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Inferring emotions from the eyes in typical development and major depression

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Für meine Familie

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LIST OF ABBREVIATIONS

2AFC	Two-Alternative Forced-Choice
95% CI	95% Confidence Interval
ANOVA	Analysis of Variance
ASD	Autism Spectrum Disorder
AUs	[Facial] Action Units
BD	Bipolar Disorder
COVID-19	Coronavirus Disease 2019
DP	Developmental Prosopagnosia
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition
EMF	Emotions in Masked Faces
ERP	Event-Related Potential
FACS	Facial Action Coding System
FDR	False Discovery Rate
fMRI	Functional Magnetic Resonance Imaging
HSD	Tukey's Honestly Significant Difference Test
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th Edition
MDD	Major Depressive Disorder
MS	Multiple Sclerosis
OCD	Obsessive-Compulsive Disorder
RMET	Reading the Mind in the Eyes Test
RT	Response Time
SARS	Severe Acute Respiratory Syndrome
SD	Standard Deviation
SEM	Standard Error of Mean
SZ	Schizophrenia
TD	Typical Development/Typically Developing
ToM	Theory of Mind

WHO	World Health Organization

1 INTRODUCTION

Interpersonal communication is a complex, multifaceted process that spreads far beyond the mere exchange of spoken words. At its core, it represents various ways of information flow where verbal and nonverbal streams convey meaning, emotion, and intention. Nonverbal communication operates through a complex assembly of bodily signals, facial expressions, gestures, and other contextual cues (de Gelder, 2006; Tamietto et al., 2007; van den Stock et al., 2007; de Gelder et al., 2010; Atkinson et al., 2012; Pavlova, 2012; Bidet-Ildei et al., 2020; Kret et al., 2020; Sokolov et al., 2020; Pavlova and Sokolov, 2022ab; Pavlova et al., 2022, 2023a). While verbal communication is usually kept under control, nonverbal communication flows more spontaneously and, therefore, is a more reliable indicator of someone's true feelings (Jones Jr, 2023). Nonverbal communication cannot be as completely intentionally controlled as verbal one and often reveals authentic emotional and cognitive states of social agents involved. It is therefore an important part of genuine interpersonal exchange, fostering empathy and social sharing. In daily social interactions, nonverbal cues are often seamlessly integrated into communication processes, enabling us to decode complex emotional messages quickly. However, when such cues are limited – as seen with face-mask use – the challenge of accurate emotion recognition intensifies, steering our focus toward the eyes.

1.1 Facial emotion recognition

Recognizing emotions from facial expression allows to interpret affective states of others, anticipate their reactions, and (re)act appropriately, which is crucial for building and maintaining balanced social interaction. The ability to infer emotions from facial expressions is supported by numerous dynamic cues from both the upper and lower regions of a face, which, in daily life, are usually not only abundant but taken for granted. It is well-known that distinct areas of a face are critical for expression and subsequent recognition of different emotions (Root and Stephens, 2003; Lian et al., 2020; Kim et al., 2022b). Emotional expressions involve the activation of specific facial muscular movements classified by the Facial Action Coding System (FACS; Ekman and Friesen, 1978). Emotions such as happiness and disgust are considered to be primarily recognized through cues from the lower part of a face, while cues from the upper part are more important for identifying anger and fear (Bassili, 1979; Wegrzyn et al., 2017). Critical cues are not the same for distinct emotional expressions fluctuating in their perceptual power: for instance, when combining diverse expressions (such as happiness and sadness) exhibited by the lower and upper face parts, steadfast happiness recognition requires a much stronger expression of happiness in the lower face part to compensate for a sad expression displayed by the upper part (Chen and Chen, 2010). Restricting lower-face cues (e.g., via face masks) forces greater reliance on the eyes for emotion recognition, which may vary across individuals depending on their ability to extract social signals.

In daily life, we deal with plenty of social information that helps to achieve prompt and accurate interpretation. With emerging challenges, such as mandatory face-mask wearing during the Singapore and Hong Kong flu pandemics in the 1950s and 1960s, the severe acute respiratory syndrome (SARS) outbreak of the early 2000s in China, Hong Kong, and Taiwan (Jones, 2020), and most recently during the COVID-19 pandemic, as well as obligatory mask wearing in some domains of medicine such as dental practice, adaptive social cognition is no longer taken for granted. Instead, agents of social interaction are forced to infer and pool together social signals from different nonverbal sources such as bodies and the eyes (with most of the face hidden behind a mask). Clearly, this represents a substantial psychological burden for nonverbal social communication (for comprehensive reviews, see Pavlova and Sokolov, 2022ab; Pavlova et al., 2023a).

The general research question is whether limited visual information from the eyes can be sufficient for inferring emotions and mental states of others. To investigate the challenges of emotion recognition in masked faces, the Emotions in Masked Faces (EMF) paradigm was developed in our research group (Pavlova et al., 2023b), based on previous work (Carbon, 2020; Carbon et al., 2022). The paradigm employs a set of photographs from the MPI FACES database (Ebner et al., 2010) showing individuals of different ages and genders, displaying six basic emotions (anger, disgust, fear, happiness, sadness, and neutrality), with face masks digitally superimposed on all faces. In a two-alternative forced-choice (2AFC) paradigm based on emotion confusion patterns (e.g., angry-disgusted, fearful-sad, neutral-happy; Carbon, 2020; Carbon et al., 2022), participants have to indicate which emotion is expressed behind a mask.

Several other established experimental tools complement this line of research. The Reading the Mind in the Eyes Test (RMET), developed by Baron-Cohen and colleagues

(Baron-Cohen et al., 1997, 2001) primarily for studying social cognitive deficits in autism spectrum disorder (ASD), is a widely used test for assessing an individual's ability to infer mental states from the eye region. It consists of 36 grayscale images displaying the eye region only, each accompanied by four descriptive options. Participants are tasked with selecting the word that best represents the emotion or mental state depicted (Oakley et al., 2016; Peñuelas-Calvo et al., 2021; Pavlova and Sokolov, 2022ab; Stafford et al., 2023). The RMET has proven to be effective in both clinical and non-clinical populations. It is commonly used to detect deficits in emotional processing in individuals with ASD, schizophrenia (SZ), neurodegenerative conditions, and social anxiety disorders (Lott et al., 2022; Pavlova et al., 2022; Stafford et al., 2023; Resch et al., 2024).

