positivity was maximal over the midline electrodes. Compared to the neutral words, the negative words elicited more positive ERPs over the frontal electrodes, but more negative ERPs over the parietal and occipital electrodes. There were no group difference (see Figures 3 and 4).

LPC time window (500-700 ms): The results are summarized in Table 4.

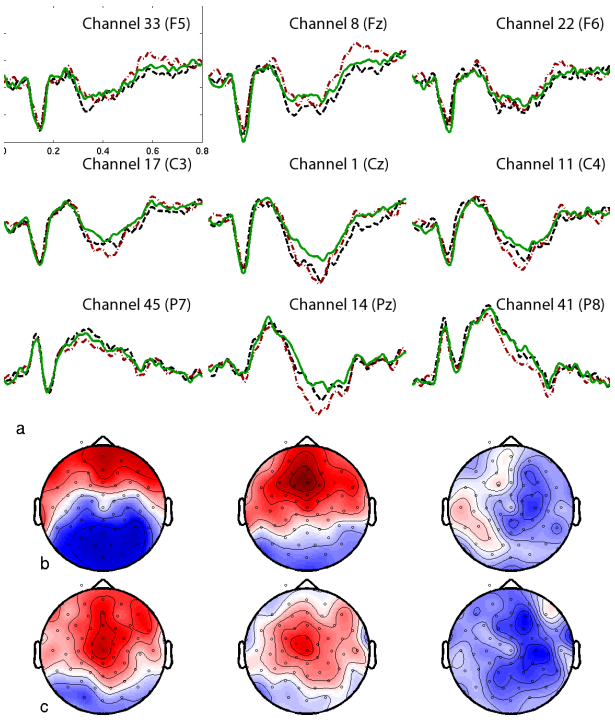

FIGURE 5.3: Valence effect in the typical group for Experiment 1. (a): Average ERP for emotionally positive words (green dashed line), emotionally negative words (red dashed and dotted line) and neutral words (black solid line). (b): Average topographies showing difference between negative and neutral words in the N400, LPC and PSW time windows (left to right). (c): Average topographies showing difference between positive and neutral words in the N400, LPC and PSW time windows (left to right).

	Positive-negative-neutral			Negative-neutral			Positive-neutral		
	F	df	p	F	df	p	F	df	p
Emotion	**5.15**	**2,108**	**.010***	**6.50**	**1,54**	**.014***	**6.98**	**1,54**	**.011***
Emotion*LR	**2.99**	**4,216**	**.029***	2.86	2,108	.067	**3.83**	**2,108**	**.028***
Emotion*AP	**6.80**	**4,216**	**.001***	**8.63**	**2,108**	**.003***	.62	2,108	.46
Emotion*AP*LR	**3.27**	**8,432**	**.008***	1.45	4,216	.24	**3.91**	**4,216**	**.012***
Group	2.55	1,54	.12	1.29	1,54	.26	2.98	1,54	.09
Group*Emotion	.72	2,108	.47	.10	1,54	.75	1.39	1,54	.24
Group*Emotion*LR	.49	4,216	.7	.16	2,108	.83	.77	2,108	.46
Group*Emotion*AP	1.14	4,216	.33	1.83	2,108	.18	1.25	2,108	.27
Group*Emotion*AP*LR	.79	8,432	.55	1.27	4,216	.29	.29	4,216	.8

TABLE 5.4: Effect of Emotion in the LPC time window (500-700 ms). Effects significant at $p < .05$ are highlighted.

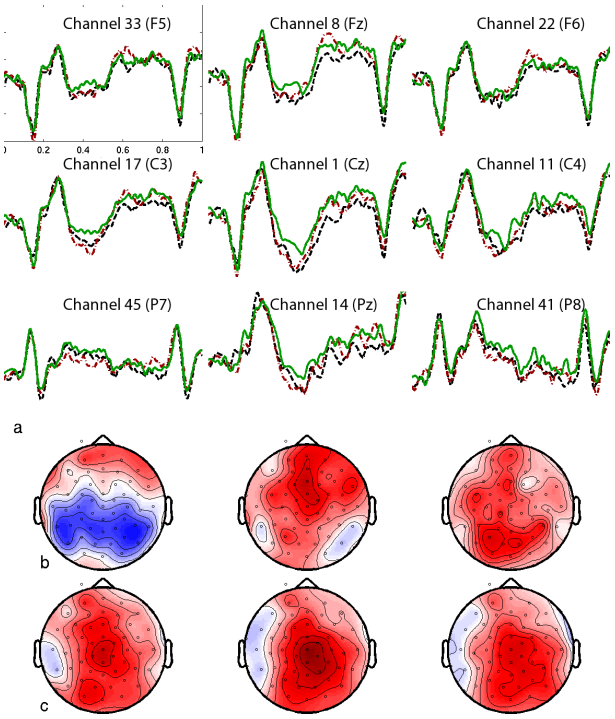

FIGURE 5.4: Valence effect in the ASD group for Experiment 1. (a): Average ERP for emotionally positive words (green dashed line), emotionally negative words (red dashed and dotted line) and neutral words (black solid line). (b): Average topographies showing difference between negative and neutral words in the N400, LPC and PSW time windows (left to right). (c): Average topographies showing difference between positive and neutral words in the N400, LPC and PSW time windows (left to right).

There was a significant main effect of Emotion as well as significant interactions between Emotion, Location-AP, and Location-LR (see Table 3). Pairwise ANOVAs comparing positive vs. neutral and the negative vs. neutral separately revealed that the positive words elicited more positive-going ERPs than the neutral words. This positivity was distributed along the midline electrodes, peaking at the central sites. The negative words compared to the neutral elicited more positive ERPs over the frontal electrodes, with no difference over the parietal and occipital electrodes. There was no group difference (see Figures 3 and 4). PSW time window (700-1000 ms): The results are summarized in Table 5. There was a main effect of Group and a Group x Emotion interaction (see Table 5). Separate ANOVAs were carried out for comparing the positive vs neutral and the negative vs neutral conditions within each group. In the typical group, none of the main effects or interactions involving Emotion reached significance. The ERPs for the positive and negative words were more negative than for the neutral words numerically. In the ASD group, the positive words elicited more positive ERPs than the neutral words (see Table 5).

	Positive-negative-neutral			Negative-neutral			Positive-neutral		
	F	df	p	F	df	p	F	df	p
Emotion	.46	2,108	.63	.87	1,54	.35	.12	1,54	.7
Emotion * LR	2.19	4,216	.08	2.52	2,108	.09	.58	2,108	.5
Emotion * AP	.35	4,216	.7	.17	2,108	.7	.54	2,108	.50
Emotion * AP * LR	1.31	8,432	.25	.27	4,216	.8	1.36	4,216	.26
Group	**6.69**	**1,54**	**.012***	2.71	1,54	.10	**5.02**	**1,54**	**.029***
Group*Emotion	**4.90**	**2,108**	**.01***	**5.02**	**1,54**	**.029***	**7.81**	**1,54**	**.007***
Group*Emotion*LR	1.99	4,216	.11	1.38	2,108	.25	**3.34**	**2,108**	**.043***
Group*Emotion*AP	.22	4,216	.8	.13	2,108	.7	.40	2,108	.56
Group*Emotion*AP*LR	.69	8,432	.64	.82	4,216	.5	.87	4,216	.45
Control group									
Emotion	2.06	2,62	.14	1.14	1,31	.29	3.09	1.31	.09
Emotion * LR	1.81	4,124	.15	3.15	2,62	.063	.90	2,62	.40
Emotion * AP	.02	4,124	.99	.02	2,62	.93	.007	2,62	.96
Emotion*AP*LR	.98	8,248	.42	.97	4,124	.39	.56	4,124	.60
ASD group									
Emotion	3.10	2,46	.056	3.75	1,23	.065	**5.29**	**1,23**	**.031***
Emotion * LR	2.15	4,92	.10	1.13	2,46	.37	2.34	2,46	.11
Emotion * AP	.44	4,92	.67	.25	2,46	.65	.66	2,46	.44
Emotion*AP*LR	1.11	8,184	.36	.13	4,92	.95	1.57	4,92	.21

TABLE 5.5: Effect of Emotion in the PSW time window (700-1000 ms). Effects significant at $p < .05$ are highlighted.

5.3 Experiment 2. Processing semantic expectancy in sentences

5.3.1 Methods

Participants

Participants were 20 high-functioning adults with ASD and 30 matched typical individuals who also participated in Experiment 1, and one additional ASD participant recruited from referrals to the Department of Psychiatry at the local medical centre who only participated in Experiment 2. The study was formally approved of by the local medical ethics committee. All participants gave informed consent to participate in the study and were reimbursed for participation at the rate of 8 euros per hour and for travel expenses.

Stimuli

	ASD (N=21)	Typical individuals (N=30)	p-value
Age	25.4 (4.9)	24.3 (4.1)	.42
Gender	14 male, 7 female	17 male, 13 female	.7
Vocabulary size (PPVT)	108.9 (10.6)	107.1 (10.1)	.55
Verbal IQ (WAIS)	111.4 (11.8)	116.9 (7.3)	.11
Nonverbal IQ (WAIS)	117.6 (16.2)	118.1 (16.4)	.9

TABLE 5.6: Participant characteristics for Experiment 2. Standard deviations are given in parentheses

We presented 120 pairs of sentences containing critical words that were either more expected or less expected, e.g., "With the lights on you can see more/less ... " The sentences were adapted from Lai and Van Berkum (in prep). The critical words never appeared in a sentence-final position and were matched in length in letters and frequency per million (see Table 7). A pretest confirmed that the manipulation of expectedness was successful. For the pretest, sentence fragments with the more and less expected critical words were divided into 2 lists via Latin Square rotation, such that each fragment appeared in each list only once. The items within each list were then randomized. Twenty-eight native Dutch raters (mean age = 20.8, range 18-26) were randomly assigned to each of the lists and were instructed to rate how plausible each critical word was given the preceding sentential context on a 1-5 scale (1=implausible; 5=plausible). The mean plausibility ratings were 4.14 for the more expected and 2.38 for the less expected words. A t-test indicated that the "more expected" words were indeed more expected than the "less expected" words ($t(13) = 18.98, p < .0001$). The characteristics of the stimuli are summarized in Table 7.

Stimuli characteristics	expected	unexpected	p-value
Frequency (number of occurrences per mln)	45.15	40.75	0.8
Length	7.2	7.3	0.9
Examples			
Butterflies are ... animals.	fragile	strong	
Around Christmas, the weather is ... outside.	cold	sweltering	
Amsterdam is a city that is relatively	big	small	

TABLE 5.7: Example sentences (translated into English) for Experiment 2, and stimulus characteristics

	Expected-Unexpected		
	F	df	p
Expectancy	**17.29**	**1,49**	**<.001***
Expectancy * LR	2.98	2,98	.058
Expectancy * AP	**8.26**	**2,98**	**.004***
Expectancy * AP * LR	**19.64**	**4,196**	**<.001***
Group	1.40	1,49	.24
Group * Expectancy	.20	1,49	.66
Group * Expectancy * LR	.93	2,98	.40
Group * Expectancy * AP	.03	2,98	.9
Group * Expectancy * AP * LR	.33	4,196	.79

TABLE 5.8: Effect of Expectancy in the N400 time window (300-500 ms) in Experiment 2. Effects significant at $p < .05$ are highlighted

Procedure The procedure was identical to Experiment 1. Each trial started with a fixation cross presented for 1000 ms, followed by the sentence presented word by word in the center of the screen. The total duration of the experiment was about 25 minutes. Data recording and analysis The data recording and analysis was identical to Experiment 1. The time windows were selected as follows. The N400 effect to semantically unexpected words is typically present between 300 and 500 ms (Chwilla et al., 2000; Pijnacker et al., 2010). Therefore, we analyzed the data within the N400 time window (300-500 ms). The spatial regions were the same as used in Experiment 1.

5.3.2 Results

The average accuracy to comprehension questions was 97.71% (SD=.97) in ASD group, and 95.31% (SD=.77) in typical group, $F(1, 50) = 3.74, p = .059$.

ERP results The results of the ANOVA are summarized in Table 8. There was a significant main effect of Expectancy, as well as significant interactions between Expectancy, Location-AP, and Location-LR (see Table 8). Semantically unexpected words elicited a more negative-going ERP compared to expected words. This negativity was maximal over posterior electrodes, which corresponds to the spatial distribution of N400. There was no group difference (see Figures 5 and 6).

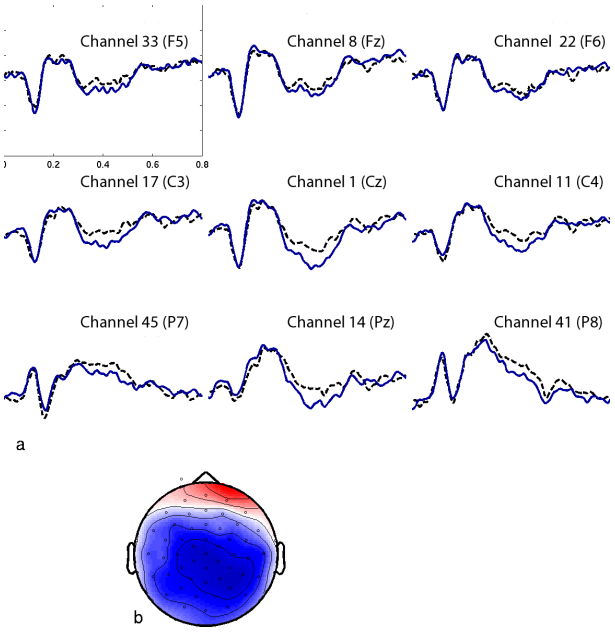

FIGURE 5.5: Semantic expectancy effect in the typical group for Experiment 2. (a): Average ERP for semantically unexpected words (blue dashed line), and semantically expected words (black solid line). (b): Average topography showing difference between semantically expected and unexpected words in the N400 time window.

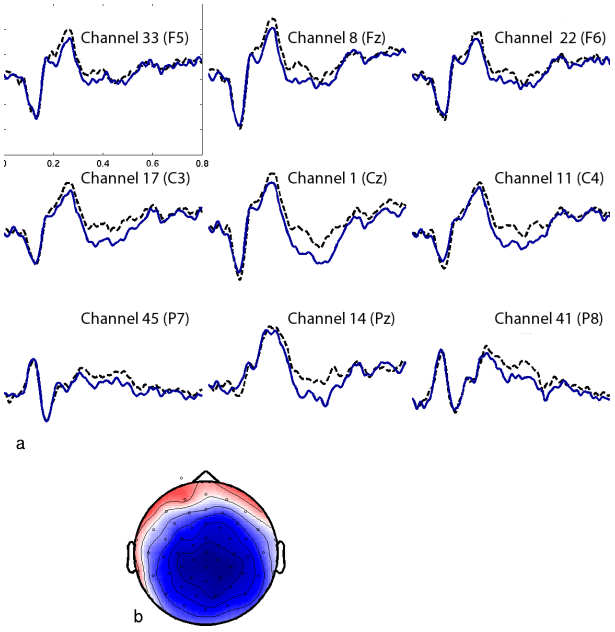

FIGURE 5.6: Semantic expectancy effect in the ASD group for Experiment 2. (a): Average ERP for semantically unexpected words (blue dashed line), and semantically expected words (black solid line). (b): Average topographies showing difference between semantically expected and unexpected words in the N400 time window.

5.4 Discussion

We investigated whether individuals with ASD process emotional content in language differently from healthy controls. Behaviorally, the emotionality ratings indicated that individuals with ASD are able to perceive the emotional content in language, but to a lesser degree than healthy controls. Specifically, both groups rated the positive sentences more positive than the neutral ones, and the negative sentences more negative than the neutral ones. The groups differed, however, in that the ASD participants rated the positive sentences as less positive than the controls, and rated the negative sentences as less negative than the controls.

The ERP results also indicate that individuals with ASD were able to notice the emotional information in language, but in contrast to the controls they held on to this information longer, which was reflected by the lengthened LPC effects. Specifically, both groups showed LPC effects for emotional words relative to neutral words, with similar effect scalp distributions. The groups differed in that the LPC effects in the ASD group lasted longer (until at least 1000 ms) than in the control group.

In the control group, we found an LPC for both emotionally positive and negative critical words that lasted approximately from 300 to 700 ms, replicating the results from previous studies (Bayer et al. 2010; Holt et al. 2008). The ASD group also showed an LPC for both emotionally negative and positive critical words with no differences from the typical group in terms of timing or distribution. The difference between groups emerged in the 700-1000 ms time window. In the typical group, the LPC was not present anymore after 700 ms, but in the ASD group it continued until 1000 ms. This type of extended LPC effects has been observed in previous studies, but only when participants were required to give emotionality ratings for the stimuli, and not in passive reading conditions. With respect to semantically unexpected words, we found similar N400 effects in both the ASD and typical groups.

LPC for positive words

The processing of emotional words in sentence context in typical populations has been studied before (Holt et al., 2008; Bayer et al., 2010). However, for the passive reading condition of our study, the LPC effect was previously found only for emotionally negative words, but not for the positive ones (Holt et al., 2008). In our study, we found the LPC effect for the positive words as well. The most likely explanation for the difference in results between our study and the study by Holt et al. Lies in the difference in stimulus materials.

Even though the pretest subjective ratings of our emotionally positive sentences were similar to those in the Holt et al. study (5.5 and 5.7 respectively), it could be that our emotionally positive sentences were perceived by participants as emotionally more salient, resulting in a more robust effect.

Positive vs negative words

Our findings for positive words and negative words differed in terms of the amplitudes of N400s and the scalp distributions of the LPC effects. The negative words elicited a posterior negativity between 325 and 425 ms (Holt et al., 2008). According to Holt et al. (2008), the posterior negativity to emotion words reflects increased processing demands due to additional allocation of attentional resources. In our study it was present for both emotionally positive and emotionally negative words relative to neutral words, but it was much less pronounced for the positive words. A possible alternative explanation is that emotionally negative words elicit an N400-like effect because of a violation of participants' expectations: Usually people do not expect bad events to happen, which reflects a so-called positivity bias (Mezulis, Abramson, Hyde, and Hankin, 2004). Several studies report that people tend to remember emotionally positive events better than negative ones (Walker, Skowronski, and Thompson, 2003), underestimate the probability of negative outcomes for themselves and their environment (Hoorens and Buunk, 1993) and produce optimistic inferences about the future (Regan, Snyder, and Kassin, 1995). In a meta-analysis by Mezulis et al. (2004), a bias towards positive information was found across a range of tasks and participant samples (Mezulis et al., 2004). In other words, negative words in sentence context may elicit more surprise and therefore require more effort to be integrated into the context than positive words.

The LPC effect for the positive words was distributed over anterior and central electrodes, with the maximum over midline-central scalp region. For negative words, the effect was distributed over anterior electrodes, with maximum over midline anterior location.

Comparison with lexical decision task

We found that high-functioning individuals with ASD showed an LPC effect for emotion words in sentences that was similar to the typical participants. This is at odds with the previous study that found no LPC effect for emotion words presented in isolation in ASD

population (Lartseva et al. 2014). The discrepancy between the two studies is most probably due to the particular processing strategy used by ASD participants in each study. The lexical decision task can successfully be performed without processing word meaning, while reading sentences for comprehension requires more extensive semantic processing. We hypothesize that typical people cannot suppress the processing of emotional meaning regardless of whether it is needed or not. On the other hand, people with ASD only process the emotional meaning when the task requires it.

Between-group differences for PSW

The results from the PSW time window analysis indicate that after 700 ms, the two groups processed emotion differently. By this time, the typical participants finished processing of the emotion word and were probably anticipating the next word. However, in ASD participants the processing of the target word still continued, as indicated by the PSW that lasted until 1000 ms. The PSW is normally seen in tasks that require in-depth processing of emotional valence, such as emotionality judgment, and reflects sustained attention and more effortful cognitive processing.