Beyond the RMET, recent advancements in mobile eye-tracking technology have provided new opportunities for studying processing of social signals in real-world settings (Schäfer et al., 2021; Schmälzle et al., 2024). The EmBody/EmFace tool (Lott et al., 2022) is another method for assessing emotion recognition. By utilizing body and facial stimuli, this tool provides a complementary perspective to the RMET and demonstrates high validity and reliability. Its applications extend to both clinical and non-clinical populations, aiding in the detection and remediation of socioemotional deficits.

1.1.1 The role of face masks in inferring of social signals

It is unlikely that face masks negatively affect recognition of all emotions to the same degree, i.e., uniformly, as properly worn masks obscure all visual cues from the lower part of the face. Indeed, studies using photographs of faces with digitally superimposed face masks found a considerable decline in the ability to confidently recognize some emotions, while leaving others intact (Carbon, 2020; Bani et al., 2021; Noyes et al., 2021). However, the outcome in regard to specific emotions may be inconsistent. For example, some studies have reported a notable decline in recognition of anger due to mask wearing (Levitan, 2022; Proverbio and Cerri, 2022; Gil and Bigot, 2023; Proverbio et al., 2023), whereas other studies have found that anger recognition remains relatively unaffected by masks (Carbon 2020; Bani et al. 2021; Noyes et al., 2021; Pazhoohi et al., 2021; Grahlow et al., 2022; Kim et al., 2022a; Shepherd and Rippon, 2023). The divergence in findings could be attributed to differences in study design, participant demographics, or specific methods used to assess emotional recognition (Pavlova et al., 2023a). Generally, happy

(Maiorana et al., 2022), fearful (Carbon, 2020; Bani et al., 2021; Leder et al., 2022; Verroca et al., 2022; Thomas and Caharel, 2024), and neutral facial expressions (Carbon, 2020; Noyes et al., 2021; Cooper et al., 2022; Leder et al., 2022; Rinck et al., 2022; Gil and Le Bigot, 2023) have been reported to be less affected by mask wearing.

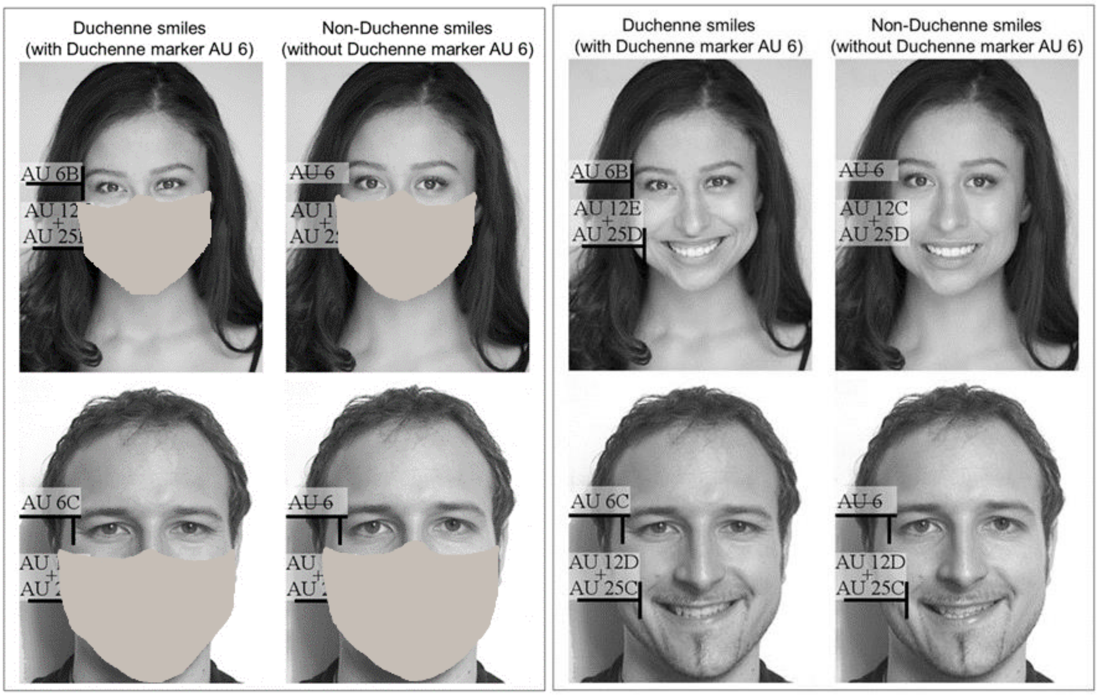

Figure 1. Examples of Duchenne and non-Duchenne smiles. A female and male poser, each displaying a Duchenne smile (left on each panel) and a non-Duchenne smile (right on each panel) and the same images with superimposed visual obstruction, similar to a face mask (right panel, modified from the left one). The Duchenne smile remains noticeable, even when the lower face is not visible. AU, action unit. Left panel from Bogodistov and Dost (2017). Proximity begins with a smile, but which one? Associating non-Duchenne smiles with higher psychological distance. *Front. Psychol*. 8:1374. doi: 10.3389/fpsyg.2017.01374; the Creative Commons Attribution [CC BY] license.

In addition, face masks may also affect the perception of specific facial expressions. For instance, a smile is not always just a smile – it can be distinguished as either a "Duchenne smile", which involves the activation of muscles around the eyes, making it appear more genuine and sincere, or a "non-Duchenne smile", which is limited to the lower part of the face and is often perceived as less authentic (Duchenne de Boulogne, 1862; Frank and Ekman, 1993; Hess and Bourgeois, 2010; Manera et al., 2011; Bogodistov and Dost, 2017). Thus, it comes as no surprise that "non-Duchenne smiles" are much harder to recognize under the condition of mask wearing, as the key muscle movements in the lower part of a face are obscured. On the other hand, a "Duchenne smile", which includes telltale signs of joy around the eyes, is still perceived as a genuine happy expression, even when the mouth is covered (Sheldon et al., 2021). As seen from **Figure 1**, "non-Duchenne smiles" serve purposes beyond simply being a weaker version of a "Duchenne smile". Social smiles often convey a range of social nuances, including politeness, ambiguity, or even emotional distance (Bogodistov and Dost, 2017). Therefore, the hindrance of non-Duchenne smiles by face masks exemplifies how alterations in facial visibility can impede the transmission of social communication cues, potentially compromising the intricate emotional exchanges that rely on partial facial expressions.

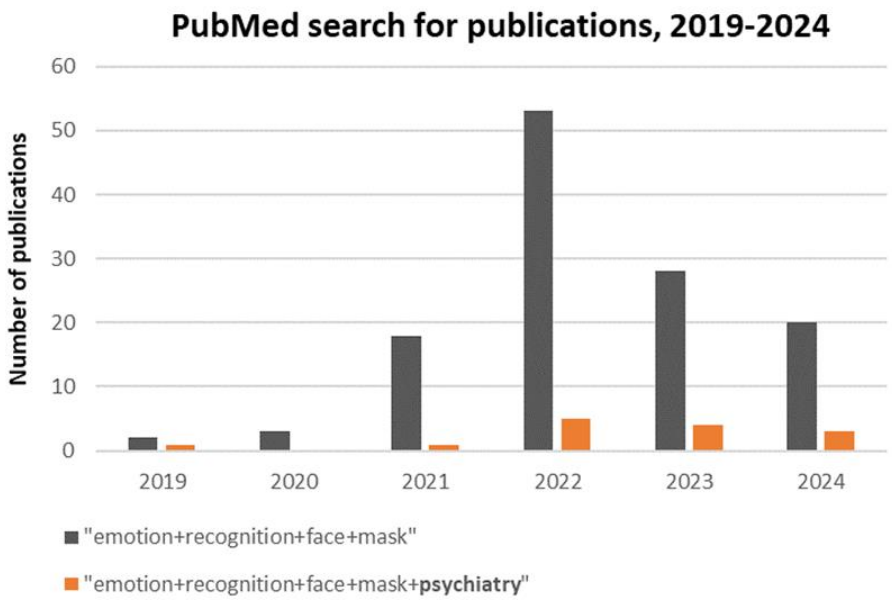

Figure 2. The outcome of PubMed® search for publications on emotion recognition in masked faces. While the COVID-19 pandemic spiked interest in the effects of mask wearing on social cognition, the effects on a diverse population with mental disorders, who are often already at a disadvantage and potentially the most vulnerable to the negative effects of mask wearing, remain gravely understudied.

The reduction in facial affect recognition caused by masks may not only impact social communication in everyday contexts but also profoundly affect various professional settings. For instance, professions requiring emotional attunement, such as psychiatric clinical practice, pediatric healthcare, and education, may suffer due to the diminished ability to detect subtle emotional cues (Carbon, 2020; Cartaud et al., 2020; Olivera-La Rosa et al., 2020; Ruba and Pollak, 2020; Biermann et al., 2021; Calbi et al., 2021; Gori et al., 2021; Grundmann et al., 2021; Marini et al., 2021; Noyes et al., 2021; Pavlova and

Sokolov, 2022a). The need for research on the impact of masks becomes especially clear in contexts such as psychotherapy, where both patients and healthcare professionals have reported negative effects on therapeutic treatment, especially in group settings (Erschens et al., 2022; Pavlova et al., 2023a). Reading covered faces can also be particularly challenging for individuals with mental conditions (Pavlova et al., 2023a), underscoring the importance of investigating the challenges posed by masked communication in vulnerable populations. However, as seen in **Figure 2**, although interest in the impact of mask wearing on emotion recognition drastically increased in recent years due to the COVID-19 pandemic, little attention had been given to the impact of face masks on social cognition in individuals with mental disorders.

Beyond reducing recognition accuracy, masks may narrow the perceived emotional spectrum by leading to a tendency to misinterpret both positive and negative emotions as neutral (Carbon, 2020; Cartaud et al., 2020; Marini et al., 2021; Pavlova and Sokolov, 2022a). This narrowing effect highlights the potential for masks to distort social interactions, possibly leading to misunderstandings of emotional signals. The deceptive evaluation of others is another critical consequence. For example, masks may dampen negative emotional expressions, leading to higher perceived trustworthiness or likability and inadvertently affecting interpersonal or professional dynamics (Olivera-La Rosa et al., 2020; Grundmann et al., 2021; Pavlova and Sokolov, 2022a; Pavlova et al., 2023a). Similarly, they may obscure genuine positive signals, exacerbating challenges in distinguishing between authentic and inauthentic expressions (Sheldon et al., 2021; Wiesmann et al., 2021). Perception of attractiveness, trustworthiness, and personality traits can also be influenced by masks, impacting interpersonal dynamics and even economic transactions (Cannito et al., 2022; Leder et al., 2022; Pavlova et al., 2023a). Consequently, these effects demonstrate that mask-induced changes in facial visibility do not simply hinder emotion recognition but fundamentally reshape the emotional and social landscape of human interaction (Pavlova and Sokolov, 2022a).

Figure 3. Better no smile than a fake smile. A woman wearing a face mask with a painted smile illustrates the challenge of conveying genuine emotions when facial expressions are obscured. Her eyes betray the absence of a true smile, highlighting the importance of visual input from the eyes for accurate emotion recognition. From Pavlova et al. (2023a). Editorial: Impact of face covering on social cognition and interaction. *Front. Neurosci.* 17:1150604. doi: 10.3389/fnins.2023.1150604; the Creative Commons Attribution [CC BY] license. Image courtesy of Jyo John Mulloor, a digital artist.

1.1.2 Experience in reading in the eyes during COVID-19

While research has demonstrated children's and adolescents' remarkable adaptability in emotion recognition during the mask-wearing periods (Ger et al., 2024; Kulke et al., 2022), several critical questions remain open. The strong contrast between young people's adaptive capabilities and adults' persistent difficulties in recognizing emotions in masked faces (Carbon et al., 2022) raises important questions about the mechanisms underlying this age-dependent plasticity. What enables the development of compensatory strategies and why do these adaptations appear to be limited in adults? Furthermore, while studies have documented the challenges faced by vulnerable populations such as individuals with ASD, Parkinson's disease, or hearing impairments (Ciccarelli et al., 2022; Escelsior et al., 2022; Schnitzler et al., 2024; Homans and Vroegop, 2021, 2022; Poon and Jenstad, 2022), there is limited understanding of how to effectively support these groups in masked communication settings. The development of targeted interventions and assistive strategies for these populations remains an important area for future research. The findings also point to broader questions about the long-term implications of communication when faces are masked. How do these adaptations (or lack thereof) influence social development and relationship formation across different age groups? What are the lasting effects on professional interactions, particularly in healthcare settings where clear communication is crucial (Aliabadi et al., 2022)? Additionally, the intersection between masked communication difficulties and pandemic-related isolation deserves further investigation, particularly regarding their combined impact on mental health outcomes (Steen et al., 2022).