The presence of a PSW in the ASD group in a passive reading task could be explained in two ways. As a first alternative, the processing of emotional valence might require more cognitive resources in case of ASD participants and might occur more slowly in general. If participants with ASD do not spontaneously pay attention to emotional valence of the stimuli, the brain networks that are involved in affective processing would remain less trained, which would in turn result in less efficient processing. As a second alternative, participants with ASD might have difficulty in disengaging from the processing of a salient emotional word when switching to the next stimulus. In this case, the networks involved in affective processing would be functioning normally, but the brain regions that are supposed to suppress those networks when the processing is over are hypoactive, which results in sustained focus on emotional content. The second explanation is compatible with the proposal of an executive function deficit in ASD (Boyd, McBee, Holtzclaw, Baranek, and Bodfish, 2009; Sinzig, Morsch, Bruning, Schmidt, and Lehmkuhl, 2008; Ozonoff et al., 2005).

Semantic expectancy and N400

With respect to the effect of semantic expectancy, we found a typical N400 response to

semantically unexpected words in our ASD sample. Our study shows that at least in the most high-functioning ASD individuals, semantically unexpected words elicit typical neural responses, indicating that cognitive-semantic processing is largely intact. This finding is in contrast with previous EEG studies that report absent or greatly diminished N400 responses to semantically anomalous sentences in the ASD population (Fishman et al., 2011; Pijnacker et al., 2010). However, our study agrees with previous fMRI studies that found typical neural responses to semantic and world knowledge violations in high-functioning ASD participants (Groen et al., 2010; Tesink et al., 2011). Even though a language acquisition delay and lower verbal abilities are common in ASD, the severity of the problems varies greatly across the spectrum, with a substantial subsample of ASD individuals having normal or high verbal abilities (Groen et al., 2008).

A limitation of this study is that ADI scores were available only for a subgroup of participants with ASD. Therefore, it might be argued that this limits a potential generalization of the findings to the ASD population as a whole. However, we would like to point out that the clinical diagnosis of ASD was beyond doubt in all participants with ASD.

How do our findings contribute to the current debate on emotional impairments in ASD? First of all, our results argue against a universal and pervading emotional deficit in the ASD population. Under certain task conditions, we found that ASD participants process emotional valence in a manner very similar to the typical population does. The ERP responses, which significantly differed between emotional and neutral words for both groups, combined with post-test ratings, suggest that ASD participants process the emotional valence of the words similar to the control group. Reading emotional words in sentence context is a more engaging and demanding task compared to reading the words in isolation, and greater involvement of the participants during sentence reading could explain the difference in the results between single words and sentence studies.

One previous study (Beversdorf et al. 1998) found no emotional memory effect in the ASD group in a task requiring memorizing emotional and neutral sentences. This is seemingly at odds with our study reporting a significant effect of emotion in the EEG in the ASD group. However, performance in memory tasks requires successful processing, storage, and retrieval, while our study only looked at the processing component. Some recent studies indicate that memory retrieval, specifically episodic memory, may be impaired in autism (Wojcik, Moulin, and Souchay, 2013), possibly contributing to the atypical performance in

the memory tasks.

We propose that in ASD encoding of emotionally positive meaning in language is not impaired, but requires more cognitive resources. Future studies should address the role of practice and training in affect recognition on one side, and the role of inhibitory control and switching in affective processing on the other side, by looking at the development across different age groups, by manipulating task demands, by comparing processing of task-relevant versus task-irrelevant features, or by looking at individual differences in executive function.

5.5 Conclusions

We conclude that processing of emotional meaning and cognitive semantics in a sentence context is not impaired in high-functioning participants with ASD. However, affective processing in ASD participants takes up more time and resources. Our results argue against a universal and pervading emotional deficit in the ASD population. Rather, they indicate that emotional deficits appear to be context-dependent, and can be influenced by task demands and individual processing strategies.

Chapter 6

Alexithymia but not ASD Traits Explains Reduced Attention to Eyes

Abstract

Individuals with Autism Spectrum Disorder (ASD) have difficulty recognizing facial expressions of emotions and show an abnormal gaze fixation pattern when looking at faces. This pattern has been proposed as a familial-genetic marker ASD. However, there are also inconsistent findings, and atypical eye gaze patterns have also found to be associated with other traits, such as alexithymia and anxiety.

After we conducted a pilot study in healthy adults, we examined 21 parents of children with ASD and 26 control participants with no ASD family history. The experimental task was based on the visual world paradigm: On each trial, participants saw four faces presented in the four quadrants of the screen, and simultaneously heard a spoken word indicating the target emotion ("happy", "angry", or "fearful"). Participants were asked to indicate whether any one of the four faces was expressing the target emotion. Additionally, all participants completed the Toronto Alexithymia Scale (TAS), Autism Quotient (AQ), and State-trait anxiety inventory (STAI).

The ASD-relatives group showed the same pattern of gaze fixations as the control group. Preferences for looking at eyes or mouth did not differ between the two groups. AQ and STAI scores also did not significantly correlate with the gaze fixation pattern. However, self-reported alexithymia was significantly associated with proportion of gaze fixation on the eyes: Participants with high alexithymia had a smaller proportion of fixations on the eye region compared to participants with low alexithymia. Our findings do not support the view that atypical gaze patterns are a familial-genetic marker of ASD. Instead, they suggest that confounding factors such as alexithymia play a role in gaze fixation patterns.

Keywords: eye-tracking, Broad Autism Phenotype, eye:mouth ratio, emotion, facial expressions

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6.1 Introduction

Research indicates that people with Autism Spectrum Disorders (ASD) have difficulty recognizing facial expressions of emotions (Harms et al., 2010; Golan, Baron-Cohen, and Golan, 2008; Simon Baron-Cohen et al., 2001). Furthermore, people with ASD have atypical gaze fixation patterns when looking at faces (Harms et al., 2010), suggesting that they use a different processing strategy. Specifically, they spend less time looking at key features of a face (eyes, mouth) and more time looking at external features (hair, forehead) (Chawarska and Shic, 2009). They also spend less time looking at the eyes and more time looking at the mouth (Klin, Jones, Schultz, Volkmar, and Cohen, 2002) and they use the information from the eyes to a lesser degree in a facial emotion recognition task (Spezio, Adolphs, Hurley, and Piven, 2006).

Genetic factors play an important role in the etiology of ASD (Geschwind, 2011). Therefore, first-degree relatives (parents and siblings) who share (about) 50% of their genes with the ASD proband, are expected to share also some of the ASD phenotypes. For example, first degree relatives of people with ASD score higher on Autism Quotient (AQ, a questionnaire developed to provide a continuous measure of autism traits), but the effect size is relatively small and only reached significance in a large sample of participants (Wheelwright, Auyeung, Allison, and Baron-Cohen, 2010). First-degree relatives of people with ASD who did not have an ASD diagnosis themselves, such as unaffected siblings (Merin N and, Ozonoff, S, and Rogers, 2007; Dalton, Nacewicz, Alexander, and Davidson, 2007) and parents (Adolphs, Spezio, Parlier, and Piven, 2008) also have reduced attention to eyes relative to mouth (the so-called eye:mouth ratio).

However, later studies failed to confirm a reduced eye:mouth ratio in people with ASD (Rutherford and Towns, 2008) or their siblings (Young, Merin, Rogers, and Ozonoff, 2009). Several systematic reviews attempted to tackle this issue, but their results are inconsistent. While one recent review concludes that there is indeed a tendency in the ASD patients to avoid looking at the eyes (Papagiannopoulou, Chitty, Hermens, Hickie, and Lagopoulos, 2014), two other reviews do not support such a conclusion (Guillon, Hadjikhani, Baduel, and Rogé, 2014; Falck-Ytter and von Hofsten, 2011). Overall, the evidence with regard to the eye:mouth ratio in the ASD population is quite mixed.

A possible explanation for the inconsistent results across studies is that a reduced eye:mouth ratio is not associated with core symptoms of autism, but with other parameters on which

people with ASD are different from typical controls. For instance, people with ASD have higher levels of alexithymia (Bird and Viding, 2014). Alexithymia is a personality trait involving difficulty in recognizing and regulating one's own emotions and distinguishing emotions from other bodily sensations (Salminen et al., 1999; Linden et al., 1995). There is some preliminary evidence that people with high alexithymia scores, regardless of their ASD diagnosis, do indeed spend less time looking at the eyes and more at the mouth (Bird et al., 2011). In addition to alexithymia, people with ASD display elevated levels of anxiety (Gillott, Furniss, and Walter, 2001), social phobia (Smalley SL, 1995; Kuusikko et al., 2008; Bellini, 2006), and other affective disorders (Kim, Szatmari, Bryson, Streiner, and Wilson, 2000; Skokauskas and Gallagher, 2010). Anxiety and social phobia have also been associated with atypical visual scanning of emotional faces (Horley, Williams, Gonsalvez, and Gordon, 2003), so this also constitutes a possible confound.

Because most studies compare people with ASD to typically developing children or adults (Harms et al., 2010; Lartseva et al., 2015), the two groups would often differ not only with respect to ASD diagnosis, but also with respect to alexithymia and anxiety. Therefore, any observed difference between groups could potentially be due to any of these confounding factors. In order to disentangle the effects of familial-genetic risk factors for autism from the effects of alexithymia and anxiety, we conducted a study in unaffected parents of children with ASD and controls from the general population.

We used the visual world eye-tracking paradigm to investigate the time course of face processing. An advantage of the visual world paradigm is that it can be used to study the time course of overt attention and cognitive processing (see Huettig et al., 2011 for a recent review). Typically, in this method a participant is simultaneously presented with a visual image and a spoken utterance. The image can include text, drawings or photographs, single objects or complex visual scenes. Likewise, the utterance can consist of a single syllable, a word or a longer speech segment (Huettig et al., 2011). The dependent variable is the probability of gaze fixation within each given spatial region of interest over successive time points. Overt attention (i.e. eye gaze) in normal viewing conditions closely follows covert attention (Jonides, 1981) and provides a real-time measure of attention focus over the course of a trial. Although the data from each individual trial are very noisy, averaging over multiple trials allows one to obtain an impression of where participants are most likely to be focusing at each point in time.

In our study, we used this paradigm in two experiments to examine the time course of face processing in a facial emotion recognition task

The purpose of Experiment 1 was to validate the paradigm and to explore how neurotypical young adults process faces over time. Experiment 2 investigated face processing in parents of children with ASD and age-matched control participants. We expected that older control participants in Experiment 2 would replicate the pattern of results observed in Experiment 1 for younger adults. We also expected that parents of children with ASD would show a different pattern compared to age-matched controls.

6.2 Experiment 1

6.2.1 Method

Participants

The participants in the Experiment 1 included 18 adults between 18 and 29 years old with normal sight and no history of neurological or psychiatric disorders, recruited from the Radboud University participant database.

Materials

We used 144 photos selected from the Radboud faces Database (Langner et al., 2010). The Radboud Faces Database (RaFD) is a set of pictures of 67 actors displaying 8 emotional expressions. The database included the results of a pre-test by a separate group of respondents who were asked to identify the expressed emotion in each photo and rate them on intensity, clarity, genuineness and emotional valence on a 1-5 scale. We selected 18 adult male and 18 adult female actors from the database. For each actor, we used four facial expressions: neutral, angry, happy and fearful. The characteristics of the stimuli can be found in Table 1. The auditory stimuli were recorded by a female Dutch native speaker. The words used were "blij" ("happy"), "boos" ("angry") and "angstig" ("fearful").

Procedure

Participants were seated in a sound-attenuated room. The head position of the participants was controlled by means of a chinrest. The stimuli were presented on a BenQ 24inch monitor 56 cm away from the participant. The eye movements were recorded with Eyelink1000

Condition	Rater agreement	Intensity	Clarity	Genuineness	Valence
Female faces					
Neutral	94.11	3.57	3.81	4.02	3.11
Happy	99.06	4.16	4.54	3.96	4.35
Angry	82.44	3.47	3.73	2.88	2.06
Fearful	89.06	4.19	4.13	3.11	2.07
Male faces					
Neutral	91.50	3.54	3.88	4.04	3.16
Happy	98.78	4.28	4.54	3.85	4.30
Angry	87.44	3.61	3.84	3.09	2.06
Fearful	85.0	4.12	3.99	2.93	2.12

TABLE 6.1: Characteristics of the stimuli

camera mounted on a stand below the monitor. The camera was 60 cm away from the participant.

The measuring session began with the camera calibration using Eyelink software. The stimuli were presented using Matlab with Psychtoolbox and Eyelink toolbox.

Each trial started with a fixation cross presented for 700 ms in the middle of the screen. Participants were asked to fixate on the cross. Then participants heard a word indicating a target emotion, and at the same time saw four photos presented in the four quadrants of the screen. The task was to indicate whether one among the four photos expressed the target emotion by pressing a "yes" or "no" button.

Each image was 500 pixels or 10 cm wide, and the gap between pictures (vertical and horizontal) was 2 cm or 60 pixels. All four faces were always from four different actors. Each actor's faces was presented equally frequently throughout the experiment. The quadrant at which the target emotion was presented, and the actor that expressed the target emotion were randomized. The experimental conditions are summarized in Table 3. Each condition contained 10 trials, and the whole experiment consisted of 200 trials. The experiment started with a practice session of 9 trials.

Data analysis

The dependent variable was the probability of fixation within a given region of interest (ROI henceforth) at each time point. We defined the facial emotional expressions corresponding

Response	Target = "happy"	Target = "angry"	Target = "fearful"
yes	1 happy, 3 neutral	1 angry, 3 neutral	1 fearful, 3 neutral
yes	1 happy, 1 angry, 2 neutral	1 angry, 1 happy, 2 neutral	1 fearful, 1 angry, 2 neutral
yes	1 happy, 1 fearful, 2 neutral	1 angry, 1 fearful, 2 neutral	1 fearful, 1 happy, 2 neutral
yes	1 happy, 1 angry, 1 fearful, 1 neutral	1 angry, 1 happy, 1 fearful, 1 neutral	1 fearful, 1 angry, 1 happy, 1 neutral
no	4 neutral	4 neutral	4 neutral
no	1 angry, 3 neutral	1 happy, 3 neutral	1 angry, 3 neutral
no	1 fearful, 3 neutral	1 fearful, 3 neutral	1 happy, 3 neutral
no	1 angry, 1 fearful, 2 neutral	1 happy, 1 fearful, 2 neutral	1 angry, 1 happy, 2 neutral

TABLE 6.2: Summary of the conditions

with the spoken word as "target" (for example, a smiling face for the word "happy"), facial emotional expression not corresponding to the spoken word as "nontarget" (for example, a smiling face for the word "angry"), and neutral faces as "neutral".

We defined the following regions of interest: 1) regions for the whole faces: target emotion, nontarget emotion, and neutral face were defined as ellipses that included the whole face region and were determined for each image individually;

2) eye and mouth regions for each of the images: the target emotion, nontarget emotion, and the neutral face. The eye and mouth regions were defined as rectangles for each image individually. The probability of fixation within a ROI was calculated separately for each time point and each region. Only the fixations were taken into account, time points corresponding to saccades and blinks were coded as missing values.

6.2.2 Results

Behavioral data

Error rates and reaction times (RTs) were analyzed with two Repeated Measures ANOVAs with Emotion (target emotion indicated by the spoken word, happy, angry or fearful) and Nontargets (number of nontarget emotional expressions on the same display, 0, 1 or 2) as within-subjects factors.

The ANOVA results for the RTs are summarized in Table 3.

Effect	F	(df)	p
Emotion	42.44	(2,34)	$< .001*$
Nontargets	12.63	(2,34)	$< .001*$
Emotion * Nontargets	.66	(4,68)	.60

TABLE 6.3: Results of the ANOVA of the RTs in the pilot group in Experiment 1.

Participants found happy emotional expression most quickly (on average 2.15 s), followed by fearful expression (2.49 s), with angry expression eliciting the slowest responses (2.59 s). The reaction times were fastest when no other (nontarget) emotional expressions were presented, and increased with the number of nontarget emotions. The average error rate was 2.89% for happy emotion, 3.91% for fearful and 10.1% for angry, indicating that participants could successfully perform the task, but were not at ceiling level. Angry emotion elicited significantly more errors than either happy or fearful, and the latter two emotions did not significantly differ in the amount of errors. The number of nontarget images present did not have an effect on error rates.

The ANOVA results for the error rates are summarized in Table 4.

Effect	F	(df)	p
Emotion	7.22	(2,34)	.011*
Nontargets	.97	(2,34)	.39
Emotion * Nontargets	1.15	(4,68)	.34

TABLE 6.4: Results of the ANOVA of the error rates in the pilot group in Experiment 1

Eye-tracking data

The fixation probabilities within the target, nontarget and neutral face are plotted on Figure 1.

Visual inspection of the data suggested that participants started looking at the images at around 150 ms after trial onset. At 200-300 ms, neutral expression started to become distinguished from the target and nontarget emotions. Up to 400 ms there was no difference in fixation probability between target and nontarget emotions, and both probabilities were larger than that of the neutral face. After 400 ms, the fixation probability became highest for

target emotion, followed by nontarget emotion and neutral face. After 800 ms, the pattern of fixation probabilities did not change.

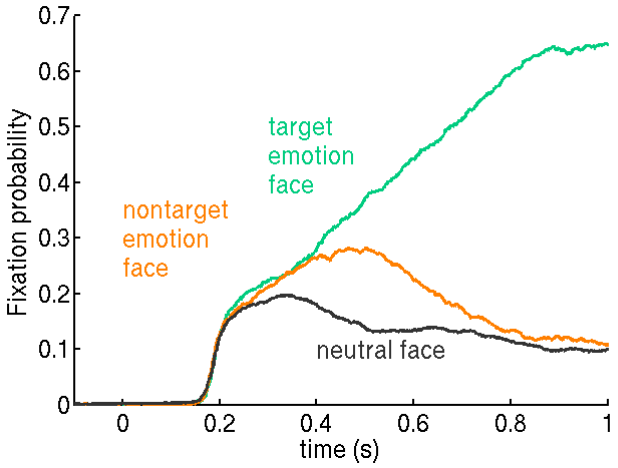

FIGURE 6.1: Fixation probability for target emotion (green), nontarget emotion (orange) and neutral face (gray).

Figure 2 shows relative fixation probabilities over time for the mouth and eye region of the target, nontarget, and neutral images. The fixation probabilities were calculated as the probability of looking at the eyes (or mouth) divided by the probability of looking at the entire face. These probabilities indicate the percentage of the time that people spent looking at the eyes (or mouth).

The first fixation between 200 and 400 ms was more likely to be on the mouth than the eyes for all images. Between 400 and 600 ms the probability of fixation on the eyes and mouth became equal, and after 600 ms participants were more likely to fixate on the eyes.

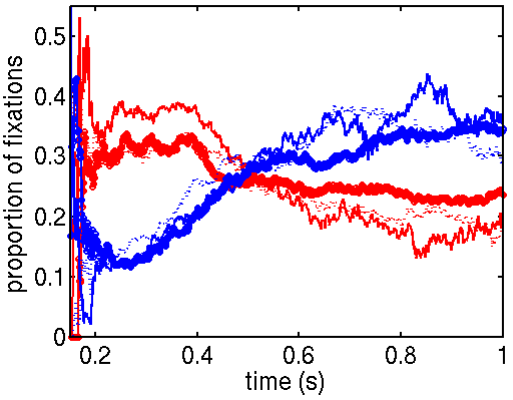

FIGURE 6.2: Relative fixation probability for eye region (blue) and mouth region (red) for target emotion (bold line), nontarget emotion (thin line) and neutral face (dotted line).

Based on the visual inspection of the time-course plots, we selected 200 ms time intervals for further analysis (200-400 ms, 400-600 ms, and 600-800 ms). To investigate the fixation probabilities over the whole faces, we ran a repeated-measures ANOVA with Image (target, nontarget, neutral) and Time (300, 500, 700 ms) as within-subject factors (see Table 3). To compare the fixation probabilities for eyes and mouth regions, we ran a repeated-measures ANOVA with Image (target, nontarget, neutral), ROI (eyes, mouth) and Time (300, 500, 700 ms) as within-subject factors (see Table 3).