1.1.3 The eyes as a gateway to emotion recognition

In art, the eyes are often referred to as 'the windows to the soul' or 'the mirror of the soul', as they seem to deliver nonverbal, reliable information about emotional states and personal traits of an interlocutor. In other words, one is supposed to be able to understand a person's emotions, intentions, drives, and desires by simply looking into his or her eyes. In the FACS (Ekman and Friesen, 1978), only seven out of the 28 action units focus on the muscles around the eyes. This underscores both how delicate communication via facial expressions can be and how much more information might be lost when wearing a mask.

Interestingly, the eye region receives earlier and longer fixations by observers in angry and sad faces, and, compared to other emotions, fearful and surprised expressions enhance gaze-orienting effects (Bayless et al., 2011; Calvo et al., 2018). Selective attention to the eyes is not only driven by perceptual salience of certain emotions but also by top-down cognitive processes. Processes such as emotional expectations, contextual interpretation, and individual experience modulate how attention is allocated to facial features (Bayless et al., 2011).

Recent functional magnetic resonance imaging (fMRI) research has demonstrated that mask-occluded facial expressions require more extensive neural resources for recognition, with increased activation in occipito-temporal regions and altered functional connectivity (Abutalebi et al., 2024). This finding accentuates the brain's adaptive capabilities in extracting emotional information under challenging perceptual conditions. When actuating selective attention to the eye region, a complex neural infrastructure that supports emotional communication can be observed. The eye region emerges not just as a metaphorical window to the soul, but as a neurobiological channel of emotional information processing.

1.1.4 Gender impact on social cognition

Experimental evidence reveals (subtle, albeit robust) *gender* (a social construct reflecting social roles, expectations, and norms, whereas *sex* refers to neurobiological factors) differences in nonverbal social cognition, the processes by which people perceive, interpret, and respond to social information. Women typically demonstrate greater emotional expressivity and higher sensitivity to subtle emotional cues (Brody and Hall, 2008), a phenomenon rooted in both biological predispositions and socialization processes. Cultural narratives and societal norms such as traditional expectations, e.g., "boys shouldn't cry", systematically shape emotional expression patterns, illustrating the dynamic interaction between innate capabilities and social conditioning (Fischer and LaFrance, 2015).

Females generally outperform males in tasks related to emotion recognition and processing, with studies showing superior facial emotion perception among females (Hoffmann et al., 2010; Menezes et al., 2017; Wingenbach et al., 2018; Bek et al., 2022; Kapitanovic et al., 2022). Female advantage appears particularly pronounced in recognizing basic emotions, which suggests a heightened ability to interpret emotional cues (Kret and Gelder, 2012). However, findings regarding other aspects of social cognition such as theory of mind (ToM), the capacity to attribute mental states – such as beliefs, desires, and intentions – to others in order to predict and understand behavior, are mixed. Some studies suggest that females may excel in affective ToM tasks, which involve understanding emotions and feelings, while males might perform better on cognitive ToM tasks requiring logical reasoning about beliefs and intentions (Navarra-Ventura et al., 2018; Kubota et al., 2022). Other research, however, has found no gender differences in the ToM abilities, including individuals with mental disorders such as SZ (Vaskinn et al., 2024).

The concept of gender as an embedded cultural construct posits that gender roles shape interpersonal interactions and self-perception, leading individuals to internalize societal expectations about gendered behavior. This internalization influences cognitive processes during social interactions and reinforces perceptual biases (Diekman and Schmader, 2024). For example, males and females may adopt different cognitive strategies when processing social information, shaped by both socialization experiences and biological factors (Ferrer-Quintero et al., 2022; Diekman and Schmader, 2024).

Narrowing in on emotion recognition in masked faces, existing research presents a heterogeneous picture: some studies found no significant gender differences (Bek et al., 2022; Carbon et al., 2022; Kim et al., 2022a), while others reported female superiority in facial emotion recognition (Grundmann et al., 2021; Huc et al., 2023). The COVID-19 pandemic provided a unique natural experiment for examining gender differences in reading masked faces. Female adults showed improved performance in reading the language of eyes during pandemic conditions (Kulke et al., 2022), a finding suggesting potential gender-specific neuroplasticity.

The exploration of gender differences reveals complex intersections between gender and social cognitive processing across various mental disorders. Notably, individuals with psychiatric conditions demonstrate substantial variations in social cognition commonly observed in typically developing (TD) populations. In SZ, male advantages in reasoning, problem-solving, and working memory found in TD are absent (Zhang et al., 2017), while gender-specific differences in hostility bias and ToM are similarly attenuated (Kubota et al., 2022). In ASD, the female advantages in social cognition observed in TD are markedly diminished (Baron-Cohen et al., 2015; Pavlova and Sokolov, 2022b). In bipolar disorder (BD), females demonstrate equivalent, rather than superior, performance in visual and auditory emotion recognition tasks (Vaskinn et al., 2007) or on the RMET (Navarra-Ventura et al., 2021), in contrast to the neurotypical female advantage. These findings indicate that the factor *disease* presumably has a much stronger influence on social cognition than the factor *gender* (Pavlova and Sokolov, 2022b) or, in other words, psychiatric conditions can alter or camouflage patterns of social cognition. At the same time, remitted female patients with SZ, schizoaffective, and BD score better on the RMET and have higher empathy levels than males (Dehelean et al., 2021).