Participants looked at the target emotion significantly more than at nontarget and neutral emotions, and this difference increased significantly over time. Early in the trial, participants

		F (df)	p	η_p^2
Whole image	Image	141.32 (2,34)	$< .001*$	.89
	Time	39.49 (2,34)	$< .001*$	.70
	Image * Time	103.98 (4,68)	$< .001*$	.86
Eyes:mouth	Image	.68 (2,34)	.45	.04
	ROI	.1 (1,17)	.76	.006
	Time	1.74 (2,34)	.2	.09
	Image * ROI	.98 (2,34)	.38	.05
	Image * Time	1.60 (4,68)	.20	.09
	ROI * Time	10.20 (2,34)	.002*	.38
	Image * ROI * Time	.62 (4,68)	.61	.04

TABLE 6.5: Results of the ANOVA for Experiment 1

looked more at the mouth and less at the eyes, 200 ms later these probabilities became equal, and in the last time interval participants looked more at the eyes compared to the mouth.

6.2.3 Discussion

In Experiment 1, we investigated processing of facial emotional expressions by young adults using eye-tracking. The results of Experiment 1 confirmed the validity of our paradigm. Although the responses time were on average around 2 seconds, participants started looking at the target image at around 400 ms after trial onset, and at 800 ms the probability of fixating at the target exceeded 50%. When we compared fixations on different parts of the face to each other, we found that the initial fixation was more likely to be at the mouth than at the eyes (between 200 and 400 ms), while at 500 ms the probabilities switched, and after 600 ms participants predominantly focused on the eyes. This finding is in agreement with results of previous studies that report an overall tendency to fixate more on the eyes in neurotypical people . However, it also suggests that the proportion of fixations on eyes and mouth can be time dependent. The percentage of looking at the eyes vs the mouth over time was the same for the target, nontarget, and neutral images.

6.3 Experiment 2

6.3.1 Method

Participants

Participants included 21 parents of children with ASD (ASD-rel) and 26 control participants matched on age and gender. The participants from the ASD-rel group were recruited from the families of children who were diagnosed with ASD at the Karakter Adolescent and Child Psychiatry Centre. All of these children met the DSM-IV-TR criteria for Autistic Disorder, Asperger syndrome or PDD-NOS. The control participants were recruited from the local community and had no history of ASD in their family. The study was formally approved by the local medical ethics committee. All participants gave informed consent to participate in the study and received compensation for participation.

	Control group (N=26)	ASD-relatives group (N=21)	t-test	(p-value)
Male:female	5:21	7:14	1.07	(.3)
Age	48.8	44.5	2.85	(.007)*
Verbal IQ	107.1	96.05	3.10	(.003)*
Raven score	15.92	15.21	0.44	(0.66)
AQ	14.12	17.71	1.54	(.13)
EQ	47.27	44.1	0.73	(.47)
SQ	44.08	44.68	0.12	(.9)
TAS	40.35	49.33	2.55	(.014*)
STAI	40.56	44.0	0.96	(.34)

Table 6.6: Characteristics of the participants in Experiment 2.

The verbal and nonverbal IQ of the participants was measured using Peabody Picture Vocabulary Test (Manschot and Bonnema, 1974) and a short version of Raven Progressive Matrices test (Hamel and Schmittmann, 2006). We also used the Autism Quotient (AQ), Empathy Quotient (EQ) and Systemizing Quotient (SQ) questionnaires (Simon. Baron-Cohen, Wheelwright, Skinner, Martin, and Clubley, 2001; Simon Baron-Cohen, Richler, Bisarya, Gurunathan, and Wheelwright, 2003). The AQ measures the level of self-reported

ASD traits and was previously shown to be significantly higher in people with a diagnosis of ASD than in general population (Wheelwright et al., 2010).

Finally, all participants filled out the Toronto Alexithymia scale (Bagby et al., 1994), and Spielberg trait Anxiety scale. Both alexithymia and self-reported anxiety were previously shown to correlate with emotion recognition abilities (Cook, Brewer, Shah, and Bird, 2013) as well as with gaze fixation pattern (Bird et al., 2011). We included those measures to test whether it is the level of ASD traits (AQ), or of other measures (alexithymia, anxiety) that would best explain the variation in gaze fixation pattern. Characteristics of the sample are summarized in Table 4.

Materials and Procedure

Materials and procedure were identical to the Experiment 1.

Data analysis

Data preprocessing and analysis was the same as in Experiment 1. We used the time intervals defined Experiment 1, namely 200–400 ms, 400–600 ms, and 600–800 ms.

6.3.2 Results

Behavioral data

Reaction times and error rates were analyzed using repeated-measures ANOVA with Group as between-subject variable, and Target emotion (happy, angry, fearful) and N competitors (0,1,2) as within-subject variables. Mean error rate for control group was 4% (95%CI 6.3 to 1.9%), and for ASD-relatives group 6% (95%CI 8.9 to 2.2%), with the main effect of Group being not significant ($F(1, 45) = .54, p = .46$). The only effect that reached significance was the main effect of Target: $F(2, 90) = 3.60, p = .038$. The trials where the target emotion was "angry" elicited more errors (6.8%) than "happy" (3.8%) or "fearful" (3.8%), replicating the pattern found for the pilot group.

In the reaction time analysis, the main effect of Group was not significant either ($F(1, 45) = .27, p = .6$. None of the interactions involving Group reached significance. The main effect of Target was significant. When the target emotion was "happy", participants responded significantly faster compared to "angry" or "fearful". The main effect of number of competitors (0, 1 or 2) on RTs was also significant ($F(2, 90) = 4.66, p = .018$). The response time

	F	(df)	p	η_p^2
Image	176.42	(2,90)	$< .001*$	.80
Time	101.61	(2,90)	$< .001*$	.69
Image * Time	86.24	(4,180)	$< .001*$	.66
Group * Image	.64	(2,90)	.48	.014
Group * Time	.56	(2,90)	.48	.012
Group * Image * Time	.03	(4,180)	.9	.001

TABLE 6.7: Summary of the ANOVA results for both groups in Experiment 2.

increased with the number of competitors on the screen. Finally, there was a significant interaction between number of competitors and target type ($F(4, 180) = 2.77, p = .042$). The increase in the response time proportionally to number of competitors reached significance only for the happy face as target, but not for the angry or fearful face. None of the covariates (VIQ, AQ, TAS or STAI) were significantly associated with error rate or reaction times.

Eye-tracking data

First, we investigated the probability of gaze fixation within the target, nontarget and neutral faces. We ran a repeated-measures ANOVA with Image (target, nontarget, neutral) and Time (300, 500, 700 ms) as within-subject factors and Group (ASD-rel, control) as between-subject factors.

The F-values were adjusted using Greenhouse-Geisser correction where appropriate. The ANOVA yielded several significant main effects and interactions which are summarized in Table 7.

The main effect of Image was significant, with the proportion of fixations being highest for Target image, followed by Nontarget image, and the least for Neutral image. The main effect of Time was also significant: The overall proportion of fixations on the images increased with time.

The interaction between Image and Time was also significant: The proportion of fixations increased with time for the Target image, but decreased or stayed the same for Nontarget and Neutral images.

The main effect of Group did not reach significance, reflecting that the ASD-relatives group

	F	(df)	p	η_p^2
ROI	3.08	(1,45)	.086	.064
Image	1.21	(2,90)	.30	.026
Time	6.51	(2,90)	.007*	.13
Image * ROI	.54	(2,90)	.57	.012
ROI * Time	35.22	(2,90)	$< .001*$	.44
Image * Time	.22	(4,180)	.89	.005
Image * ROI * Time	.93	(4,180)	44	.020
Group * ROI	.50	(1,45)	.48	.011
Group * Image	3.20	(2,90)	.056	.066
Group * Time	1.42	(2,90)	.25	.031
Group * Image * ROI	1.98	(2,90)	.15	.042
Group * ROI * Time	.37	(2,90)	.58	.008
Group * Image * Time	.1	(4,180)	.97	.002
Group * Image * ROI * Time	.21	(4,180)	92	.005

TABLE 6.8: Results of the ANOVA for the eye and mouth fixations for both groups in Experiment 2

on average looked at the faces just as long as the control participants. None of the interactions involving Group reached significance. Adding AQ, TAS, and STAI as covariates also did not change the pattern of results.

The fixation probability on eye and mouth regions was analyzed using repeated-measures ANOVA with Group as between-subject variable, and Time (300, 500, 700 ms), ROI (eyes, mouth) and Image (Target, Nontarget, Neutral) as within-subject variables. The results of the ANOVA are summarized in Table 7. The values were adjusted using Greenhouse-Geisser correction.

The only effects that reached significance were the main effect of Time (the proportion of fixations on eyes and mouth together increased relative to the rest of the face), and the interaction between ROI and Time (the initial fixation was more likely to be on the mouth, while fixations later on were more likely to be on the eyes). We did not observe any group differences.

Finally, we explored whether any of the covariates (AQ, alexithymia, or anxiety) could

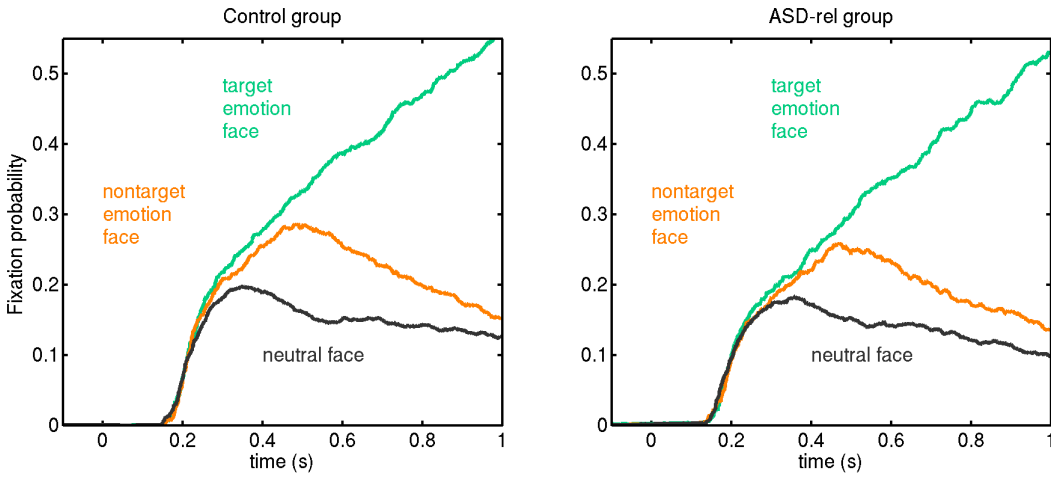

FIGURE 6.3: Average time course of gaze fixation for the control and ASD-rel groups in Experiment 2

explain the tendency to focus on the eyes vs the mouth overall. As Figure 4 shows, there was considerable individual variability within both groups with respect to overall looking proportion on the eyes vs the mouth.

We used the average fixation proportion on the eyes and the mouth over the whole time interval (200-800 ms) as dependent variable and ran a repeated-measures ANOVA with ROI (eyes, mouth) as within-subject variable, Group (ASD-rel, control) as between-subject variable and AQ, TAS and STAI as covariates. The results are summarized in Table 8.

The only effect that reached significance was the effect of TAS as a covariate. Participants with higher alexithymia scores looked relatively less of the time at both the eyes and at the mouth (and looked more at the other parts of the face such as hair, cheeks, forehead). This effect was independent of group.

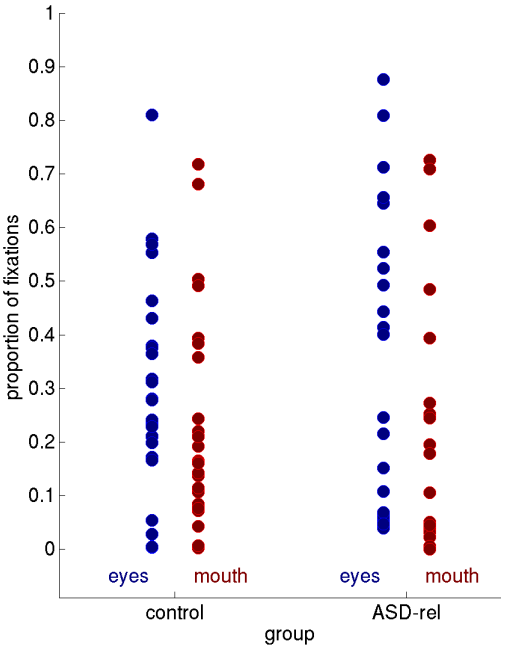

FIGURE 6.4: Scatter plot for individual proportions of looking at the eyes (blue circles) or the mouth (red circles).

6.3.3 Discussion

We investigated the time course of face processing in a facial emotion recognition task in first-degree relatives of people with ASD and neurotypical control people.

First of all, parents of children with ASD differed from the control participants on two measures, namely verbal IQ and alexithymia. Although non-verbal IQ (measured by Raven progressive matrices) did not differ between the groups, the verbal IQ scores of the ASD parents group was on average 11 points lower. The discrepancy between verbal and nonverbal IQ with relation to autism has been discussed as a potential marker for ASD (Ankerman et al. 2014; Munson et al. 2008). A large scale study in children with ASD has shown that on average, children with ASD tend to have lower verbal IQ compared to nonverbal IQ, and the difference between nonverbal and verbal IQ scores had a positive association with the severity of ASD symptoms (Ankenman, Elgin, Sullivan, Vincent, and Bernier, 2014). Our results suggest that a discrepancy in verbal and nonverbal IQ scores may be a familial risk factor of ASD.

The second test that produced different results in the two groups was the TAS. Parents of ASD children reported higher levels of alexithymia. Alexithymia has been previously associated with autism (Bird and Viding, 2014), with 50% of patients with autism having high levels of alexithymia. One earlier study also found increased alexithymia scores in parents of children with autism (Szatmari et al., 2008). Our finding is consistent with this result and suggests that alexithymia is associated with familial risk for ASD.

Factor	F (1,42)	p
ROI	1.11	.30
ROI*group	1.09	.30
ROI*AQ	.26	.62
ROI*TAS	2.28	.14
ROI*STAI	1.34	.25
group	2.55	.12
AQ	.25	.62
TAS	5.37	.025*
STAI	2.63	.11

TABLE 6.9: Summary of covariance analysis results.

The two groups did not differ in their behavioral performance on our task, such as the proportion of errors and response latencies. Neither of the groups was at ceiling, and the average error rate was below 10%, indicating that both groups were able to perform the task.

With respect to the eye-tracking measures, both groups showed surprisingly similar patterns of gaze fixation. Both ASD parents and control participants were equally fast to start looking towards the target emotion. Even though the button press was on average about 2 seconds

after the stimulus presentation, the first fixations on the target image occurred within the first 500 ms, and by 1 second the probability of fixation on the target emotion was 70%. Between 400 and 600 ms, both groups kept looking at the nontarget emotional images, indicated by the proportion of fixations on the target and nontarget emotions being similar to each other. However, after 600 ms participants moved their eyes away from the nontarget emotion and concentrated on the target.

With respect to the proportion of looking at the eyes compared to the mouth both groups demonstrated an enormous amount of variability between individuals, with no significant difference between the groups on average. When other traits, namely AQ, anxiety, and alexithymia were taken into account, alexithymia was the only variable that turned out to be significantly associated with the proportion of eye region fixations: People with lower alexithymia scores focused on the eyes and mouth more often compared to people with higher alexithymia.

The fact that parents of children with ASD in our sample did not show a tendency to avoid looking at the eyes and/or focus more at the mouth goes against the hypothesis that lower eye:mouth ratio is one of the familial features of ASD. While some studies supported this hypothesis (Klin et al., 2002), other studies failed to replicate the reduced eye:mouth ratio (Falck-Ytter and von Hofsten, 2011; Guillon et al., 2014). This suggests that the lower eye:mouth ratio might not be associated with ASD, or might be present only in a subgroup of ASD participants. Our finding that alexithymia rather than ASD traits (measured by AQ) or family history of ASD predicted the proportion of fixations on the eyes, is consistent with earlier results that alexithymia, but not ASD diagnosis, significantly predicted fixations on the eye region (Bird et al., 2011).

6.4 General discussion

Much research has focused on the processing of facial expressions of emotions by individuals with ASD. It has been suggested that people with ASD (Jemel et al., 2006; Harms et al., 2010), as well as their first-degree relatives (Dawson et al., n.d.; Spencer et al., 2011), have subtle deficits when it comes to processing facial expressions. One of the proposed explanations for this difference holds that people with ASD, as well as their first-degree unaffected relatives, use a different processing strategy when it comes to faces: They pay less attention to the core features of the face, and in particular avoid looking at the eyes. This way they

miss some important information about the facial expression, which leads to problems with interpreting them. Several eye-tracking studies seem to support this hypothesis. However, in the last years eye tracking studies report increasingly inconsistent findings with respect to whether gaze trajectory in ASD is abnormal or not (Falck-Ytter and von Hofsten, 2011; Guillon et al., 2014).

At the same time, the role of alexithymia in ASD has become a debated issue (Bird and Viding, 2014). One study found that individuals with high alexithymia, regardless of their ASD diagnosis, showed an attenuated neural response to pain of other people, suggesting that alexithymia may be associated with a deficit in empathy (Bird et al., 2010). In another study, people with high alexithymia were found to have difficulty distinguishing subtle differences in facial expressions of emotion, while ASD diagnosis had no effect on the performance (Cook et al., 2013). Finally, in an eye-tracking study participants with high alexithymia were found to avoid looking at eyes and fixate more on the mouth (Bird et al., 2011). In our study, we found that reduced proportion of fixation on the eyes was associated with high alexithymia scores, but not with family history of ASD, further supporting the hypothesis that alexithymia may be a major confound in many of the ASD studies.

Little is known about the developmental course of alexithymia; however, it would be an interesting issue to investigate in the future studies. It is likely that the development of awareness of one's own emotions and emotions in other people go hand in hand (Bird and Viding, 2014). Insufficient awareness of one's own emotion probably leads to an inefficient processing strategy when evaluating emotions in other people. This in turn may reduce the ability to recognize emotions in other people and delay the process of learning about one's own emotions.

Our study also demonstrates that gaze fixation on the eyes and the mouth is time dependent and changes over time during the stimulus presentation. In our study, the overall tendency was to initially fixate on the mouth and then move the attention towards the eyes. This was true for younger adults in Experiment 1, as well as for older adults and parents of children with ASD in Experiment 2. This result has an implication for future studies: It is important to consider not only overall proportion of fixations, but also changes in the proportion of fixations over time. For example, if people with ASD were slower to disengage from looking at the mouth, then in the average fixation rate it would appear as if they avoided looking at the eyes, while in fact they were just slower to switch.

Finally, the results of our study suggest that multiple covariates have to be considered when studying ASD. ASD is a heterogeneous condition, with high levels of psychiatric comorbidity (Simonoff et al., 2008). Even when other psychiatric disorders are not present, individuals with ASD may still show high levels of hyperactivity and inattention, alexithymia, anxiety, compulsivity, and others. Considering these covariates will allow researchers to better estimate whether any difference that is found can be attributed to autism or to other variables. Additionally, it will allow us to identify meaningful subtypes of ASD and better explain the observed clinical and biological heterogeneity in the empirical literature.

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Chapter 7

General Discussion

7.1 Thesis Summary

The overall aim of my thesis was to extend our understanding of the processing of emotion language in ASD. In this chapter I will first shortly summarize the main findings of each chapter. Next, I discuss more general issues related to my studies and outline implications for further research. In the Introduction, we formulated a number of questions with respect to these levels of processing. Do people with ASD process emotion words differently from the 'typical' population of language users? If this is the case, is that effect sensitive to the frequency with which those words are used in daily life? And how do they process emotion words when these words are integrated in a sentence context? It could be that any observed differences at the word level might be reduced in context, or perhaps increased. And do any emotion effects in ASD increase or decrease when one shifts from a task that is not explicitly oriented towards emotion to a task that explicitly asks for an emotion evaluation? What are the EEG correlates of all these effects? Can we see differences in emotion word processing in the brains of ASD and typical participants? To what extent is there a general emotional impairment in autism, going beyond language and extending, for instance, to face perception? Finally, can we find out more about the underlying mechanisms by studying the parents of people with ASD?

All these questions were considered in the different chapters of this thesis. Here, I will first shortly summarize the main findings of each chapter. Next, I will discuss more general issues related to my studies and outline implications for further research.

In **chapter 2** I reviewed the current literature on emotion language processing in ASD. Previous work had showed that people with ASD have trouble recognizing expressions of emotions in visual stimuli, such as photos and videos of people. In the review I concluded that the evidence for atypical processing of emotion by people with ASD extends also to language, suggesting for a general emotional impairment. However, the limited number of studies does not allow us to draw conclusions about possible extent and mechanisms of this impairment in emotion processing. If this impairment is indeed present and affects all aspects of emotional processing including emotional language, it poses a challenge for current cognitive theories of ASD which mostly focus on the domains of social interaction and communication, but take processing of emotions less into account. New models of ASD need to be considered, which take into consideration the interplay between the emotional and emotional - motivational factors and their role in social and cognitive development.

In the empirical chapters of the thesis I investigated different aspects of emotion word processing. In **chapters 3 and 4** I studied processing of single words with behavioral measures (reaction times and EEG). Surprisingly, I found similar behavioral effects of emotion processing (emotion facilitation effect and affective priming effect) in the typical control participants and the ASD participants; however, the brain waves for the emotional stimuli differed between the groups, suggesting that at the neural level participants with ASD recruited somewhat different brain networks to process emotional valence. In **chapter 5** I investigated the semantic integration of words in context during passive reading of sentences using EEG. I found that when the task required participants to read sentences for comprehension, emotion words were processed in a similar manner by typical and ASD participants. Finally, in **chapter 6** I looked at the matching of auditorily presented words to facial expressions in a visual world paradigm. I compared parents of children with ASD to control participants with no history of ASD in their family to disentangle the effects of familial risk for ASD from personality traits such as alexithymia (difficulty with understanding one's own emotions) and anxiety. The behavioral results (reaction times and error rates) did not significantly differ between groups. Furthermore, parents of children with ASD demonstrated similar time courses in fixating at the target emotion, and showed similar gaze fixation pattern with respect to eyes and mouth. However, alexithymia was found to be significantly associated with the proportion of fixations on the eyes, suggesting that alexithymia may potentially mediate some of the effects found in the eye-tracking studies in ASD participants.

Thus, across my experiments, a mixed pattern of results was observed: Sometimes the ASD group differed from the typical population, but sometimes no differences were observed.

To interpret and integrate the findings of the various chapters of my thesis, I will consider a number of theoretical issues in the following sections of this chapter. First, I will argue that there are early and late stages of emotion processing, and that a difference between participants with ASD and typical participants might show up at one stage but not necessarily the other. Second, I will argue that a similar reasoning may hold for effects of tasks and instruction: Participants with ASD may have processing strategies that differ from typical participants under some experimental conditions, but not under other conditions. As a third issue, I will discuss the possibility that participants with ASD may be differently responding to words that are different in valence. In other words, they might be differently sensitive to positive and negative emotion words. If this would be the case, there might not

be a general but specific processing difference relative to typical participants. Finally, I will discuss individual differences in the ASD group with respect to a number of factors (e.g., alexythymia, verbal IQ, Autism Quotient, and anxiety), participant categorization (e.g., autism vs Asperger), and strategic rather than pathological differences in performance. I will end the chapter with some suggestions for future research.

7.2 Dissociation Between Early and Later Stages of Emotion Processing

Emotion influences different stages of word processing. Emotion words, just like all emotional stimuli, are perceived by the brain as having greater salience. The initial detection of emotional valence happens very fast and is probably driven by bottom-up and more automatic processes involving subcortical structures such as the amygdala (Phelps and LeDoux, 2005). In this way emotion words activate the salience detection system, and recruit additional processing resources, resulting in higher detection rate and faster recognition (Kousta et al., 2009). At the behavioral level, the effect of emotional valence results in faster and more accurate recognition of emotion words (Kousta et al., 2009). Additionally, emotion words of the same emotional valence can prime each other, resulting in faster and more accurate responses when they are presented in short succession or simultaneously (Klauer and Musch, 2003).

With respect to electrophysiological activity, early effects of emotion mostly activate subcortical structures, such as the amygdala, which does not produce a reliable ERP (Garolera et al., 2007). As a consequence, different studies produce different findings, with some researchers reporting an Early Posterior Negativity within 200 ms after stimulus onset (Wang et al., 2013), others reporting it within a later time window (Kissler et al., 2009) or extending up to 400 ms (Citron et al., 2013), and others reporting no EPN (Dillon et al., 2006) or even more positive amplitude for emotion words (Schupp et al., 2000), in other words an opposite effect compared to EPN.

In our studies, we investigated two early effects of emotion: the emotion facilitation effect and the affective priming effect. At the start of the study, we expected to replicate the findings of Gaigg and Bowler (2009) and Corden et al. (2008) who found impaired emotional processing at the early stages in patients with ASD. However, contrary to our initial hypothesis, both

effects investigated by us were present to a similar degree in the ASD and the control group. This suggests that early initial detection of emotion was not impaired in ASD (Lartseva et al. 2014).

However, a different picture emerged with respect to later stages of emotion processing. After the meaning of the word is processed, emotion words still require more cognitive resources compared to neutral words. At the neural level this is indicated by a long lasting positive ERP component (LPC) that starts (according to different studies) between 300 and 500 ms and lasts until 600-900 ms after the word onset. This ERP component is also associated with better memory encoding (Dolcos and Cabeza, 2002). Previous studies have reported absent emotional memory effect in ASD participants, especially over longer time intervals (Deruelle et al., 2008; Gaigg and Bowler, 2008, 2009b; Kennedy et al., 2006). Based on those studies, we expected to find attenuated or absent LPC in the ASD group. Indeed, we found the ASD and control groups to differ with respect to the LPC. The LPC was absent in the ASD group in chapter 3 (Lartseva et al., 2014), and had a different topography in chapter 4.

The early effects in word processing are mostly bottom-up and stimulus driven, and reflect to a greater degree automatic processing tendencies (Hauk, Davis, Ford, Pulvermüller, and Marslen-Wilson, 2006), while effects that occur later in time are mostly top-down and are more likely to be influenced by participants' strategy and by task demands (Schacht and Sommer, 2009). For example, in an experiment where participants had to respond whether the word was printed in regular font or in italics, typically developing participants also did not show an LPC effect (Schacht and Sommer, 2009).

How can we explain the fact that participants with ASD showed abnormal (i.e. absent or different) late effects of emotion, but a typical early effect? Early processing stages are more stimulus-driven and are more involved with processing of sensory characteristics of the stimuli, while the processing that takes place at the later stages is associated with conceptual processing and contextual integration (Schacht and Sommer, 2009). People with ASD are characterized by a particular cognitive style that includes greater attention to isolated features and details and less focus on the global structure (Happé and Frith, 2006; Mottron et al., 2006). It is unclear whether an initial deficit in global processing causes people with ASD to adopt a detail-focused strategy as a compensatory mechanism, or vice versa, the habit of focusing on isolated features leads to global processing being less frequently used

and less trained.

In case of word processing, participants with ASD might try to adopt this detail-oriented style to increase their performance. In case of lexical decision, participants with ASD would then focus on the word form processing and ignore the meaning of the word, which is in principle not relevant for performing the task. In case of affective priming, participants with ASD would put extra effort in suppressing the processing of the prime word and focusing only on the target, which would lead to an increased LPC effect.

This explanation is also compatible with our finding of a normal LPC effect in **chapter 5**. When the task requires participants to read sentences for comprehension, then they would have to abandon the detail-focused processing strategy and process sentences as a whole, just like the typical participants did.

7.3 Effects of task and instruction

Participants with ASD and typical participants might not only be differentially sensitive to early and late stages of emotion processing, but also to task demands and the instructions they are given.

Studies investigating processing of emotions in facial expressions found that people with ASD are in principle able to correctly recognize facial expressions of emotions when given explicit instructions to do so (Uljarevic and Hamilton, 2013), but they are not always able to do that spontaneously. Effects of task variables can have a strong impact on the performance, depending on whether participants have to pay attention to the emotional valence of the words, or if the emotional valence is irrelevant for the task; in other words, depending on whether it is an explicit or implicit emotion task.

In our studies we found that effects of task instruction can indeed make a difference in how individuals with ASD process emotion in words. In our first study (**chapter 3**) emotion was irrelevant for the task, which required participants to only distinguish between existing Dutch words and pseudowords. In this task, participants with ASD showed the same pattern of brain activity for emotional and neutral words, suggesting that they probably just ignored the emotional aspect of the word.

In our next study (**chapter 4**) participants were explicitly asked to classify words as emotionally positive or emotionally negative. In this study, the pattern of brain activity of participants with ASD was already more similar to the control participants: the LPC was

found in both groups. However, the topography of the effect was significantly different between the groups, suggesting that there could be a difference in the network of brain regions that each group recruited in order to perform the task.

Finally, in **chapter 5** participants were asked to read complete sentences and answer comprehension questions. One word in the middle was manipulated to be emotional or neutral. In this study, even though we did not explicitly draw participants' attention to the emotional valence of the words, they still were required to process the meaning of the words in order to understand the complete sentence. In this study, we found no differences in the brain activity between the two groups.

Taken together, our results suggest that typical participants are not really able to ignore emotional valence of the stimuli, and they will pay attention to it even though it may be task-irrelevant. In contrast, participants with ASD are able to process emotional valence, but they not always do process it. This could be explained in two alternative ways. The first possibility could lie in the detail-oriented processing style that is characteristic for ASD: Participants with ASD may be better able to focus on isolated features of the stimuli and ignore everything else. According to this hypothesis, the findings of other researchers reporting no effect of emotion in the ASD group (Corden et al., 2008; Gaigg and Bowler, 2009a) can be explained not as impairment but as a different processing strategy. The second possibility is that processing of emotion is more effortful to participants with ASD and requires more cognitive resources. In this case, selectively ignoring processing of emotional valence unless it is explicitly required by the instruction may be an adaptive strategy for ASD participants. Explicit instructions which activate the top-down mechanisms of cognitive control may facilitate processing of emotional valence. Likewise, when contextual cues are present, for example during reading of sentences, participants with ASD are also more likely to pay attention to the emotional valence of the words and process it in a more typical manner.

7.4 Positive and negative emotion

Another potential difference between participants with ASD and typical participants could be that both groups are to some extent sensitive to the emotional force of words, but are different in how they cope with the positive and negative valence of such words. Studies on processing of emotion often discuss processing of positive and negative stimuli together as

opposed to neutral. In some aspects, processing of positive and negative emotional stimuli is similar, but not in all. Both emotionally positive and negative information is perceived by the brain as having motivational relevance and greater salience (Wang et al., 2013; Kissler et al., 2007). Because of that, both positive and negative stimuli are detected by the brain faster and more accurately (Kuchinke et al., 2007; Zohar Eviatar and Zaidel, 1991), and also are better encoded in the memory (Dolcos and Cabeza, 2002; Dolcos et al., 2004; Kensinger and Corkin, 2003). In this way positive and negative information is processed similarly.
However, there are also important differences. First, negative emotion is thought to have a greater motivational significance than positive emotion (Dahl, 2001; Nasrallah et al., 2009), because avoiding harmful situations is generally more important for survival than looking for positive ones (Taylor, 1991). Positive and negative emotion are also associated with opposite action tendencies, with positive emotions triggering an approach response and negative emotions eliciting avoidance (Russell and Mehrabian, 1978). In our study, participants with ASD differed from controls in their processing of emotion, with respect to both positive and negative emotion. Negative emotion had a stronger effect in participants with ASD in a task requiring explicit evaluation judgment (**chapter 4**), while in a non-emotional task (**chapter 3**) emotionally negative words elicited a weaker effect. The results suggest that participants with ASD may be hypersensitive to negative emotion. On the other hand, they appear to be hyposensitive to positive emotion, which would explain the reduced effects from positive emotional stimuli in the evaluation judgment task which required explicit attention to the emotional content of the words.

7.5 Individual differences

The overview of our findings so far suggests that there may be processing differences between participants with ASD and typical participants. However, there may also be considerable differences within the group of ASD itself.
In fact, ASD is a very heterogeneous group, which may include etiologically different disorders that present with the same behavioral manifestations. Previous studies have found considerable inter-individual variability and have attempted to identify cognitive and biomarkers to better subtype the participants. Among those markers are alexithymia (Bird et al., 2011, 2010), patterns of sensory processing problems (Lane, Young, Baker, and Angley, 2010), restricted/repetitive behaviors (Lam, Bodfish, and Piven, 2008) verbal IQ (Rapin

and Dunn, 2003), nonverbal IQ (Bishop et al., 2006) or the difference between the two (Koyama, Tachimori, Osada, Takeda, and Kurita, 2007). However, the common problem with those attempts is that there is a lot of variability between the studies, and associations that are found between different domains are not always replicated (Howlin, 2003).

In our study, we found that several parameters differentiated between ASD participants. One important factor was vocabulary size measured by Peabody Picture Vocabulary Test (Manschot and Bonnema, 1974). The outcome of this test is a verbal IQ score, and it has been shown to be highly correlated with other measures of verbal IQ (Hodapp and Gerken, 1999). In two of our studies verbal IQ was inversely correlated with the effect of emotion. In other words, participants with ASD and lower verbal IQ showed a strong effect of emotion, and were in that respect more similar to control participants, while participants with higher verbal IQ showed a smaller effect of emotion, and were in that sense more similar to the participants from the previous studies. A possible explanation for this is that in participants with lower verbal IQ, language processing takes longer and requires more effort and greater involvement of the underlying neural mechanisms. If the processing is more extended in time, then there is a longer time window during which emotional aspects of the word meaning can get processed and influence the task performance. Participants with lower verbal IQ also demonstrated longer reaction times overall, which is consistent with this explanation.

In **chapters 4 and 6**, we additionally measured Autism Quotient (AQ) and Empathy Quotient (EQ) - self-report questionnaires measuring empathy and autism traits (Baron-Cohen et al. 2001; Baron-Cohen and Wheelwright 2004). People with an ASD diagnosis had significantly higher AQ scores and significantly lower EQ. However, after correcting for presence/absence of the ASD diagnosis, none of these parameters turned out to be correlated with emotion processing. Failure to find a correlation between AQ and emotion processing could be due to a number of reasons. In the control group, we had a relatively restricted range of AQ scores. We did not preselect control participants based on AQ, and consequently the distribution of AQ scores in our control sample was normal with most scores clustering around 10-16, with only a few scores falling into a low (10 and below) or high (20 and above) range. Participants with ASD, on the other hand, mostly had very high AQ scores, but presence/absence of an ASD diagnosis was still a better predictor of between-subject differences than AQ or EQ. Potentially, selecting participants from different ranges of AQ scores and ensuring that AQ scores are distributed uniformly across the control group could

be better suited for exploring whether people with high levels of ASD traits in the general population would be more similar to the patients with ASD in their pattern of responses. Alternatively, it could be that the questionnaires do not measure the construct that was investigated in this experimental design.

In **chapter 6**, we additionally measured alexithymia and anxiety. A number of studies have shown that high levels of alexithymia are associated with impairments previously attributed to autism: poor facial emotion recognition, reduced empathy, and atypical pattern of gaze fixation (Bird and Viding, 2014). Specifically, individuals with high alexithymia from both ASD and control groups avoided looking at the eyes and looked more at the mouth, while people with low alexithymia showed an opposite pattern. Anxiety has received less attention in relation to ASD, but a few studies have demonstrated a link between anxiety and atypical processing of emotional stimuli in ASD (Kleinhans et al., 2010). If alexithymia or anxiety are indeed confounding factors behind some traits previously attributed to ASD, then they would explain the between-subject differences better than group (ASD or control) or AQ. In our task, alexithymia did not significantly predict accuracy or reaction time, but it was associated with the proportion of looking towards the eyes. Anxiety did not turn out to be a significant predictor for either the behavioral or the eye-tracking results.

Recently, many studies have investigated gaze fixation pattern during face processing in ASD, but the findings have been largely inconsistent, as recent meta-analyses showed (Guillon et al., 2014; Papagiannopoulou et al., 2014; Falck-Ytter and von Hofsten, 2011). While some studies found big differences between ASD and control groups with respect to the amount of fixations on the eyes compared to mouth regions, other studies reported no differences. However, most of these studies did not consider potentially confounding factors, such as alexithymia. Although alexithymia has been considered in only a few studies so far, it is a trait that can potentially be used to subtype the ASD population into different subgroups and explain part of the heterogeneity in the results of different studies.

7.6 Autism vs Asperger syndrome: Does verbal ability matter?

In connection with the introduction of DSM-5 last year, there has been discussion on the merging of Autistic Disorder and Asperger Syndrome into one category of Autism Spectrum

Disorder. People with classic autism are characterized by a delay in language development, while people with Asperger syndrome reach all of the normal milestones. Some studies show that there are qualitative differences between those two subtypes of ASD (Koyama et al., 2007), while other studies find that they are similar to each other (Szatmari et al., 2009). The results of our studies suggest that verbal IQ is indeed a useful concept to subtype people with ASD. However, it was verbal IQ in adulthood and not the history of language delay that was associated with performance in our tasks. Moreover, all our participants had verbal IQ within normal range, but even this relatively small variation was nevertheless significantly associated with task performance. Our data suggest that differences associated with verbal IQ are better considered in the context of a continuous spectrum and do not support the breakdown of ASD into separable subtypes such as autism versus Asperger syndrome.

7.7 Participants are a subselection of the entire ASD population

In our research, we only included high-functioning people with ASD. All our participants had verbal and nonverbal IQ within normal range. As we discussed in **Chapter 2**, most of the current studies of ASD focus on the high-functioning end of the autism spectrum. There are several reasons for this: Working with high-functioning participants enables the researcher to use more difficult tasks and study more complex cognitive processes; it is possible to use healthy typical people as controls, who are very easy to find; low-functioning patients with ASD more often have serious psychiatric or somatic illnesses which can make participating in research a greater burden for them. As a result, not enough is known about how people with low-functioning ASD process emotion words. It is not clear whether people with low-functioning ASD would show the same problems in emotion processing, or if they would be more similar to controls, or would show a different pattern altogether. Our results suggested that variation in verbal IQ can account for a significant proportion of variance in task performance. However, it is not clear whether the trend that we observed within participants with normal range IQ scores would remain if we had included patients with mild intellectual disability.

7.8 Atypical vs pathological

Obviously, any variation in the participant group of people with ASD has its consequences on performance. When a study in ASD participants finds a difference in brain activity or behavior between ASD and typical groups, those differences are often interpreted as a deficit or impairment. However, this is not always right. In fact, a difference can potentially also reflect an alternative strategy or an adaptive compensatory mechanism. Processing style of ASD participants may be "different" from controls, but this does not necessarily mean "maladaptive".

However, the situation is even worse, due to the discussed variability within the ASD group itself. We know that the degree of ASD traits does not completely overlap with occupational or social functioning. Someone may be highly autistic and still well adapted because of high IQ or learned compensatory strategies. Other people can have a relatively mild ASD but have severe problems in psychosocial adaptation because of comorbid symptoms and stress or negative events at school or in the family situation.

Because of that, it is important to study people who share some of the ASD traits but do not have a clinically significant impairment in their everyday life. One possible way is to study first-degree relatives of people with ASD. First-degree relatives (such as parents or siblings) share on average 50% of the genetic risk for ASD, but do not have the disorder itself. It has been shown that parents and siblings of ASD frequently display the traits characteristic for ASD, but to a lesser degree. The term "Broad Autism Phenotype" (BAP) has been proposed to describe individuals who have a higher-than-average degree of ASD traits, but do not have an impairment to fulfill the criteria for a diagnosis of an ASD.

When a BAP group is added in addition to patients with autism and neurotypical controls, there are 3 possible outcomes:

1. BAP group is not significantly different from the controls, but significantly differs from ASD;
2. BAP group does not significantly differ from ASD, and is significantly different from controls.
3. The performance of the BAP group is at an intermediate level between ASD and control groups.