1.2 Major depressive disorder (MDD)

Building on the understanding of gender differences in social communication and cognition, it is clear that these mechanisms do not operate in a vacuum. They are critically intertwined with the pathophysiology of psychiatric disorders, including major depressive disorder (MDD). MDD is one of the most prevalent psychiatric disorders worldwide and a leading cause of disability, as noted by the World Health Organization (WHO, 2020), with disruptions in mood and cognitive processing undermining social interactions. It is characterized by prolonged periods of emotional disturbance, including persistent feelings of guilt, hopelessness, and anhedonia (the inability to derive pleasure or motivation from activities that once brought joy or satisfaction). This emotional and psychological cost extends far beyond individual suffering, contributing to a significant global economic burden. In 2019 alone, the economic burden of MDD is estimated at 333.7 billion US Dollars, in the USA alone. These expenses are largely attributed to MDD-related healthcare costs, diminished productivity, and absenteeism within the workforce (Greenberg et al., 2023). The disorder has a widespread impact on cognitive functioning, as noted by the American Psychiatric Association in their 2015 DSM-5® Selections on Depressive Disorders (APA, 2016), with impairments in memory, processing speed, attention, and concentration.

Despite extensive research, the etiology of MDD is not yet fully understood. Numerous hypotheses have been proposed, but none of them seem to explain in full the complex and multifaceted manifestations of the disorder (Cui et al., 2024). This uncertainty presents a challenge for treatment approaches, as even patients in remission often experience persisting cognitive symptoms (Bora et al., 2013). Furthermore, research indicates that while antidepressants may improve mood symptoms, they tend to show only a small positive effect on cognitive domains such as memory recall and psychomotor speed (Rosenblat et al., 2015).

1.2.1 Gender/sex in MDD

Gender differences in MDD further complicate its understanding and treatment. Research consistently shows that women are more likely to experience MDD than men, with lifetime prevalence rates of approximately 7.2% for women and 4.3% for men (Picco et al., 2017). This disparity, which emerges during adolescence and persists throughout life, reflects a combination of biological, psychological, and sociocultural factors (Picco et al., 2017; Salk et al., 2017; Tian et al., 2024). The age of MDD onset differs between genders as it coincides with the hormonal fluctuations of puberty (Parker and Brotchie, 2010).

Biological factors including hormonal fluctuations related to menstrual cycles, pregnancy, and menopause contribute to women's increased vulnerability to MDD, alongside potential genetic differences in susceptibility and treatment response (Kim et al., 2018; Zhao et al., 2020). Sociocultural influences such as societal roles, experiences of violence or trauma, and discrimination also play a substantial role in shaping the expression and impact of MDD across genders. Women, in particular, may face stressors that exacerbate the feelings of helplessness and worthlessness associated with depression (Piccinelli and Wilkinson, 2000; Salk et al., 2017). They are also more likely to experience atypical symptoms such as hypersomnia, increased appetite, and pronounced somatic complaints (Piccinelli and Wilkinson, 2000; Schuch et al., 2014; Tu et al., 2022).

Men, on the other hand, often remain underdiagnosed due to societal norms and stereotypes that discourage emotional expression and help-seeking behavior (Seidler et al., 2016). In contrast to women, they tend to exhibit impulsivity, substance use disorders, and an increased risk of suicide (Piccinelli and Wilkinson, 2000; Picco et al., 2017; Tu et al., 2022; Tian et al., 2024). The multifaceted nature of MDD, compounded by gender-specific differences in prevalence, symptomatology, and treatment response, underscores the complexity of the disorder. Addressing the gender-specific dynamics is critical for advancing prevention and treatment strategies, thereby improving outcomes for affected individuals.

1.2.2 Social cognition in MDD

Social cognition encompasses the intricate processes involved in perceiving, interpreting, and responding to social signals from others. Thus, it is conceivable that deficits in these abilities would contribute to impaired social functioning and interpersonal relationships. In line with this, current research suggests general deficits of facial emotion recognition in MDD (Krause et al., 2021). Similar to other psychiatric disorders, MDD is associated with deficits in ToM, the ability of inferring mental states of others, with the degree of impairment aligning with the severity of depressive symptoms (Bora and Berk, 2016; van Neerven et al., 2021). The deficits occur in both cognitive and affective empathy, which are crucial for maintaining healthy social relationships. A well-documented phenomenon in individuals with MDD, which might in part account for these deficits, is an enhanced sensitivity towards, or alternatively, a proneness to detect negative emotional expressions such as sadness, anger, or fear (Gollan et al., 2008; Bourke et al., 2010; Milders et al., 2010; Dalili et al., 2015). By contrast, the ability to accurately identify positive emotions like happiness is often diminished (Gollan et al., 2008; Bourke et al., 2010; Milders et al., 2010; Dalili et al., 2015; Krause et al., 2021), with a tight link between performance and symptom severity (Krause et al., 2021; Porter-Vignola et al., 2021; Yuan et al., 2023). Negative bias has also been observed in respect to neutral or ambiguous faces, which are more often perceived as sad (Lee et al., 2016). This could reflect the broader cognitive impairments associated with depression, where negative information is given greater weight, both in social interactions and internal thought processes.

The question arises as to how these deficits impact more complex, socially-relevant functions. It is well established that the cognitive deficits of MDD result in diminished social functioning (Evans et al., 2014; McIntyre et al., 2016; Knight and Baune, 2018), as it has also been found to be the case in late-life depression (Szanto et al., 2012). For example, both the cognitive and affective processing of humor (Uekermann et al., 2008) as well as the interpretation of sarcasm (Ladegaard et al., 2014; Thoma et al., 2015) are hindered in MDD, suggesting a potential breeding ground for miscommunication in daily-life scenarios. At initial stages of MDD however, previous research has highlighted elevated levels of empathy (Choi et al., 2024) and that higher sensitivity to social signals, combined with low psychological resistance might cause vulnerability towards developing MDD (Kubon et al., 2021).

The implications of diminished social functioning and difficulties in interpersonal relationships, due to the difficulties in accurately deciphering emotional cues from others, may lead to social withdrawal, misinterpretation of social signals, and impaired social problem-solving skills. Furthermore, the stigma surrounding depression may exacerbate social isolation and undermine social support networks, further perpetuating the cycle of depressive symptoms.

Inferring of emotions in masked faces may be particularly challenging for individuals with MDD who have been characterized by aberrant social cognition already in the pre-pandemic period (Pavlova and Sokolov, 2022b). As we pointed out (Moosavi et al., 2024b), only a handful of studies have addressed this issue (see also **Figure 2** above). For example, in a relatively small and inhomogeneous sample of MDD patients with an unbalanced number of females and males (N = 19; 15 females, 4 males), masked happiness expressed with low intensity yields difficulties in recognition as compared with unmasked faces. This holds true also when comparing with TD controls (N = 28; 23

females, 5 males) and patients with BD (*N* = 13; 5 females, 8 males) (Escelsior et al., 2022).

1.3 Goals

The rapid and crucial changes of social communication, particularly during the COVID-19 pandemic and the widespread adoption of face masks, identified several gaps in our understanding of emotional recognition and nonverbal communication. These changes have emphasized the need to better understand how we process emotional signals under challenging conditions.

The overarching aim of this work is to explore the ability to infer social signals from the eyes, with a focus on differences across gender, age, and mental health status. Social cognition is altered in a wide range of mental disorders, including MDD, where deficits in emotion recognition may give rise to or exacerbate social withdrawal and interpersonal difficulties. Despite the growing awareness of these issues in social community, the existing research often lacks ecological validity, fails to address key demographic disparities, or yields inconsistent findings.

(i) Previous work has provided controversial results regarding potential gender impact on inferring emotions from the eyes, largely due to most studies suffering from the limitations of online experimentation, such as a lack of control over the experimental setting and female predominance, and the resulting lack of person-by-person matched comparison.

(ii) Social cognition is dynamic and evolves with accumulated social interactions, exposure, and shifting cognitive strategies (Wascher et al., 2018; Stevens and Jovanovic, 2019; Dziura et al., 2023). However, there is a lack of research on possible alterations in the ability to read language of the eyes across early to mid-adulthood.

(iii) It is widely unknown whether, and if so, how face masks affect inferring emotions in individuals with MDD as well as social cognition at large.

The present work addresses this knowledge gap through three interrelated studies, exploring the effects of gender and experience in reading in the eyes both in the neurotypical population and in individuals with mental disorders such as MDD.

The first study (Pavlova et al., 2023b) focuses on gender effects in inferring basic emotions from the eyes in masked faces in TD young adult females and males. The outcomes of previous research on gender impact on emotion recognition in masked faces are inconsistent, relying on online experimenting in samples predominated by females. By contrast, the present work represents a controlled, face-to-face investigation with a gender-balanced, age-matched sample of young individuals with a homogeneous cultural background. This work intends to set a blueprint for exploring reading the eyes in faces hidden by masks in clinical populations.

The second study (Moosavi et al., 2024a) narrows the focus further to examine, under similar experimental conditions, whether reading emotions in the eyes in masked faces improves with life experience. In other words, the question was how the ability to read emotions in the eyes is altered across healthy adulthood, namely, from young adulthood to middle age. In search of group homogeneity, a focus had been set on female participants, especially to provide a foundation for evaluation of findings in clinical populations.

Finally, the third study (Moosavi et al., 2024b) examines reading in the eyes in females with MDD, asking (i) whether the recognition of facial affect in masked faces is impaired in female MDD and (ii) whether and if so, how the ability to infer emotions in masked faces is intimately tied with reading language of the eyes as assessed by the RMET.

2.1 Emotions behind a mask: the value of disgust

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Emotions behind a mask: the value of disgust

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The impact of face masks on social cognition and interaction became a popular topic due to the long-lasting COVID-19 pandemic. This theme persists in the focus of attention beyond the pandemic, since face covering not only reduces the overall amount of face information available but also introduces biases and prejudices affecting social perception at large. Many questions are still open. One of them is whether gender of beholders affects inferring of emotions covered by face masks. Reading covered faces may be particularly challenging for individuals with mental disorders, most of which are gender-specific. Previous findings are not only sparse, but inconclusive because most research had been conducted online with resulting samples heavily dominated by females. Here in a face-to-face study, females and males were presented with a randomized set of faces covered by masks. In a two-alternative forced-choice paradigm, participants had to indicate facial emotions displayed by posers. In general, the outcome dovetails with earlier findings that face masks affect emotion recognition in a dissimilar way: Inferring some emotions suffers more severely than others, with the most pronounced influence of mask wearing on disgust and close to ceiling recognition of fear and neutral expressions. Contrary to our expectations, however, males were on overall more proficient in emotion recognition. In particular, males substantially excelled in inferring disgust. The findings help to understand gender differences in recognition of disgust, the forgotten emotion of psychiatry, that is of substantial value for a wide range of mental disorders including schizophrenia. Watch Prof. Marina Pavlova discussing this her work and this article: https://vimeo.com/860126397/5966610f49?share=copy.

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INTRODUCTION

The impact of face masks on social cognition and interaction became a valuable and popular research topic due to the long-lasting COVID-19 pandemic with compulsory face-masks-wearing safety regulations. This theme remains in the focus of research attention beyond the pandemic, since face coverings not only reduce the overall amount of face information but introduce perceptual biases and prejudices affecting efficient social interaction and mental health at large[1,2].

For inferring most emotional expressions (in particular, subtle), complementary information flows from the upper and lower face parts are desirable. Indeed, in daily life, beholders habitually have access to a plenty of facial cues. Yet, it is assumed the lower part of a face is essential for the recognition of happiness and disgust, the upper portion for anger and fear, and both for surprise and sadness[3,4]. Already initial studies in the field indicated that not all emotions are equally affected by medical face masks covering the lower portion of a face[2,5]. Irrespective of differences in cultural/ethnical background (East Asians prioritize global information and fixate more on the center of a face, the nose area, and less on the eyes and mouth areas than Westerners[6–8]), digital superimposing masks on photographs of faces persistently leads to a substantial decrease in inferring sadness, and, in particular, disgust as well as their perceived intensity and confidence in recognition[9–27]. On the same wavelength, in UK residents of different ethnicity (Caucasian, Black, and Asian/Pacific observers), face masks are reported to primarily hamper inferring disgust and sadness, also having substantial impact on the recognition of happiness[28]. In Turkish university students, neither effects of mask pattern (angular or curvy) nor color (black or white) on facial emotion recognition was found, with the most pronounced influence of all types of masks on afraid/fearful and disgusted faces[13]. The findings obtained with the separate groups tested in May 2020 and July 2021 indicate that the unfavorable influence of face masks on sadness and disgust recognition still persists after more than a year of the pandemic[14], or, in other words, the impact of habituation or experience with masked faces on face reading appears to be rather negligible. Noteworthy, comparable effects of face covering are obtained using female faces expressing emotions with a face mask and in faces with a mask artificially imposed onto face photographs (except anger), with the poorest recognition of disgust and sadness[16]. Brief exposure (for 250 s) to masked faces results in a basically similar pattern of results, with recognition of facial disgust affected most strongly, along with a rather limited impact on recognition of anger[29].