In the first case, the measured variable most probably reflects individual liability that may contribute towards the risk of developing ASD (ASD state), but are not related to ASD traits,

that is the symptoms and impairment of functioning on itself. The second outcome would be strongly suggestive that the effect of interest indeed reflects something about the broader social-communicative and/or sensory traits in ASD, whereby the BAP group probably has some compensatory mechanisms that prevent them from developing the clinical disorder. The last outcome is an intermediate case. In our study involving parents of children with ASD, we found no difference between the ASD parent group and matched controls. This result is consistent with option 1, suggesting that preference for mouth and avoiding the eyes is not an effect of ASD traits.

7.9 Suggestions for future research

The studies presented here investigated only some aspects of emotion processing of ASD; and there are still questions that need further study.

In **Chapters 3 and 4** we found differences in the event-related neural responses to emotion words between ASD and typical group. However, EEG has a limited spatial resolution and reduced sensitivity to the brain activity coming from deep sources. Because of that, it is unclear whether participants with ASD who show a different pattern of activity on the scalp, activate the same set of brain areas as the typical group, but to a different degree than controls, or alternatively, if they activate and use different brain areas. Therefore, a study combining EEG with MRI measures would be able to shed more light on these issues.

In some of the studies we found that verbal IQ in the ASD group was significantly correlated with effects of emotion. Interestingly, the correlation was inverse: Participants with lower verbal IQ showed a stronger effect, and participants with a higher verbal IQ showed a weaker effect. In the previous literature on emotion processing, only very few studies reported the results with verbal IQ added as a covariate, therefore it is not clear whether there is any association between those two parameters. The link between verbal IQ and emotion deserves further study.

Recently, alexithymia has been proposed as a useful concept to subtype individuals with ASD into subgroups. Specifically, it was suggested that people with ASD and high alexithymia have severe problems with empathy, understanding of other people's emotions and recognizing facial expressions of emotions. In contrast, people with ASD and low alexithymia have the same empathic abilities as typical people, and do not have a specific deficit in facial emotional expressions. In our last chapter, we failed to find an association between alexithymia

and behavioral performance; however, we found a tendency in people with high alexithymia to focus at the eyes less compared to people with low alexithymia. More large-scale studies with participants preselected based on their alexithymia scores are required before we can draw definite conclusions about the contribution of alexithymia to emotion processing. We also suggest that future studies of emotion processing in ASD measure alexithymia as an additional variable, and report the results of their analysis with alexithymia as a covariate, regardless of whether it was significant or not.

Finally, it is important to explore how emotion processing is tied to other aspects of cognition and motivation. Previous studies have suggested that people with ASD have an impairment in learning stimulus-reward associations (Dichter, Felder, et al., 2012; Dichter, Richey, et al., 2012; Kohls et al., 2011). Being associated with reward or punishment is one way for stimuli to get positive or negative emotional valence; therefore impairment in reward learning and emotion processing could be causally related.

Appendix A

Studies reviewed in Chapter 2

Abbreviations:

ABC	Autism behavior checklist	LFA	low-functioning autism
ADI	Autism diagnostic interview	MA	mental age
ADOS	Autism diagnostic observation schedule	NVIQ	nonverbal intelligence quotient
AS	Asperger syndrome	NVMA	nonverbal mental age
ASD	Autism Spectrum Disorder;	PDD	pervasive developmental disorder
ASDS	Asperger syndrome diagnostic scale	PIQ	performance intelligence quotient
CA	chronological age	TD	typically developing
CARS	Childhood Autism rating scale	VIQ	verbal intelligence quotient
DD	developmental delay	VMA	verbal mental age
DS	Down syndrome	WS	Williams syndrome

Authors	Group characteristics	Stimuli and task	Reported results
Lexicon and semantics			
Hobson and Lee (1989)	21 LFA (Rutter 1974): age: 18;09 (3.75) VIQ: 65.5 (16.6) 21 controls age: 18;05 (3.9) VIQ: 66.5 (17.4)	Implicit: Matching words to pictures using Peabody Picture Vocabulary test	Implicit: + Subjects with ASD performed the test at the same level as the controls for abstract items and items with social content, but control subjects were significantly better on emotional items (between-group t-test: $t = 2.79, p < 0.01, d = 0.44$; group by type of item interaction: $F(1, 20) = 5.89, p < 0.05$).
Beversdorf et al (1998)	10 ASD (ADI-R): age: 30.8 (9.3) IQ: 109.7 (16.2) 13 controls age: 30.6 (12.8) IQ: 117.3 (11.2)	Implicit: Listening to word lists, sentences and stories and subsequently recalling them.	Implicit: + Control subjects but not ASD recalled emotional sentences better than non-emotional sentences (significant group by emotion interaction: $F(1, 21) = 7.394, p = 0.013, d = 0.47$); no between-group differences in recall of word lists, sentences, coherent stories or sentences with theory of mind content.
Hillier and Allinson (2002)	10 LFA (n/a): age: 12 VMA: 9.7, NVMA: 10 10 learning disability 10 controls (MA-matched) 10 controls (CA-matched)	Explicit: rate the level of embarrassment of a protagonist of a scenario.	Explicit: +/- Children with autism have difficulty with such concepts as empathic embarrassment (autism < MA-matched controls: $p < 0.05$; autism < CA-matched controls, $p < 0.001$) but showed a good understanding of other variables manipulated such as the presence of an audience.
Bauminger (2004)	16 autism (DSM-IV, ADI-R): age: 11.14 (3) IQ: 92.81 (14.15) 17 controls Age: 11.5 (2.6) IQ: 98.35 (7.2)	Explicit: expression and understanding of jealousy	Explicit: +/- Children with autism expressed jealousy in situations similar to their typical age mates but manifested it in different behaviors. Compared to TD children, children with autism were significantly less likely to look at the parent and/or the rival child ($F(1, 29) = 4.10, p < 0.05, d = 0.75$) but were significantly more likely to act toward them ($F(1, 29) = 14.87, p < 0.001, d = 1.43$). Moreover, children with autism revealed a less coherent understanding of the feeling.
Kennedy et al (2006)	15 ASD (10 HFA, 3 AS, 2 PDDNOS) (ADI, ADOS) Age: 25.49 ± 9.61 IQ: 96.1 (16.5) 14 TD controls Age: 26.07 ± 7.95 IQ: n/a	Implicit: counting Stroop task (count the number of words on the screen); surprise recognition test. Stimuli: emotional (negative), neutral, and number words.	Implicit; +/- Reaction time and accuracy: no effect of emotion, no emotion by group interaction. Memory: effect of emotion in controls ($t(1, 8) = -4.02; p = 0.004$), no effect of emotion in ASD group ($t(1, 11) = -1.15; p = 0.274$), group by emotion interaction at trend ($F(1, 19) = 4.24, p = 0.062$). fMRI: between-group difference in brain activity in PCC and PrC dorsal MPFC for (emotion vs rest) contrast, in ventral MPFC / rACC for (emotion vs neutral) contrast.
Rieffe et al (2007)	22 ASD (DSM-IV): age: 10.2 IQ: normal range 22 controls IQ: n/a	Explicit: Provide explanations about situations involving single and multiple emotions	Explicit: + Children with autism have difficulties identifying their own emotions and less developed emotion concepts; they are more biased towards a single emotion perspective, especially within negative domain.

Authors	Group characteristics	Stimuli and task	Reported results
Corden et al (2008)	17 AS (ADOS): Age: 34.2 IQ:112.9 17 controls Age: 32.3 IQ:109.9	Implicit: Attentional blink paradigm using emotional/neutral words (experiment 1) and neutral words of varying brightness (exp 2); SCR response to emotion words. Explicit: subjective rating of arousal	Implicit: +/-, Explicit: - No differences in subjective ratings of arousal; no group * word type interaction in SCR measurement. In exp. 1, significant word type * time lag * group interaction ($F(3, 96) = 5.2, p = .002$). At shorter time lags, control subjects detected emotional words more successfully than AS group. In exp. 2, visual salience had the same effect on both groups (the main effect of group and all interactions involving group are nonsignificant)
Gaigg and Bowler (2008)	18 ASD (ADOS): age: 32.8 IQ: 106.3 18 controls Age: 33.2 IQ:105.1	Implicit: Reading a list words containing unrelated neutral, semantically related neutral and emotional words, and recalling them at different time intervals.	Implicit: + ASD patients showed less correlation between SCR and subjective valence ratings (difference between groups: $t = 2.62, df = 34, p < .05$) and higher forgetting rates for emotional words. In the typical group recall rates significantly decreased for unrelated neutral ($t = 2.46, df = 17, p < .05$) and related neutral ($t = 3.66, df = 17, p < .005$) words but not for the emotional words ($t = 0.98, df = 17, ns$). For the ASD group, only the decrease in recall of arousing words over the 24 h period ($t = 2.57, df = 17, p < .05$) was significant.
Mason et al (2008)	18 ASD (ADI-R, ADOS-G, expert clinical opinion): Age: 26.5, IQ: 101.9 18 TD Age: 27.4, IQ: 105.5	Implicit: read short stories that contain physical, intentional or emotional inferences.	Implicit: + (neural activity) fMRI: The ASD group activated areas in right hemisphere which is interpreted as spillover processing.
South et al (2008)	37 ASD (ADI-R, ADOS) Age: 19.7 (5.3) IQ: 107.7 (15.1) 38 TD controls Age: 19.2 (6) IQ:112.7 (14.1)	Implicit: visual search task; exposure task, word memory task and gambling task	Implicit: - No differences between groups on all 4 tasks. Emotion words memory subtest: group by word valence interaction: $F(2, 70) = .14; p = .87$; group by word arousal interaction: $F(2, 70) = .33; p = .72$.
Gaigg and Bowler (2009a)	25 ASD (ADOS): age: 38.4, IQ: 105.2 25 controls Age: 36.2 (11.8) IQ: 105.8 (15.1)	Implicit: Attentional blink paradigm using emotional words, neutral words and male first names.	Implicit: + In the control group, detection rates of emotional words had significantly higher detection rate than names and neutral words ($F(2, 23) = 21.69, p = 0.001, d = 2.75$). This was not the case for the ASD group ($F(2, 23) = 2.61, ns, d = 0.95$). Emotionality effect was correlated with VIQ in ASD subjects ($r = 0.502, p < 0.05$) but not in controls.
Gaigg and Bowler (2009b)	22 ASD (ADOS): age: 33.5, IQ: 98.7 22 controls Age: 35.2 (9.6) IQ: 103.7 (13.1)	Implicit: Memorizing a list of orthorgaphically related neutral and emotional words with subsequent recognition memory test.	Implicit: + Control subjects were significantly less likely to falsely remember emotional words (main effect of emotional/neutral word: $F(1, 21) = 9.27; p < 0.01$; effect size $r = 0.55; d = 1.33$). In subjects with ASD false recall rates of emotional and neutral words were not different ($F(1, 21) = 0.49; ns$; effect size $r = 0.15; d = 0.31$).

Authors	Group characteristics	Stimuli and task	Reported results
Williams and Happe (2010)	21 ASD (DSM IV-TR): age: 12.3 VIQ: 73.24; PIQ: 67.10 21 controls (CA and MA matched)	Explicit: Report their own experience on various emotions and recognize them in video clips	Explicit: - No between-group difference in patterns of performance; in both groups social emotions were more difficult to recognise and report than non-social emotions. In ASD, verbal mental age was significantly correlated with quality of reports of both social (r=0.66, p=0.003) and non-social (r=0.65, p=0.004) emotion experiences. In contrast, in controls VMA was significantly correlated with the ability to recognise non-social emotions ($r = .56, p = .008$), but not social emotions ($r = .32, p = .16$).
Han et al (2014)	10 ASD (ADOS) age: 16.03 (1.9) IQ: 81.5 (8.9) 10 controls age: 14.9 (2.7) IQ: 106 (10)	Explicit: detecting emotionally negative words	Explicit: + Participants with ASD made more errors detecting emotionally negative words (53.0±14.6% correct) compared to control group (90.3±9.1% correct) fMRI: increased activity in fusiform gyrus in ASD group in response to emotion words
Voice-intonation			
Boucher et al (2000)	19 LFA (DSM-IV) age: 9;7 VMA: 5;11, NVMA: 8;9 19 SLI (CA and MA-matched) 19 TD control (MA-matched)	Explicit: Naming expressed emotion in a voice sample, matching voice to facial expression	Explicit: +/- On vocal affect naming ASD were better than SLI ($p < 0.5, d = 0.4$) and not different from controls. On matching vocal to facial expressions ASD were superior to the children with SLI ($p < 0.01, d = 1.09$), but impaired relative to TD children ($p < 0.01, d = 1.03$).
Lindner and Rosen (2006)	14 ASD (ASDS, PDD Checklist): Age: 10.21 (2.89) VIQ: 114.8 (17.15) 16 TD Age: 10.19 (3.12) VIQ: 117.3 (14.3)	Explicit: Naming emotions in photos, videos, intonation, verbal content and combined stimuli.	Explicit: + Participants with ASD were worse at correctly identifying emotion in prosody, $F(1, 26) = 14.52, p < .01, \eta_p^2 = .36$
Korpilahti et al (2007)	14 AS (ADI-R, ADOS-G): age: 11.2 (9-14) IQ: 110 (84-150) 12 fathers of AS: age: 42.8 (37.5- 49.5) 13 controls age: 10.8 (9.1-11.7), IQ: n/a	12 fathers of controls Implicit: Passive listening to words with neutral and angry intonation	Implicit: + In ASD group were found neural difficulties with processing of affective prosody, based on N1 and MMN evoked potentials. N1: longer latencies for children with ASD compared to controls ($p = 0.021, d = 0.538$), no difference for fathers. MMN: greater amplitudes of early MMN and shorter latencies of late MMN (p=0.041) in children; significant differences in both MMN latency values ($eMMN, p = 0.001; lMMN, p < 0.001$) in fathers.

Authors	Group characteristics	Stimuli and task	Reported results
Peppe et al (2007)	31 HFA (ICD-10, DSM – IV, CARS, Gilliam Autism Rating Scale, ADOS) Age: 9;10 (2.3) VMA: 7.09, VIQ: 81.6 (15.6) 72 TD children Age: 6;10 (1.5) VMA: 7.53, VIQ: 107.5 (9.6) 33 TD adults Age: 18 – 59	Explicit: PEPS-C test: a prosody comprehension and production task including affective prosody.	Explicit: + ASD group performed worse both in perception ($F(1,97) = 16.21, p < .001, \eta_p^2 = .14$) and production ($F(1,97) = 11.32, p < .01, \eta_p^2 = .10$) of affective intonation.
Jarvinen-Pasley et al (2008)	21 ASD (DSM-IV, ICD-10): Age: 12.55 (2.50) VIQ: 84 (19.33), NVIQ: 89 (14.44) 21 TD Age: 12.21 (2.15) VIQ: 87 (21.32), NVIQ: 88 (17.92)	Explicit: PEPS-C test: a prosody comprehension and production task including affective prosody.	Explicit : + ASD group performed worse on Affect (Affective intonation) subtest: $t = -2.38, p = .022$
Volden and Sorenson (2009)	32 ASD (DSM-IIIR or DSM IV): age: 10 (2.4) VMA: 7.9, NVMA: 10.6 29 controls age: 8.8 (2.4) VMA: 8.9, NVMA: 10.4 26 controls age: 8.8 (2.4) VMA:8.1, NVMA:8.7	Explicit: Production and perception of "bossy" and polite requests	Explicit: - participants with ASD were as adept as controls in both producing and judging polite ($F(1,85) = .607, n.s.$) and bossy requests ($F(1,85) = 1.46, n.s.$).
Grossman et al (2010)	16 ASD (DSM-IV, ADI-R, ADOS): age: 12;4 (2;3) IQ: 106.7 (10.6) 15 controls age: 12;7 (3;1) IQ: 108.9 (11.3)	Explicit: classifying filtered and unfiltered spoken sentences as neutral, sad or happy	Explicit: - No differences between groups in affective prosody perception task: main effect of group: $F(1,29) = .44, p = .51, \eta_p^2 = .02$, group by task interaction: $F(1,29) = .35, p = .56, \eta_p^2 = .01$, group by emotion interaction: $F(1,29) = 2.3, p = .11, \eta_p^2 = .07$.

Authors	Group characteristics	Stimuli and task	Reported results
Hesling et al (2010)	8 ASD (DSM-IV-R, ADI-R): age: 23.38 (2.1) IQ: 89 (7.9) 8 controls age: 23.05 (2.02) IQ: 128.3 (4.6)	Explicit: PEPS-C test: a prosody comprehension and production task including affective prosody. Implicit: fMRI task: listening to speech stimuli with varying intonation, rhythm, focus and affect prosodic aspects.	Implicit: +, explicit: + ASD subjects were significantly lower on all prosody tasks (p¡0.001); fMRI: ASD group showed differences in brain activation.
Kuchinke et al (2011)	15 AS (DSM, ICD-10): Age: 35.6 (6.9) IQ: normal range 19 controls Age: 34.8 (7) VIQ: different NVIQ: matched	Implicit: Passive listening to sentences spoken with neutral or emotional intonation, pupil size recording. Explicit: subsequent valence rating.	Implicit: +, explicit: + Pupil diameter measurement: In passive listening condition, there was a significant emotion by group interaction ($F(2,64) = 4.634; p < 0.05$). AS group demonstrated increased pupillary response to negative sentences and decreased response to positive sentences, compared to controls. During explicit evaluation, no interaction or main effect involving group was significant. The main effect of emotion was significant ($F(2,64) = 10.236; p < 0.001$, greater pupil dilation in response to emotional sentences). Subjective valence ratings: Lower ratings of positive ($t(1,24) = 5.643; p < 0.001$) as well as negative sentences ($t(1,24) = -2.206; p < 0.05$) sentences in the AS group compared to control group.
Eigsti et al (2012)	16 ASD (DSM-IV, ADI-R, ADOS-G): Age: 13.7 (2.8) IQ: 96.7 (14.9) 11 TD Age: 13.7 (2.6) IQ: 111.9 (10.9)	Implicit: Listening to angry and neutral sentences in an fMRI scanner	Implicit: + (neural activity) fMRI: in TD group compared to ASD, angry sentences elicited more activity in the L IFG and lower activity in the R MFG and R STG.
Production			
Tager-Flusberg (1992)	6 ASD (Rutter 1978, DSM-III-R): age: 3-8 IQ: 61-108 6 Down syndrome (matched on CA and language ability)	Implicit: Analysis of spontaneous speech samples collected over the course of 1-2 years	Implicit: + Children with autism were comparable to the Down syndrome control subjects in their talk about desire, perception and emotion. However, they used significantly less language to call for attention ($t(10) = 4.47, p < .001$) and to refer to psychological states ($t(10) = 1.98, p < .05$)

Authors	Group characteristics	Stimuli and task	Reported results
Capps et al (2000)	13 LFA (DSM-III-R, CARS, ABC) age: 12.6 IQ: 75.2 13 TD controls age: 6.0 (1.6) 13 DD controls age: 9.8 (2.8) IQ: 78.9 (13.1)	Implicit: Telling a story based on a picture book	Implicit: + Compared to TD, ASD and DD children produced shorter stories ($p < 0.05, d = 1.05$), less complex syntax ($p < 0.02, d = 1.04$), more restricted range of evaluative forms ($p < 0.1, d = 1.14$); used causal attribution less often in the references of the emotional state ($p < 0.005, d = 1.44$), but more often to describe physical events ($p = 0.07, d = 0.79$). No difference between ASD and DD groups was found. In ASD, but not in DD group, there were significant correlations between theory of mind performance and narrative qualities ($r(10) = 0.56 - 0.78, p < 0.05$); and conversational competence with syntactic diversity ($r(10) = 0.67, p < 0.05$) and evaluative diversity ($r(10) = 0.75, p < 0.01$).
Adams et al (2002)	19 Asperger syndrome (ICD-10): age: 13.81 (2.6) IQ: 92.53 (22.8, 71-141) 19 conduct disorder age: 14.5 (1.6) IQ: 85.5 (13.2)	Implicit: Two structured conversations based on ADOS: on a social-emotional topic and about a non-routine event.	Implicit: + In social-emotional conversation the AS group showed more response problems ($p < .0005, d = 1.97$); more pragmatic problems ($p < .0005, d = 2.78$); same in the non-routine conversation: for overall response problems $p = 0.006, d = 1.49$; for pragmatic problems $p = 0.008, d = 0.7$.
Pearlman-Avnion and Eviatar (2002)	13 ASD (DSM-IV) Age: 11.54 (8-16) 13 younger TD Age: 7.36 13 older TD Age: 11.5 13 WS Age: 14.39 (8–21)	Implicit: tell a story after a slide show	Implicit: + Affective expression analysis: HFA group performed significantly lower than TD and WS group. Interaction between Group (ASD, Williams syndrome, typical) and task (emotional, informational): $F(3, 48) = 3.85, p < .05$.
Mueller and Schuler (2006)	13 ASD (ADI, ABC): age: 8-11 IQ: 70-140 13 TD controls age: 8-11 IQ: n/a	Implicit: Spontaneous interactions of subjects with family members.	Implicit: + Children with AS and HFA engaged in a higher proportion of affect marking and provided a higher proportion of affective explanations than typically developing children ($p < 0.01, d = 0.68$), yet were less likely to initiate affect marking sequences ($t = -2.75, p < 0.01, d = -0.55$) or talk about the affective responses of others ($t = 1.52, p < 0.05, d = 0.65$). No significant differences in terms of the marking of positive and negative affect.
Losh and Capps (2007)	28 ASD (DSM, ICD-10, ADI-R): age: 11.1 (8-13) IQ: 98 (76-132) 22 TD controls Age: 10.6 (8-12) IQ:108 (102-123)	Implicit: Discourse analysis of personal accounts of emotional and non-emotional events	Implicit: + No difference in describing non-emotional events between the groups. The descriptions of emotional events in ASD children were less contextually appropriate, less elaborate and contained less evaluations of causes, especially for complex emotions (effect sizes $0.81 - 1.52, p < 0.05$) and self-conscious emotions (effect sizes $0.77 - 1.74, p < 0.05$).