There is much less harmony concerning emotional expressions most resistant to face masks wearing. Experimental studies underscore neutral expressions[9,11,14,21,24,28] and happiness[19]. The primacy of anger in the sense of its robustness against face masks is also emphasized[20,24,26,30], albeit the opposite effects are described as well[9,10,12,15,17,29]. This discrepancy may be attributable to methodological issues, in particular, differences in emotion expression by posers (Fig. 1) or faces databases used such as the MPI FACES database or Radboud Faces Database. In some studies, visual input for emotional impressions is hardly comparable in terms of head tilts, rolls, and yaws. Moreover, cultural differences in emotion expression and experience may contribute to inconsistency of the findings. For example, face masks hamper recognition of happiness in US American but not in Japanese individuals[31].

The pattern of results similar to the effects obtained with static photographs is demonstrated using more ecologically valid faces in motion. In videos of dynamic faces, masks impair inferring sadness, disgust, and happiness, leaving neutral expressions, fear,

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Fig. 1 Differently expressed anger by posers with diverse cultural background. Anger expressed with different involvement of the upper and lower face parts in an Italian poser (left panel; from Proverbio and Cerri, 2022, Front Neurosci; the Creative Commons Attribution [CC BY] license) and in a face taken from the Vienna Emotion Recognition Task, VERT-K, with subsequent modification (right panel; from Grahlow et al., 2022, PLoS ONE; the Creative Commons Attribution [CC BY] license) may lead to different conclusions by studying facial expressions under unusual viewing conditions, for example, when hidden behind a mask.

and social (fake/dishonest/polite) smiling largely untouched[32,33]. Face masks affect ratings of the extent to which reward, affiliation, and dominance smiles in moving faces convey positive feelings, reassurance, and superiority, respectively[34]. Fairly unexpectedly, however, social smiles are reported to appear more honest in masked than unmasked dynamic faces[33]. Under usual viewing conditions, social smiles are determined primarily by information from the mouth with indifferent *cold* eyes, whereas shining warm eyes make *real* smiles[35]. Yet, even covered by masks true smiles are rated as happy and pleasant or, in other words, the glow of real smiles still shows[36]. However, hidden behind masks happiness is often mistaken for neutral expressions, a poker face[37]. Noteworthy, individuals with higher empathic concern demonstrate higher recognition levels for disgust in masked faces, but not for other basic emotions[29]. Principally, this agrees with the findings that emotional intelligence as well as self-reported emotional intelligence do not affect emotion recognition in both masked and unmasked faces[14]. In the same vein, both affective and cognitive empathy are not tied with emotion recognition in masked faces[27].

Reading covered faces may be particularly challenging for individuals with mental, neurological, and psychosomatic disorders characterized by deficient non-verbal social cognition already in the pre-pandemic period[2]. However, the data is extremely sparse and controversial. Most neuropsychiatric conditions are gender- (a social construct reflecting social norms, roles, biases, and practices) and/or sex- (a neurobiological construct) specific, possessing a skewed ratio: females and males are differently affected in terms of prevalence, clinical manifestation, and symptom severity. Major depressive disorder (MDD) shows a female preponderance with around twice as many women affected as men[38]. By contrast, in schizophrenia (SZ), males are more often affected with a ratio ranging from 1.4 to 1.6 with an earlier age of onset, worse premorbid functioning, and a greater severity of negative symptoms[39]. Moreover, males and females with SZ may possess distinct profiles in social cognition and metacognition[40,41].

The question arises whether individuals with mental disorders exhibit gender differences in reading faces covered by masks? To date, only a handful of studies address this issue even in typically developing (TD) individuals, and the outcome is inconclusive. The primary reason is that most studies have been conducted online with samples heavily predominated by females. This makes revealing gender differences questionable: gender comparisons in unbalanced samples may lead to paradoxical statistical outcomes. Studies with designs balanced in respect to gender either report the absence of gender differences in static[14,17,42] and dynamic masked faces[34], or reveal female superiority in reading covered faces[42,43]. Females rate negative emotions covered by face masks as more negative, and positive emotions as more positive than males[44].

Covering faces with masks leaves a comparable amount of visual information for face reading as the Reading the Mind in the Eyes Test (RMET) that contains a set of photographs of a pair of the eyes along with the surrounding part of a face[2,45]. Most recent work indicates that the RMET predicts the accuracy of facial affect recognition in masked faces, whereas the Tromsø Social Intelligence Scale (TSIS) does not[46]. Considering well-documented (small, but reliable) female proficiency in reading language of the eyes as assessed by the RMET[2,45,47], one can expect that females are also more skillful in reading emotions in masked faces. The present work intended to clarify whether gender of perceivers affects inferring emotions in faces covered by face masks.

METHODS

Participants

Overall, 53 participants (25 females and 28 males) were engaged in the study. The data sets of two male participants had to be discarded, since routine check prior to data analysis revealed that they were outliers with the overall recognition accuracy beyond ±3 standard deviations (SDs) of other male participants. Thus, the data of 26 male participants entered the data processing. None of them had head injuries, a history of mental disorders (including autism spectrum disorders (ASD), SZ, and MDD), or regular drug intake (medication). Males were aged 23.69 ± 3.90 years (mean ± SD; median, Mdn, 23 years, 95% confidence interval, CI [23.08, 24.31]; age range 18–33 years), and females 22.28 ± 3.34 years (Mdn, 22 years, 95% CI [21.74, 22.82]; age range 18–31 years), with no age difference between the groups (Mann-Whitney test, $U = 261$, $p = 0.230$, two-tailed, n.s.). As performance on the task required a proficient language command, German as native language (mother tongue) served as an inclusion criterion. We also strived for homogeneity in respect to cultural background that can potentially affect reading of masked faces[31]. The number of participants was determined prior to the study by demands of statistical data processing. As in previous work[48–51], gender was self-identified by participants; there were also no female participants with extreme masculine appearance and behavior, and vice versa. All observers had normal or corrected-to-normal vision. Participants were run individually and were naïve as to the purpose of the study. None had previous experience with such displays and tasks. The study was conducted in line with the Declaration of Helsinki and approved by the local Ethics Committee at the University of Tübingen Medical School. Informed written consent

Fig. 2 A female poser expressing six basic emotions. Faces are shown under full-face (top) and covered-by-mask conditions (bottom row). From Carbon, Front. Psychol. (2020), the Creative Commons Attribution [CC BY] license. These images are presented for illustrative purposes only, and had not been used as experimental material in the present study.

was obtained from all participants. Participation was voluntary, and the data sets were processed anonymously.