Authors	Group characteristics	Stimuli and task	Reported results
Bang et al (2012)	20 HFA (DSM-IV, ADOS-3, SCQ): Age: 11;0 (1;11) PIQ: 106.5 (17) 17 TD Age: 10;10 (1;5) PIQ: 112.5 (14)	Implicit: free conversation with experimenter	Implicit: - No difference between groups in terms of producing emotion and desire terms (ASD group: 3.40 (0–12 words), median 2.5; typical group: on average 3.76 (0–13 words), median 2; Mann–Whitney $U = 181.50, p = 0.72, r = .06$)
Brown et al (2012)	30 ASD (DSM-IV): Age: 6–14 IQ: 107.5 (15.6) 20 TD Age: 8.95 (2.35) IQ: 111.00 (11.53)	Explicit and Implicit: Autobiographical memory interview on 3 topics: 1) earliest memory; 2) positive; and 3) negative memory	Explicit: -, implicit: + No difference in response rate and narrative length between different types of narratives. Usage of internal state terms: Typically-developing children used more emotional terms ($F(1, 126) = 9.11, p < .01, \eta_p^2 = 0.07$).
Siller et al (2014)	21 ASD (ADOS) age: 7.2 (1.5) VIQ: 100.6 (16.3) 24 TD age: 6.8 (1.6) VIQ: 99.4 (10.9)	Implicit: telling a story after a picture book	Implicit: + ASD group produced shorter narratives ($F(1, 40) = 13.6, p < .01$), less references to characters emotions ($F(1, 40) = 13.2, p < .01$) but the same amount of references to cognitive states ($F(1, 40) = 3.4, p = .07(\eta_p^2 > .08)$).

Abbreviations:

ABC - Autism behavior checklist
ADI - Autism diagnostic interview
ADOS - Autism diagnostic observation schedule
AS - Asperger syndrome
ASD - Autism Spectrum Disorder
ASDS - Asperger syndrome diagnostic scale
CARS - Childhood Autism rating scale
CA - chronological age
DD - developmental delay
DS - Down syndrome
LFA - low-functioning autism
MA - mental age
NVMA - nonverbal mental age
NVIQ - nonverbal intelligence quotient
PDD - pervasive developmental disorder
PIQ - performance intelligence quotient
TD - typically developing
VIQ - verbal intelligence quotient
VMA - verbal mental age
WS - Williams syndrome

Appendix B

Words used in Chapter 3

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
positive high frequency	1	avontuur	3	5.15	4.60	4.07	20	8
positive high frequency	2	bevrijding	3	5.76	5.03	4.25	30	10
positive high frequency	3	familie	3	5.88	5.44	6.00	122	7
positive high frequency	4	feest	1	5.96	5.67	5.51	40	5
positive high frequency	5	genot	2	6.23	5.60	3.95	25	5
positive high frequency	6	glimlach	2	6.19	5.56	6.19	76	8
positive high frequency	7	held	1	5.67	4.88	4.82	22	4
positive high frequency	8	ideaal	3	5.53	4.55	3.25	29	6
positive high frequency	9	kleding	2	5.32	4.97	6.08	23	7
positive high frequency	10	kracht	1	5.20	4.63	3.85	149	6
positive high frequency	11	lied	1	5.37	5.12	5.38	20	4
positive high frequency	12	liefde	1	6.53	6.20	4.17	168	6
positive high frequency	13	moed	1	5.59	5.00	3.95	50	4
positive high frequency	14	natuur	2	5.29	4.51	5.02	91	6
positive high frequency	15	opwinding	3	5.06	4.78	4.22	35	9
positive high frequency	16	plezier	2	6.06	5.63	4.41	62	7
positive high frequency	17	reis	1	5.65	5.14	5.10	82	4
positive high frequency	18	schoonheid	2	5.75	4.97	4.17	42	10
positive high frequency	19	trouw	1	5.82	5.48	3.97	26	5
positive high frequency	20	vakantie	3	6.12	5.86	5.58	49	8
positive high frequency	21	voordeel	2	5.45	4.65	4.25	45	8
positive high frequency	22	vrede	2	6.22	5.49	3.75	51	5

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
positive high frequency	23	vreugde	2	6.04	5.56	4.38	41	7
positive high frequency	24	vriend	1	6.26	6.00	5.84	143	6
positive high frequency	25	warmte	2	5.54	4.80	4.73	47	6
positive high frequency	26	wens	1	5.86	5.17	3.80	38	4
positive high frequency	27	wijsheid	2	5.92	4.76	3.92	25	8
positive high frequency	28	winst	1	5.49	4.94	4.90	38	5
positive high frequency	29	zomer	2	6.02	5.53	5.58	68	5
positive high frequency	30	zonlicht	2	5.96	5.35	5.73	23	8
positive low frequency	1	aardigheid	3	6.15	5.22	4.29	3	10
positive low frequency	2	beloning	3	5.73	5.07	4.77	19	8
positive low frequency	3	blijdschap	3	6.04	5.73	4.90	10	10
positive low frequency	4	cadeau	2	6.13	5.43	5.90	13	6
positive low frequency	5	daglicht	2	5.53	5.00	5.57	12	8
positive low frequency	6	durf	1	5.34	4.76	3.71	6	4
positive low frequency	7	eerlijkheid	3	6.02	5.53	4.34	8	11
positive low frequency	8	engel	2	5.32	4.44	3.84	15	5
positive low frequency	9	euforie	3	6.27	5.44	4.00	3	7
positive low frequency	10	gebak	2	5.37	4.55	5.97	4	5
positive low frequency	11	geliefde	3	6.32	6.08	5.36	8	8
positive low frequency	12	goedheid	2	5.83	4.80	3.59	11	8
positive low frequency	13	grap	1	5.47	4.94	4.76	15	4
positive low frequency	14	juichkreet	2	5.73	5.02	5.37	1	10
positive low frequency	15	kerstmis	2	5.58	5.42	5.64	16	8
positive low frequency	16	kus	1	6.28	6.17	6.02	15	3
positive low frequency	17	lof	1	5.76	4.71	3.71	9	3
positive low frequency	18	luxe	2	5.13	4.52	4.38	12	4
positive low frequency	19	melodie	3	5.51	4.90	4.98	8	7
positive low frequency	20	mirakel	3	5.46	4.66	2.84	3	7
positive low frequency	21	passie	2	6.13	5.76	4.15	6	6
positive low frequency	22	pret	1	5.96	5.58	4.80	8	4
positive low frequency	23	regenboog	3	5.57	4.97	5.90	4	9
positive low frequency	24	rustdag	2	5.26	4.74	4.90	1	7
positive low frequency	25	schat	1	5.52	5.00	4.40	19	5

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
positive low frequency	26	sieraad	2	5.41	4.37	5.78	3	7
positive low frequency	27	winnaar	2	5.80	5.10	5.48	3	7
positive low frequency	28	zang	1	5.34	4.86	5.14	6	4
positive low frequency	29	zegen	2	5.29	4.29	3.53	11	5
positive low frequency	30	zoen	1	6.33	5.91	6.15	8	4
neutral high frequency	1	bedrag	2	4.16	3.39	4.75	38	6
neutral high frequency	2	bericht	2	4.14	3.42	4.70	33	7
neutral high frequency	3	buurt	1	4.55	3.53	4.98	105	5
neutral high frequency	4	heilige	3	3.90	3.58	3.28	35	7
neutral high frequency	5	hoeveelheid	3	3.88	2.57	3.41	55	11
neutral high frequency	6	hoogte	2	4.03	3.42	4.27	117	6
neutral high frequency	7	horloge	3	4.53	3.31	6.14	32	7
neutral high frequency	8	inrichting	3	3.83	3.83	4.38	33	10
neutral high frequency	9	kern	1	4.00	2.81	3.59	35	4
neutral high frequency	10	kip	1	4.37	3.40	6.53	19	3
neutral high frequency	11	krant	1	4.36	3.27	5.93	72	5
neutral high frequency	12	leerling	2	4.44	3.42	5.69	27	8
neutral high frequency	13	loop	1	3.90	2.98	3.78	103	4
neutral high frequency	14	maand	1	3.90	2.87	4.87	74	5
neutral high frequency	15	markt	1	4.42	3.47	5.44	61	5
neutral high frequency	16	moeite	2	3.61	4.05	3.80	148	6
neutral high frequency	17	neiging	2	3.65	3.43	2.98	47	7
neutral high frequency	18	onderdeel	3	3.83	2.95	3.60	42	9
neutral high frequency	19	punt	1	4.04	2.78	4.62	124	4
neutral high frequency	20	schaduw	2	3.59	3.39	4.96	53	7
neutral high frequency	21	slag	1	3.55	3.18	3.67	51	4
neutral high frequency	22	sprong	1	4.37	3.51	5.33	30	6
neutral high frequency	23	stap	1	4.12	2.88	4.41	82	4
neutral high frequency	24	stelsel	2	3.82	2.67	3.16	31	7
neutral high frequency	25	stemming	2	4.26	3.76	3.42	40	8
neutral high frequency	26	stroom	1	4.31	3.24	4.65	39	6
neutral high frequency	27	toestel	2	3.92	2.88	4.54	21	7
neutral high frequency	28	verzoek	2	4.18	3.18	3.56	54	7

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
neutral high frequency	29	wagen	2	4.20	3.20	5.49	43	5
neutral high frequency	30	zijde	2	4.45	3.06	4.43	57	5
neutral low frequency	1	aanblik	2	4.10	3.55	3.02	15	7
neutral low frequency	2	adelaar	3	4.05	3.29	5.85	3	7
neutral low frequency	3	ambt	1	3.86	2.97	3.68	11	4
neutral low frequency	4	arbeider	3	3.95	3.10	5.00	13	8
neutral low frequency	5	beambte	3	3.94	2.82	3.73	2	7
neutral low frequency	6	beitel	2	3.57	2.65	5.71	2	6
neutral low frequency	7	bestek	2	4.05	2.75	5.93	9	6
neutral low frequency	8	bewering	3	3.86	3.02	3.07	11	8
neutral low frequency	9	druppel	2	3.88	3.25	5.37	10	7
neutral low frequency	10	gehakt	2	3.98	3.47	5.69	2	6
neutral low frequency	11	hert	1	4.49	3.29	6.06	4	4
neutral low frequency	12	kaneel	2	4.47	3.27	5.75	3	6
neutral low frequency	13	kenmerk	2	4.02	2.85	3.80	18	7
neutral low frequency	14	kier	1	3.84	2.62	4.14	9	4
neutral low frequency	15	kijker	2	4.10	3.12	4.44	13	6
neutral low frequency	16	klei	1	3.94	3.00	5.50	8	4
neutral low frequency	17	kleurstof	2	3.72	2.80	4.33	2	9
neutral low frequency	18	leniging		3.98	3.62	3.52	1	8
neutral low frequency	19	mengsel	2	3.86	2.78	3.78	18	7
neutral low frequency	20	naaister	2	3.88	3.06	5.24	2	8
neutral low frequency	21	notitie	3	4.08	2.86	4.53	5	7
neutral low frequency	22	oefening	3	4.53	3.60	4.45	18	8
neutral low frequency	23	omtrek	2	3.94	2.71	4.12	8	6
neutral low frequency	24	overgave	4	3.93	3.95	3.20	13	8
neutral low frequency	25	paddestoel	3	4.02	3.05	6.05	2	10
neutral low frequency	26	prikkel	2	3.73	3.90	3.27	8	7
neutral low frequency	27	raadsel	2	4.44	3.78	4.24	14	7
neutral low frequency	28	schotel	2	3.90	2.64	4.28	7	7
neutral low frequency	29	vee	1	3.98	3.38	5.58	17	3
neutral low frequency	30	wolk	1	4.44	3.49	5.54	15	4
negative high frequency	1	afscheid	2	2.35	5.14	4.73	49	8

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
negative high frequency	2	angst	1	2.10	5.14	4.16	162	5
negative high frequency	3	armoede	3	1.78	5.13	4.33	21	7
negative high frequency	4	bedreiging	3	1.68	5.25	4.19	19	10
negative high frequency	5	ellende	3	1.64	4.86	4.06	36	7
negative high frequency	6	gevaar	2	2.13	4.98	4.00	98	6
negative high frequency	7	geweer	2	2.10	4.96	5.78	32	6
negative high frequency	8	geweld	2	1.55	5.33	5.15	57	6
negative high frequency	9	haat	1	1.47	5.33	4.07	37	4
negative high frequency	10	hekel	2	2.14	4.88	4.04	19	5
negative high frequency	11	kwaad	1	1.95	5.25	4.37	36	5
negative high frequency	12	leed	1	1.98	4.86	4.06	22	4
negative high frequency	13	lijden	2	1.54	5.35	3.98	33	6
negative high frequency	14	lijk	1	1.43	5.37	5.29	23	4
negative high frequency	15	moord	1	1.33	5.51	5.04	38	5
negative high frequency	16	ongeluk	3	1.84	5.06	4.94	42	7
negative high frequency	17	oorlog	2	1.47	5.53	4.63	184	6
negative high frequency	18	pijn	1	1.85	5.31	4.63	149	4
negative high frequency	19	pistool	2	1.84	4.88	5.86	26	7
negative high frequency	20	ruzie	2	1.68	5.13	4.70	35	5
negative high frequency	21	schade	2	2.22	4.04	5.22	40	6
negative high frequency	22	scheiding	2	1.98	5.00	4.75	36	9
negative high frequency	23	schuld	1	2.14	4.66	3.90	81	6
negative high frequency	24	slachtoffer	3	1.98	4.69	4.64	32	11
negative high frequency	25	strijd	1	2.94	4.29	4.02	119	7
negative high frequency	26	verdriet	2	1.96	5.31	4.75	54	8
negative high frequency	27	verlies	2	2.00	4.76	4.30	36	7
negative high frequency	28	vijand	2	1.82	4.90	4.84	40	6
negative high frequency	29	vrees	1	2.49	4.66	3.66	34	5
negative high frequency	30	ziekte	2	1.47	5.48	4.75	87	6
negative low frequency	1	aanranding	3	1.57	4.98	4.36	1	10
negative low frequency	2	bedrieger	3	1.71	5.02	4.78	3	9
negative low frequency	3	bedrog	2	1.98	4.73	3.73	13	6
negative low frequency	4	beul	1	2.08	4.56	4.80	5	4

Condition	N	Word	Syl	Val	Aro	Con	FreqMln	Len
negative low frequency	5	bom	1	1.58	5.11	5.46	12	3
negative low frequency	6	dief	1	1.68	4.68	5.51	8	4
negative low frequency	7	gevecht	2	2.12	4.80	5.12	18	7
negative low frequency	8	gezwel	2	1.83	4.76	4.71	4	6
negative low frequency	9	gif	1	1.82	4.49	4.98	5	3
negative low frequency	10	graf	1	1.96	4.82	5.73	29	4
negative low frequency	11	indringer	3	1.95	4.72	4.85	3	9
negative low frequency	12	jaloersheid	3	2.26	5.08	4.32	2	11
negative low frequency	13	kakkerlak	3	1.67	4.97	5.80	1	9
negative low frequency	14	kanker	2	1.27	5.75	5.10	18	6
negative low frequency	15	kwaal	1	2.07	4.58	3.40	9	5
negative low frequency	16	leugen	2	2.02	5.23	4.20	13	6
negative low frequency	17	misbruik	2	1.56	5.29	4.19	13	8
negative low frequency	18	misdaad	2	1.80	5.17	4.72	16	7
negative low frequency	19	ongeval	3	1.78	5.03	4.65	6	7
negative low frequency	20	overlijden	4	1.44	5.75	5.60	9	10
negative low frequency	21	rouw	1	1.96	4.80	4.24	6	4
negative low frequency	22	schurk	1	2.10	4.56	4.82	5	6
negative low frequency	23	slaaf	1	1.57	4.96	4.96	16	5
negative low frequency	24	slachting	2	1.57	4.68	4.50	2	9
negative low frequency	25	spijt	1	2.83	5.13	3.78	13	5
negative low frequency	26	stank	1	1.96	4.54	5.51	16	5
negative low frequency	27	traan	1	2.78	4.69	5.63	4	5
negative low frequency	28	verminking	3	1.44	5.82	4.98	1	10
negative low frequency	29	verraad	2	2.08	4.90	3.98	13	7
negative low frequency	30	verrader	3	1.67	5.12	4.37	5	8

Appendix C

Additional analysis for Chapter 4

Covariance analysis with verbal IQ as a covariate

Affective priming

In a previous study, we found a significant association between verbal IQ and emotion facilitation effect in the ASD group (Lartseva et al. 2014). Therefore, in the current study we also tested the effects of verbal IQ. When verbal IQ was added as a covariate, the interaction between VIQ and group was significant (raw data: $F(1, 52) = 8.39, p = .006$; log data: $F(1, 52) = 9.74, p = .003$), as was the Group by Congruency by VIQ interaction (raw: $F(1, 52) = 8.50, p = .005$; log: $F(1, 52) = 4.67, p = .035$). This means that verbal IQ had a different impact in ASD and typical group, making covariate analysis inappropriate. To further investigate the effect of verbal IQ, we calculated correlations between VIQ and the magnitude of priming effect (RT difference for the same target words in congruent and incongruent condition) for positive and negative target words in ASD and typical group.

In the typical group, the correlation between VIQ and priming effect did not reach significance for either positive (raw: r=.34, p=.043; log: r=.18, p=.29) or negative words (raw: r=.23, p=.19; log: r=.21, p=.22). In the ASD group, the correlation between VIQ and priming effect also did not reach significance for either positive (raw: r=-.29, p=.2; log: r=-.40, p=.07) or negative (raw: r=-.42, p=.06; log: r=-.19, p=.4) words. The trend was in the positive direction in the typical group (higher VIQ led to greater affective priming) and in the negative direction in the ASD group (lower verbal IQ led to greater affective priming), and this difference most probably gave rise to the significant interaction between Group and VIQ.

Semantic priming

When verbal IQ was added as a covariate, the main effects of Emotion and Relatedness were not significant anymore. The interaction between VIQ and Group was significant (in Raw data: $F(1, 52) = 8.50, p = .005$; in Log data: $F(1, 52) = 10.08, p = .003$), as was the Emotion * Relatedness * Group * VIQ interaction (in Raw data: $F(1, 52) = 8.21, p = .006$, log data: $F(1, 52) = 3.91, p = .053$). This means that the contribution of the verbal IQ to the semantic priming effect was different for the ASD and typical group, making a covariate analysis inappropriate. To explore the effect of VIQ further, we conducted the analysis in each group separately.

We calculated correlations between the semantic priming effect (difference between response time for the same target words in semantically related and unrelated condition) and verbal IQ of the participants. In the typical group, verbal IQ was not associated with the semantic priming effect for positive words (raw data: $r = -.01, p = .96$; log data: $r = -.01, p = .96$) or for negative words (raw: $r = .26, p = .13$; log: $r = .22, p = .19$). However, in the ASD group, there was a significant correlation with verbal IQ for emotionally positive words: The size of semantic priming effect was significantly inversely correlated with VIQ (raw: $r = -.56, p = .009$; log: $r = -.50, p = .022$). In other words, participants with lower VIQ were significantly speeded up by a semantically related prime, but participants with high VIQ showed a much smaller effect size. For emotionally negative words, there was no correlation between priming effect size and VIQ (raw: $r = .37, p = .10$, log: $r = .35, p = .12$).

EEG results for emotionally positive and negative words separately

Repeated measures ANOVA for emotionally positive words with Group (ASD, typical) as between-subject factor, and Congruency (congruent, incongruent), Location-LR (left, mid-line, right), and Location-AP (anterior, central, posterior) as within-subjects factor.

Effect	N400	time	window	
Both groups	F (df)	p	F (df)	p
Congruency	.79 (1,55)	.38	3.52 (1,55)	.066
Congruency*LR*	.45 (2,110)	.63	1.23 (2,110)	.29
Congruency*AP	1.07 (2,110)	.31	.08 (2,110)	.85
Congruency*LR*AP	1.75 (4,220)	.16	1.99 (4,220)	.14
Group*Congruency	1.32 (1,55)	.26	.02 (1,55)	.90
Group*Congruency*LR	.62 (2,110)	.53	.09 (2,110)	.90
Group*Congruency*AP	2.40 (2,110)	.12	3.13 (2,110)	.069
Group*Congruency*LR*AP	2.53 (4,220)	.067	.08 (4,220)	.93

TABLE C.1: ERP results, affective priming condition, emotionally positive words.

Repeated measures ANOVA for emotionally negative words with Group (ASD, typical) as between-subject factor, and Congruency (congruent, incongruent), Location-LR (left, midline, right), and Location-AP (anterior, central, posterior) as within-subjects factor.

Effect	N400	time	window	
Both groups	F (df)	p	F (df)	p
Congruency	6.02 (1,55)	.017*	9.94 (1,55)	.003*
Congruency*LR	.63 (2,110)	.51	6.76 (2,110)	.002*
Congruency*AP	.06 (2,110)	.83	.93 (2,110)	.35
Congruency*LR*AP	.3 (4,220)	.80	5.81 (4,220)	.002*
Group*Congruency	1.84 (1,55)	.18	1.87 (1,55)	.18
Group*Congruency*LR	.14 (2,110)	.84	.74 (2,110)	.48
Group*Congruency*AP	.08 (2,110)	.81	3.23 (2,110)	.07
Group*Congruency*LR*AP	.26 (4,220)	.83	.51 (4,220)	.64

TABLE C.2: ERP results, affective priming condition, emotionally negative words.

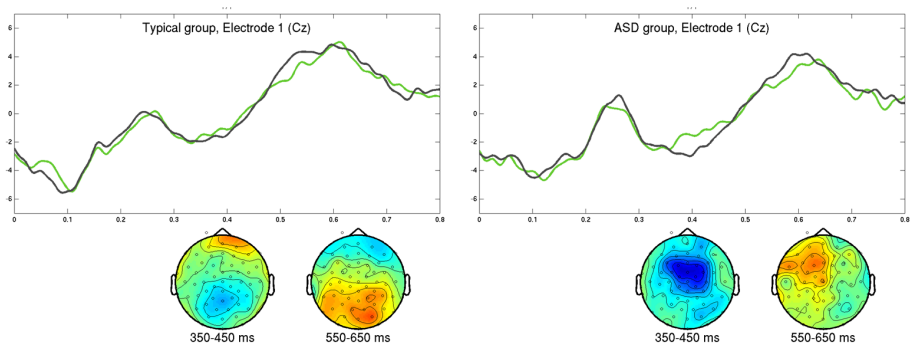

FIGURE C.1: Affective priming effect for positive target words in ASD group (right) and control group (left). Green line: targets preceded by emotionally congruent prime; gray line: targets preceded by incongruent prime.

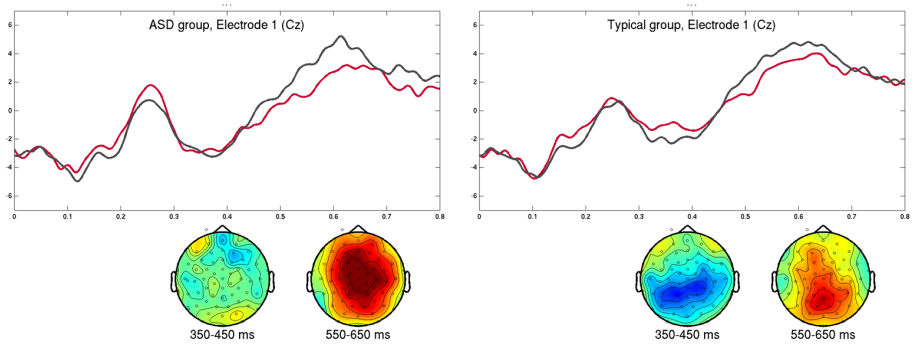

FIGURE C.2: Affective priming effect for negative target words in ASD group (left) and control group (right). Red line: targets preceded by emotionally congruent prime; gray line: targets preceded by incongruent prime.

Appendix D

Sentences used in Chapter 5

N	Sentence	Critical words
1	Jaap opende de envelop die net was bezorgd. Het ging om een ... die hij verwachtte.	felicitatie / advertentie / geldboete
2	Er was een oud park met een beeldentuin vlakbij het stadscentrum. Het park was ... en had een vijver.	zonnig / omheind / vervuild
3	Pieter kreeg een telefoontje van zijn vrouw.Hij reageerde ... toen hij het nieuws hoorde.	verheugd / rustig / geschokt
4	Lotte kreeg onlangs een andere betrekking. Ze vond haar nieuwe werk ... door de gewijzigde taken.	uitdagend / ongewoon / vreselijk
5	De oude mentor van de klas ging met verlof. De nieuwe mentor was ... zoals de leerlingen al hadden gehoord.	knap / Engels / lastig
6	De lezing werd gegeven door een oude professor. Deze lezing was ... volgens alle aanwezigen.	interessant / theoretisch / saai
7	Anne was onlangs overgeplaatst naar een nieuwe school. Van de leerlingen in de opleiding was zij de ... van allemaal.	liefste / kalmste / domste
8	Lize en Tom hadden een belangrijke beslissing te nemen. Ze besloten om te ... in de lente van het komende jaar.	trouwen / verhuizen / scheiden
9	Anouk sliep deze morgen niet uit. Ze was ... vanwege alle gebeurtenissen.	verheugd / alert / onrustig
10	Veel straten in het centrum waren afgesloten. Er was een ... midden in het stadje.	feest / bouwplaats / opstand
11	Leanne ging naar de woonkamer. Ze hoorde haar dochter ... toen ze langs haar kamer liep.	lachen / opruimen / huilen
12	Geleidelijk leerde Alex meer over het bedrijf. Zijn baas was een ... in de ware zin van het woord.	genie / stedeling / crimineel

N	Sentence	Critical words
13	Omwonenden spraken veel over de gebeurtenissen in de familie van Johannes. Wat zijn broer deed was ... in de ogen van anderen.	nobel / vereist / verkeerd
14	Jolijn moest vroeg in de ochtend vertrekken. Ze moest naar een ... in een nabijgelegen stad.	feestje / afspraak / begrafenis
15	In de buurt opende een nieuw restaurant zijn deuren. Het eten daar was ... klaargemaakt.	heerlijk / traditioneel / slecht
16	Michael hoorde een zacht geluid en draaide zich om. Achter de deur zag hij een ... liggen.	cadeau / takje / slang
17	De uitgeverij ontving het manuscript van een beginnende schrijver. Het boek werd ... door de uitgever.	goedgekeurd / gelezen / afgekeurd
18	Op de middelbare school was Tim een beetje lui. Hij veranderde in een ... student op de hogeschool.	uitstekende / doorsnee / achterlijke
19	Marijn studeerde op dezelfde hogeschool als Geert. Hij was Geerts ... gedurende vele jaren.	vriend / huisgenoot / rivaal
20	Ruud werkte jarenlang op hetzelfde kantoor. Hij werd ... vanwege zijn karakter.	aangenomen / geacht / gemeden
21	Joep was voor de eerste keer in Marijke's kamer. Marijke's kamer was ... met veel antieke meubelstukken.	fraai / ingericht / vies
22	Na zijn afstuderen kreeg Pieter veel nieuwe vrienden. Zijn vrienden waren ... zoals hij al snel ontdekte.	betrouwbaar / getrouwd / verslaafden
23	Vandaag kwam Jana laat thuis. Toen ze binnen kwam, kon iedereen haar ... zien.	blijheid / kapsel / boosheid
24	Annemijn had vanmorgen een gesprek met haar arts. Haar ... werd definitief vastgesteld.	genezing / conditie / leukemie
25	Bianca's moeder kwam plotseling haar kamer in. Bianca probeerde hard om haar ... snel te verbergen.	verrassingskado / notities / wanhoop
26	Koens gedrag werd vaak door de buren besproken. Het was zijn ... waar iedereen nieuwsgierig naar was.	optimisme / houding / zelfmoord
27	Timo had lange tijd met zijn familie doorgebracht. Hij had veel ... voor zijn neef.	sympathie / nieuws / angst
28	Na zijn dienstreis ging Jonas direct naar huis. Hij gaf zijn vrouw een ... toen hij binnen kwam.	zoen / boekentas / klap
29	Renate heeft een belangrijke beslissing genomen. Ze wil vandaag Ben over haar ... vertellen.	liefde / keuze / ziekte
30	Robert zat al vele jaren in de politiek. Na de verkiezingen werd hij als ... in de krant beschreven.	winnaar / democraat / verrader

N	Sentence	Critical words
31	Christine was de hele dag buiten. Die avond vond ze een ... naast haar bed.	cadeau / sleutel / kakkerlak
32	Laura kende Mark al vele jaren. Mark was haar ... vanaf het begin.	geliefde / buurman / vijand
33	De notaris vroeg Charlotte langs te komen voor een gesprek. Charlotte's ouders hadden haar een ... nagelaten.	fortuin / dagboek / schuld
34	Reinier had een plan voor een productielijn. Zijn voorstel werd ... door de commissie.	aanvaard / overwogen / afgewezen
35	Na de examenweek ontving Markus een brief. Hij kreeg een ... van de docent.	prijs / opdracht / straf
36	Simone's chef vertelde dat hij een andere baan had. Simone bevond zich daardoor in een ... situatie wat haar werk betrof.	gunstige / veranderde / wanhopige
37	Henk hield contact met zijn klasgenoten. In de loop van de tijd zijn ze ... geworden.	vriendelijk / volwassen / vijandig
38	Tineke's moeder heeft veel huisdieren. Zo heeft ze een ... kater in haar tuin.	leuke / bruine / agressieve
39	Tijdens de lunch begon Martin een discussie. Iedereen vond dat hij daarbij een ... opmerking maakte.	grappige / gepaste / schandelijke
40	Johan begon onlangs bij een nieuw bedrijf. Aan het eind van de maand werd Johans werk ... door zijn baas.	geprezen / bekeken / gehekeld
41	Agnes had een drukke dag. Ze moest haar vriendin naar een ... brengen.	bruiloft / winkel / ziekenhuis
42	Isabelle presenteerde een nieuw project. Haar collega's hebben daarna veel ... opmerkingen over haar gegeven.	vleiende / doordachte / bijtende
43	Jeannette werd hoofd van de afdeling. Ze kreeg tot haar verbazing al direct ... van haar collega's.	complimenten / adviezen / klachten
44	Mona woonde in een rustige straat. Op woensdagochtend hoorde ze een ... in de verte.	nachtegaal / wekker / schot
45	Na de lezing kwam Wim naar Corry. Hij gaf haar een ... en nam afscheid.	liefdesbrief / leerboek / berisping
46	Suzanne's zoon was een lange tijd weg. Suzanne wilde hem ... toen ze hem eindelijk weer zag.	omhelzen / ondervragen / slaan
47	Sybrine is avontuurlijk. Ze had een ... tijdens haar laatste reis.	romance / gids / ongeval
48	Mariëlle boekte voor het eerst in jaren een vliegvakantie. De reis bleek ... te zijn.	aangenaam / langdurig / vervelend
49	Er staat een kasteel op de top van de berg. De bergweg is ... tijdens het laatste stuk.	prachtig / bochtig / gevaarlijk

N	Sentence	Critical words
50	Na de toespraak van Daniël was er een discussie. Bijna iedereen was van zijn ... overtuigd.	oprechtheid / koppigheid / bedrog
51	Na een lange tijd zag Jelle zijn grootmoeder. Hij voelde zich ... na haar bezoek.	blij / ambivalent / schuldig
52	Jonathan maakte veel mee in zijn jeugd. Op de middelbare school was Jonathan heel ... geworden.	populair / rustig / ziek
53	Esther opende haar kast. Ze zag dat er ineens een ... in zat.	bonbondoos / envelop / kakkerlak
54	Aletta heeft samen met haar vriend een huis gehuurd. Aletta's ouders hebben haar ... toen ze daarover hoorden.	gefeliciteerd / opgebeld / beledigd
55	Dirks vriend vroeg hem om hulp tijdens de verhuizing. Dirk vond het ... om te helpen.	geweldig / normaal / vreselijk
56	Joep haastte zich naar huis. Hij wilde zijn zoon een ... geven voor zijn gedrag.	geschenk / verklaring / straf
57	Tanja was een eerstejaars studente. Ze heeft haar examen ... na een hele nacht studeren.	gehaald / geschreven / gemist
58	Op vrijdagavond ging Hans naar een casino. Hij voelde zich ... toen hij het casino verliet.	gelukkig / slaperig / ellendig
59	Merel dacht vaak aan haar jeugd. Ze realiseerde zich dat haar moeder haar ... tijdens haar tienerjaren.	bewonderde / bewaakte / afwees
60	Stijn is een amateur-hardloper. Vorig jaar hield hij een ... over aan een reeks van wedstrijden.	medaille / leerervaring / letsel
61	Nadine wandelde langs de zee. Plotseling zag ze een ... in het zand liggen.	parel / sandaal / lijk
62	Sander en Nicole reisden door een kleine stad. Ze brachten een nacht door in een ... herberg vlak bij een rivier.	mooie / houten / vieze
63	Julius was een veteraan. Als hij over de duinen keek, dacht hij aan een ... van vele jaren geleden.	liefde / gebeurtenis / invasie
64	Erik was zeer ijverig in zijn werk. Hij had deze maand zijn stagiaire ... zonder opgaaf van reden.	gepromoveerd / aangesproken / ontslagen
65	Wiebe keerde terug naar huis. Ineens zag hij dat een ... hem volgde.	hondje / buurvrouw / moordenaar
66	Jan en Elly waren collega's. Jan liep Elly's kantoor binnen en ... haar.	prees / begroette / sloeg
67	Wouter maakte een late wandeling. Een paar omstanders keken hem ... aan tijdens zijn wandeling in het park.	vriendelijk / verbaasd / grimmig
68	Doriens favoriete plek was een meer met vele zwanen. Door het hete weer ... de vogels er vaak.	speelden / doken / stierven

N	Sentence	Critical words
69	Alle buren kwamen bij elkaar om buiten te eten. De eerste barbecue van het seizoen was een ... avond volgens de aanwezigen.	gezellige / drukke / ongezellige
70	Jan werkt in een chemische fabriek. De technologie daar is zeer ... van aard.	veilig / gewoon / schadelijk
71	Lars leerde hoe de nieuwe stereoinstallatie werkte. Hij kwam erachter dat deze door ... was gemaakt.	liefhebbers / Koreanen / prutsers
72	Robert had een bijbaantje. Hij handelde in ... prachtige spullen.	prachtige / tweedehandse / illegale
73	Jacob kwam bij de psychotherapeut. Na een half uur voelde hij zich ... door al het gepraat.	begrepen / slaperig / raar
74	Niemand twijfelde over Mary's toekomst. Ze was al een ... voordat ze twintig was.	manager / echtgenote / prostituee
75	Yvette had de weg in die grote stad niet kunnen vinden. De man met de hoed op had haar ... in het steegje.	geholpen / epasseerd / aangevallen
76	Victor had net zijn vijftiende verjaardag gevierd. Hij was een hele ... jongen.	sympathieke / gewone / gemene
77	Noud kwam een week te laat met de gegevens. Zijn baas was ... toen hij die afleverde.	blij / afwezig / woedend
78	Diederik had het heel druk. Deze week moest hij naar een ... vergadering in plaats van zijn baas.	interessante / geplande / vervelende
79	Mira is moeder van een vijfjarige dochter. Toen die haar 's nachts riep, kwam Mira haar ... in haar kamer.	voorlezen / opzoeken / opsluiten
80	Judiths ouders gingen verhuizen. Hierdoor was ze bijzonder ... over haar toekomst.	hoopvol / nadenkend / verdrietig
81	Lenny was dol op muziek. Ze werd door velen beschouwd als een ... muzikant op de gitaar.	formidabele / beginnende / vreselijke
82	Jens was nog nooit eerder in Parijs geweest. Na een uurtje lopen voelde hij zich ... in deze stad.	thuis / hongerig / verloren
83	Met Kerstmis kwam de hele familie bij elkaar. Tijdens het kerstdiner heerste er een ... stilte aan tafel.	prettige / duidelijke / lastige
84	Toen Petra klein was, had ze een wilde fantasie. Ze geloofde dat er ... onder haar bed woonden.	feeën / autootjes / monsters
85	Markus bleef sporten ondanks zijn persoonlijke omstandigheden. De trainer vond hem ... in alles wat hij deed.	uitstekend / acceptabel / onbekwaam
86	Dat komt voor in de gezondheidszorg. Het ziekenhuis is met behoorlijk ... materiaal ingericht.	modern / duur / ouderwets

N	Sentence	Critical words
87	Boudewijn's begeleider gaf hem een boek. Boudewijn ... het bijna direct.	las / herkende / verloor
88	Joep's huis had een tuintje. Deze tuin stond al vol met ... sinds hij er woonde.	bloemen / tegels / afval
89	Lex werd uitgenodigd om een toespraak te geven. Midden in de lezing kreeg hij een ... uit de zaal.	applaus / verzoek / belediging
90	Max was op weg naar het postkantoor. Hij was van plan een ... aan zijn vriendin te sturen.	gedicht / bericht / dreiging
91	Bart was een bekende persoon in de wijk. Zijn ... was torenhoog.	inkomen / appelboom / schuld
92	Monika bezat een bijzondere vaas in Griekse stijl. Enige tijd geleden was deze ... door bekenden.	geschonken / opgemerkt / gestolen
93	Laurens had genoten van een lange wandeling door de hei. Hij had daardoor behoorlijk wat ... gekregen.	inspiratie / dorst / verwondingen
94	Oma Maartje kwam van haar werk terug. Ze zag dat haar kinderen het appartement ... hadden achtergelaten.	netjes / afgesloten / ongeregeld
95	Er was een nieuwsbericht over het lokale museum. Een zeldzaam werk uit de kubistische fase was ... vorige week.	gedoneerd / getoond / gejat
96	Boudewijn was recentelijk afgestudeerd. Na zijn studie werkte hij als een ... samen met zijn vriend.	bedrijfsleider / verkoper / drugsdealer
97	De hele familie was bij de buren op visite. De kinderen waren ... met elkaar bezig.	lief / buitenshuis / vechtend
98	Mark had recentelijk zijn jubileum gevierd. De felicitaties die hij ontving waren ... geformuleerd.	schitterend / beknopt / achteloos
99	Nienke ging de kamer in en zag haar huisdier. De kat lag te ... op de bank.	spinnen / slapen / kotsen
100	Pim lag lange tijd in het ziekenhuis. Gedurende die tijd in bed had hij veel ... gekregen.	inspiratie / drinken / zweren
101	Sander en zijn alpinistenteam gingen naar het gebergte. Hij brak een ... tijdens het klimmen.	wereldrecord / ijspegel / been
102	De lokale overheid besprak het lot van de oerbossen. Ze besloten de oerbossen te ... in de komende jaren.	beschermen / omheinen / vernietigen
103	Pim en Robert waren bedrijfspartners. Tijdens de moeilijkere tijden heeft Robert het geld ... dat het bedrijf nodig had.	verzameld / bewaard / gestolen
104	Iris en Jakob zijn net getrouwd. Hun huwelijksreis was de ... vakantie die ze ooit hebben gehad.	beste / langste / ergste
105	Lennart begon te studeren aan de universiteit. Hij vond de nieuwe cursussen ... om te volgen.	fascinerend / belangrijk / vervelend

N	Sentence	Critical words
106	Martins bedrijf had enige moeilijkheden tijdens de economische crisis. Hij werd ... door zijn oude zakenpartner.	gered / geadviseerd / verraden
107	Lotte zit op de middelbare school. Voor een belangrijke test heeft ze een ... cijfer gekregen.	uitstekend / gemiddeld / laag
108	Kees heeft het hele jaar hard gewerkt. Hij had wel een weekend in een ... doorgebracht.	vakantieoord / dorp / ziekenhuis
109	Aart was een politieambtenaar. Vorige week werd hij ... als gevolg van veranderingen in het personeelsbeleid.	bevorderd / verplaatst / ontslagen
110	Laura had haar vriend voor de eerste keer in enkele jaren gezien. Haar vriend zag er ... uit, meer dan Laura had verwacht.	prachtig / ouder / uitgeput
111	Vorig jaar had Dietrich zijn spaargeld op de bank gezet. Dit jaar had hij zijn spaargeld ... op een effectenbeurs.	verdubbeld / geïnvesteerd / verloren
112	Lienekes gezin ging verhuizen naar een andere stad. Lieneke was ... om te verhuizen.	enthousiast / bereid / bang
113	Jolien is onlangs gehuwd. Haar man is een ..., volgens haar buren.	miljonair / bestuurder / alcoholist
114	Joliens vrienden praatten vaak over haar gezin. Ze dachten dat haar man ... tegenover haar was.	attent / schuchter / oneerlijk
115	Anne's klasgenoten nodigden haar uit voor een film. Anne vond het ... om met ze naar de film te gaan.	gezellig / normaal / vervelend
116	Robert ging naar zijn kamer om naar muziek te luisteren. Hij luisterde altijd naar muziek wanneer hij ... was.	blij / vrij / angstig
117	Linda stond op om haar kamer op te ruimen. Opruimen maakte haar altijd ..., vond ze.	vredig / slaperig / geërgerd
118	Karin moest haar project spoedig af maken. Ze voelde zich ... wanneer ze daar aan dacht.	geïnspireerd / kalm / wanhopig
119	Albert is een grote fan van sporten. Hij heeft een plaatselijke hardloopwedstrijd ... dit jaar.	gewonnen / gekeken / verloren
120	Maria wilde de examencijfers zien. Ze was ... toen ze de resultaten zag.	blij / nadenkend / verdrietig

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Nederlandse samenvatting

Definitie van de Autisme Spectrum Stoornis

Autisme Spectrum Stoornis (ASS) is een ontwikkelingsstoornis die begint in de vroege kinderjaren en het hele leven blijft bestaan. Het concept "autisme" werd voor het eerst voorgesteld door Kanner in 1943. Kanner publiceerde in dat jaar een beschrijving van een aantal patiënten die een aantal gemeenschappelijke gedragssymptomen hadden: ze waren emotioneel koud en afstandelijk, vermeden elke vorm van sociale interactie en waren geobsedeerd door één specifieke activiteit, zoals het in een bepaalde volgorde neerleggen van speelgoed, in de rondte draaien of in hun handen klappen.

Voordat Kanner's artikel verscheen werden zulke kinderen vaak gezien als verstandelijk gehandicapten. Maar daarna werd de stoornis steeds vaker herkend als autisme en werd het duidelijk dat kinderen met autisme ook een normale of zelfs een hoge intelligentie kunnen hebben. Gedurende lange tijd dacht men in de tweede helft van twintigste eeuw dat autisme een zeldzame stoornis was. Maar geleidelijkaan veranderde de mening daarover toen psychiaters leerden om autisme beter te onderscheiden van verstandelijke handicaps en taalstoornissen. Ze leerden ook beter om subtiele en milde vormen van autisme te diagnosticeren bij mensen met een normale intelligentie die voorheen niet gediagnosticeerd werden. In lijn met deze ontwikkeling wordt de diagnose "autisme" steeds frequenter gebruikt. Autisme (ASS) wordt tegenwoordig gediagnosticeerd aan de hand van de criteria van de DSM (Diagnostic and Statistical Manual of mental disorders). Volgens de meest recente versie van deze DSM wordt de diagnose ASS toegekend op grond van twee groepen symptomen: langdurige problemen in sociale communicatie en interactie, en zeer specifieke interesses en zich herhalende patronen van gedrag.

Emoties in de Autisme Spectrum Stoornis

In de lijst van symptomen van autisme in de DSM staan ook emotionele problemen vermeld, zoals een gebrek aan emotionele wederkerigheid en aan de behoefte om emoties en plezier te delen. Een aantal studies heeft laten zien dat mensen met ASS problemen hebben bij het herkennen van en reageren op emoties van andere mensen, en ook bij het herkennen van gezichtsuitdrukkingen die bij bepaalde emoties horen.

Als men emoties in een sociale context onderzoekt, is het moeilijk om te bepalen of de problemen emotioneel of sociaal van aard zijn. Misschien werkt de emotieverwerking bij mensen met autisme net zoals bij mensen zonder ASS (oftewel "neurotypische" mensen) en zijn de problemen met gezichtsuitdrukkingen en sociale scenes een gevolg van een geringere interesse in zulke stimuli (mogelijk gepaard aan minder ervaring daarmee). Verder vonden enkele studies geen verschil tussen mensen met en zonder ASS in termen van emotieherkenning, zelfs als er sprake was van moeilijkere taken. Een eerste mogelijke verklaring voor deze tegenstrijdige resultaten is dat de problemen in emotieverwerking van emoties het gevolg zijn van minder ontwikkelde sociale vaardigheden; hoog-functionerende mensen met ASS die betere sociale vaardigheden zouden dan ook minder problemen vertonen met de verwerking van emotionele stimuli . Een tweede mogelijke verklaring is dat mensen met ASS een aangeleerde strategie gebruiken om bijv. foto's van verschillende emoties correct te benoemen. Om te bepalen of problemen rond emotieverwerking (deels) het gevolg zijn van sociale problemen is het noodzakelijk om emotieverwerking van meerdere kanten te bestuderen, bijvoorbeeld door in onderzoek uiteenlopende taken en verschillende soorten stimuli toe te passen.

Eerder onderzoek heeft al een begin gemaakt met de studie naar de autistische verwerking van gezichten, maar ook van woorden en afbeeldingen. Zo is bijvoorbeeld gevonden dat mensen met ASS emotionele informatie op een andere manier onthouden dan andere mensen. In algemeen onthouden mensen emotionele woorden en afbeeldingen beter en langer dan niet-emotionele, maar bij mensen met ASS is er minder verschil tussen het onthouden van emotionele en niet-emotionele stimuli. Een mogelijke verklaring is dat voor mensen zonder autisme emotionele stimuli meer saillant zijn en daardoor beter in het geheugen liggen opgeslagen, terwijl dat bij mensen met ASS wellicht niet zo is.

In andere studies was het object van studie de aandacht voor emotionele stimuli. Deelnemers keken naar het midden van een computerscherm waar snel het een na andere woord verscheen. In de woordenreeks bevonden zich af en toe woorden in een andere lettertype, en de proefpersoon moest elk woord in dat andere lettertype hardop benoemen. Wanneer twee van zulke woorden snel na elkaar verschijnen, missen mensen vaak het tweede woord. Dit effect wordt Attentional Blink (dat betekent zoiets als: 'aandachtsknipper') genoemd. Het effect werkt niet of veel minder bij emotionele woorden: die vallen zo erg op, dat mensen deze woorden zelfs opmerken als ze kort tevoren met een eerder doelwoord bezig waren.

Uit onderzoek met mensen met ASS blijkt dat zij deze emotionele woorden net zo vaak missen als niet-emotionele woorden. Dit resultaat ondersteunt de hypothese dat emotionele informatie door mensen met ASS op een andere manier wordt verwerkt.
Samengevat bestaat er dus bewijs dat mensen met ASS emotionele stimuli op een andere wijze verwerken dan andere mensen, niet alleen in sociale situaties, maar ook buiten een sociale context. Toch er is niet genoeg onderzoek gedaan om definitieve conclusies te trekken. Verder is niet duidelijk wat er precies gebeurt in de hersenen als informatie inderdaad anders verwerkt wordt. Om op deze vragen een antwoord te geven, wordt in dit proefschrift de verwerking van emotionele woorden bij mensen met ASS nader onderzocht.

Taalgebruik en de Autisme Spectrum Stoornis

Taalproblemen vormen geen diagnostisch criterium voor ASS, maar verschillende soorten taalstoornissen komen vaak voor bij ASS. In zeldzame gevallen gebruiken mensen met ASS helemaal geen taal , maar zelfs hoog functionerende mensen met ASS hebben vaak problemen om ironische en figuurlijke taal te begrijpen. In onderzoek naar taalverwerking moet men er daarom zeker van zijn dat er geen verschillen bestaan tussen het gemiddelde taalniveau van de ASS groep en van de neurotypische groep.

Doel van dit proefschrift

Wij weten lang niet genoeg over hoe mensen met ASS emotioneel positieve en negatieve woorden verwerken in vergelijking met neutrale woorden. Wat gedragseffecten betreft bestaan slechts enkele studies. Wat hersenactiviteit betreft hebben enkele studies met fMRI gevonden dat mensen met ASS andere hersengebieden aanspreken bij de verwerking van emotionele woorden. De onderzoekers menen dat mensen met ASS moeite hebben met de verwerking van emoties, en extra hersengebieden activeren om daarvoor te compenseren. Maar er is tot nu toe geen onderzoek voorhanden naar de temporele aspecten van de hersenactiviteit bij de verwerking van emotionele taal. Zo is niet bekend of mensen met ASS de emotionele betekenis van een woord later opmerken (in dat geval zou het effect later beginnen), of langere tijd nodig hebben om deze te verwerken (in dat geval zou het effect langer duren). Het is ook niet duidelijk in welke opzichten de verwerking van emotionele betekenis en andere aspecten van woorden verschillen.

Het doel van dit proefschrift is om onze kennis van emotieverwerking in ASS uit te breiden. Wij hebben ons op de volgende onderzoeksvragen gericht:

1. Hoe verwerken mensen met ASS emotionele woorden in een taak waarbij ze niet uitdrukkelijk op de emotionele betekenis hoeven te letten? Wat gebeurt er in hun hersenactiviteit? Zijn er ook eventuele verschillen te zien voor andere woordkenmerken, zoals de gebruiksfrequentie van een woord?
2. Hoe verwerken mensen met ASS emotiewoorden in een taak waarbij ze uitdrukkelijk woorden moeten classificeren als emotioneel positief en negatief?
3. Zijn er ook verschillen in verwerking van emotiewoorden indien mensen deze woorden midden in de zin te lezen krijgen?
4. Zijn er verschillen in emotieverwerking tussen eerstegraadsverwanten van mensen met ASS en mensen zonder ASS in de familie?

Resultaten

In **Hoofdstuk 2** heb ik de literatuur over emotieverwerking in ASS systematisch besproken en samengevat. Vorige studies toonden aan dat mensen met ASS moeite hebben met de herkenning van emoties in gezichtsafbeeldingen. Op grond van de verzamelde data kom ik in dit hoofdstuk tot de conclusie dat een atypische verwerking van emoties in ASS ook te zien is in de taalverwerking. Deze bevinding spreekt voor het bestaan van een algemene probleem met emotieverwerking in ASS. Maar door het kleine aantal beschikbare onderzoeken kunnen we nog niet definitief een conclusie trekken over de strekking en onderliggende mechanismes van deze problemen. Indien er inderdaad een algemene stoornis bestaat in emotieverwerking, heeft dat gevolgen voor de huidige theorieën van ASS die zich vooral richten op sociale interactie en minder op emotie.

In de volgende hoofdstukken heb ik onderzoek gedaan naar de verwerking van verschillende aspekten van emotiewoorden. In **Hoofdstuk 3** heb ik de verwerking van emotiewoorden onderzocht met behulp van reactietijden en hersenactiviteit (gemeten in een elektroencephalogram of EEG). De deelnemers zagen woorden en letterreeksen op een computerscherm verschijnen en moesten zo snel mogelijk beslissen of ze een bestaande Nederlandse woord zagen of een willekeurige letterreeks. Ik vond dat proefpersonen met en zonder ASS allemaal tot een snellere beslissing kwamen bij emotionele woorden dan bij neutrale woorden. Dat betekent dat bij beide groepen de emotiewoorden meer opvielen en sneller verwerkt werden

dan niet-emotionele woorden. Tegelijkertijd waren er wel verschillen in de hersenenactiviteit. Ongeveer 600 ms na het verschijnen van het woord was er voor de typische (niet-ASS) groep een verschil in de hersenenactiviteit voor emotionele en niet-emotionele woorden. Dit verschil geeft aan dat typische mensen meer moeite doen om emotionele woorden goed te verwerken. In de ASS-groep was er echter geen verschil in hersenenactiviteit tussen emotionele en neutrale woorden te bespeuren. Dit resultaat wijst op het bestaan van subtiele verschillen in emotieverwerking bij ASS en niet-ASS proefpersonen, maar het lijkt hierbij meer te gaan over verschillen in verwerkingsstrategieën dan over diepgaande stoornissen.

In de volgende studie, beschreven in **Hoofdstuk 4** keek ik naar de expliciete verwerking van emotiewoorden. De taak voor deelnemers was nu om zo snel mogelijk de beslissen of het woord dat ze op het scherm zagen emotioneel negatief of positief was. Een voorbeeld zijn de woorden GELUK en PIJN. De helft van deze woorden werden gepresenteerd na een woord met dezelfde emotionele waarde (bijvoorbeeld een negatief woord gevolgd door een andere negatief woord), en de andere helft na een tegenovergesteld woord (bijvoorbeeld een negatief woord na een positief woord). Normaal gesproken kunnen mensen sneller een woord classificeren indien ze net daarvoor een woord met dezelfde emotionele waarde hebben gezien. Dit effect vond ik inderdaad in de typische groep, maar opmerkelijk genoeg ook in de ASS groep. Ook hier waren er dus geen gedragsverschillen te zien tussen de twee groepen proefpersonen.

In **Hoofdstuk 5** heb ik onderzocht hoe men emotionele woorden verwerkt die in een zin staan. In de zinsverwerkingtaak vond ik geen verschillen in hersenactiviteit tussen de twee proefpersoongroepen. Kennelijk verwerken mensen met ASS emotiewoorden op verschillende manieren, afhankelijk van de taak die ze uitvoeren. Als ze alleenstaande woorden lezen hanteren ze, zo lijkt het, een minder grondige verwerkingsstrategie, maar woorden binnen een zin worden wel verwerkt op een gebruikelijke manier.

Ten slotte heb ik in **Hoofdstuk 6** onderzoek gedaan naar de emotieverwerking bij eerstegraads verwanten van mensen met ASS. ASS komt vaak voor samen met een aantal andere persoonlijkheidstrekken, zoals een relatief hoge angstscore of alexithymia. Bij alexithymia is sprake van een moeilijkheid om onderscheid te maken tussen de eigen emoties en andere gevoelens in het lichaam. In dit experiment kregen proefpersonen een aantal gezichtsuitdrukkingen te zien en een emotiewoord te horen. De taak was om te zeggen of de emotie die bij het woord hoort wel of niet aanwezig was tussen vier gezichtsuitdrukkingen (bij het

woord "blij" hoort een bepaalde positieve gezichtsuitdrukking). Ik heb gemeten hoe mensen keken naar gezichten in een display en vond bij eerstegraads verwanten van mensen met ASS geen verschillen met andere proefpersonen. Alexithymia was echter wel gecorreleerd met het patroon van de blikrichting: mensen met een hoge score op alexithymia keken relatief weinig naar de ogen in de gezichten.

Samengevat, de verschillende studies in dit proefschrift laten een gemengd patroon van resultaten zien. In sommige taken vertoonde de ASS groep hetzelfde gedrag of dezelfde hersenactiviteit als de standaardgroep, terwijl er in andere taken wel verschillen optraden.

Toekomstig onderzoek

Onze resultaten openen mogelijkheden voor vervolgonderzoek. In onze studies observeerden we veel individuele verschillen. Parameters zoals verbaal IQ en alexithymia correleerden met de grootte van de gevonden effecten. In toekomstige onderzoek kunnen we groepen proefpersonen testen met een hoog en een laag IQ, en een hoge en lage score op alexithymia, om deze verschillen systematisch te bestuderen.

Bij emotieverwerking is een breed netwerk van hersengebieden betrokken. Met de EEG metingen die wij hier hebben gebruikt kan men heel nauwkeurig het tijdverloop van hersenactiviteit te bestuderen, maar niet de locatie daarvan. Waar de activiteit optreedt kan men met een andere techniek zichtbaar maken, namelijk met fMRI. Door tegelijkertijd EEG en fMRI data te verzamelen in een experiment, kan in toekomstig onderzoek bekeken worden welke hersengebieden verschillend werken bij mensen met en zonder ASS.

Al met al onderstreept het huidige proefschrift het belang van onderzoek naar de ontwikkeling van emotieverwerking in wisselwerking met andere cognitieve vaardigheden, zoals taalgebruik, sociale ontwikkeling en het leren van straf en beloning.

Curriculum Vitae

Alina Lartseva received a Bachelor degree in psychology from Lomonosov Moscow State University, Russia in 2008. After that, she received a Radboud Scholarship to follow a Master study at Radboud University in Nijmegen.

In 2010 Alina graduated from Master program in Cognitive Neuroscience with specialization in psycholinguistics. For her Master thesis, she studied processing of emotion words in first and second language using fMRI. She tested German-English bilinguals while they were reading German and English words while lying in the scanner.

After finishing her Master. Alina was awarded a Top Talent PhD scholarship that allowed her to define her own research topic. She chose to study processing of emotion words in patients with Autism Spectrum Disorders (ASD). During her PhD, she conducted several EEG experiments investigating different aspects of emotion processing in people with ASD and in healthy controls. She found that in some aspects, patients with ASD process emotion words differently, but this difference was apparent only in specific tasks.

Publications

Lartseva, A., Dijkstra, T., & Buitelaar, J. (2015). Emotional language processing in autism spectrum disorders: a systematic review. *Frontiers in Human Neuroscience*, 8.

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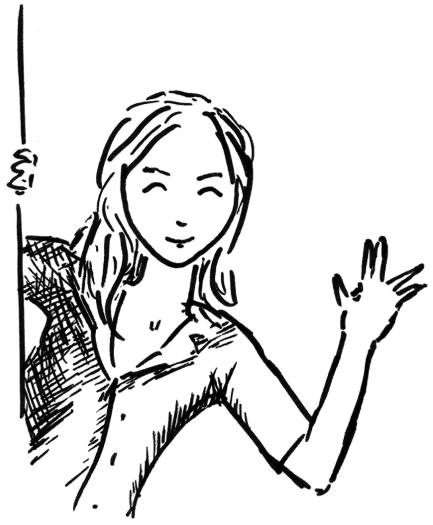

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