Face stimuli, task, and procedure

The original face stimuli without masks were taken from the MPI FACES database[52] with the project-specific permission, and then modified by superimposing face masks with a graphics editor[9]. Frontal photographs of six (three female and three male) Caucasians were used from three distinct age groups (young, middle, and older age). Each depicted person displayed six emotional states (anger, disgust, fear, happiness, sadness, and neutrality; Fig. 2). A typical face mask in beige (a so-called "community mask" commonly used during the COVID-19 pandemic) was applied by means of a graphics editor to all faces and adapted individually to properly fit the specific face. Realistic shadow effects were added to improve the naturalistic impression of the images with masked faces (Fig. 2). The stimulus set comprised 36 images (6 emotions × 2 genders × 3 age groups) repeated three times per session, resulting in a total of 108 trials. As the task was designed for later use in patients, unlike[9,14], we used only two (one correct and one incorrect) rather than all possible six alternative responses for emotion recognition. Using only two response alternatives leads to a considerable decrease in task difficulty (in the sense of decision-making complexity as well as reliance on language proficiency and comprehension) and test duration, both of which are welcome in examination of patients. The response alternative pairs were chosen based primarily on the emotion confusion data[9,14]: angry— disgusted, fearful—sad, and neutral—happy. For avoiding possible transfer and passive leaning effects on emotion recognition, we used masked faces only.

Participants were administered a computer version of the emotion recognition task by using Presentation software (Neurobehavioral Systems, Inc., Albany, CA, USA). The stimuli subtended a visual angle of 9.8° × 9.8° at an observation distance of 70 cm. They were presented in a pseudo-randomized order, one at a time for 2 s in three runs separated by short breaks. A schematic representation of experimental procedure (each trial) is given in Fig. 3. Upon image offset, two words (correct and incorrect

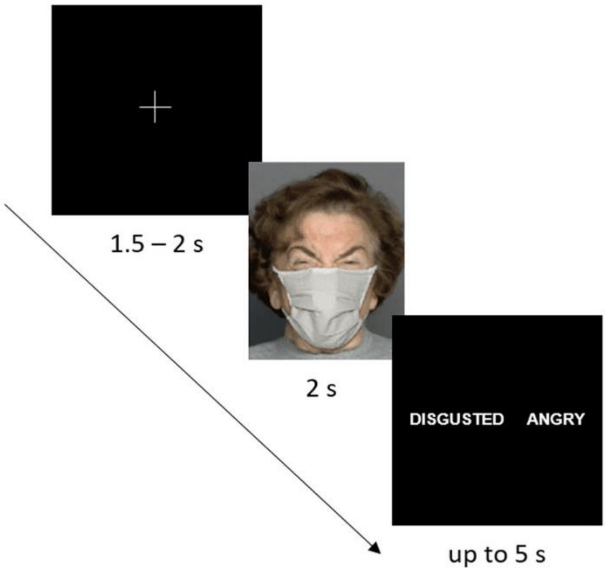

Fig. 3 Schematic representation of experimental procedure. Each trial started with presentation of a white fixation cross in the middle of the screen for 1.5–2 s followed by 2-s presentation of one out of six facial emotional expressions hidden behind a mask. After stimulus presentation, participants had to indicate, within 5 s in a 2AFC task, the displayed emotion by choosing one response option among two alternatives (correct and incorrect response; for example, either disgusted [correct] or angry [incorrect] facial expression). The face image is presented for illustrative purposes only, and had not been used as experimental material in the present study.

responses) appeared on the right and left sides of a black screen. The correct response position varied randomly across trials. Participants were asked to respond as accurately but also as fast as possible once a response screen was on (with a time limit of 5 s). On each trial, they had to indicate a displayed emotion by pressing a respective key on the side of correct response. Once a response was given (or else the time limit elapsed), a white fixation cross appeared for a duration jittered between 1.5 and 2 s prior to the start of next trial. Instructions were carefully explained to participants and their understanding had been proven with pre-testing (about ten trials) performed under supervision of an examiner. No immediate feedback was provided to participants. The testing lasted for about 15 min.

Data processing and analysis

Prior to statistical data processing, normality of data distributions was routinely examined by using Shapiro-Wilk tests with subsequent use of either parametric (for normally distributed data sets) or non-parametric statistics. For not normally distributed data sets, additionally to means and SDs, Mdns and 95% CIs are reported. Statistical inference was accomplished by means of mixed-model analyses of variance (ANOVAs, the outcome of which is reported to be resistant to normality of data distribution[53–55]) and post-hoc pairwise comparisons by using Tukey's honestly significant difference (HSD) tests with software package JMP (Version 16, SAS Institute, Cary, NC, USA). Non-parametric statistics (Mann–Whitney test and Wilcoxon signed-rank test) were performed for between- and within-group comparisons, respectively, with MATLAB (version 2022a; MathWorks Inc., Natick, MA, USA).

RESULTS

Recognition accuracy

Individual correct response rates were submitted to a two-way mixed-model ANOVA with the within-subject factor Emotional Expression (angry, fearful, neutral, disgusted, happy, and sad) and between-subject factor Observer Gender (female/male). A main effect of Gender was significant ($F(1,245) = 4.17$, $p = 0.042$; effect size, eta-squared $\eta^2 = 0.079$), albeit, contrary to our expectations, with a higher emotion recognition accuracy in males than in females (Fig. 4). A main effect of Emotional Expression was highly significant ($F(5,245) = 78.15$, $p < 0.0001$; effect size, $\eta^2 = 0.615$). A Gender by Emotion interaction tended to reach significance ($F(5,245) = 2.14$, $p = 0.062$).

In accord with previous findings (see "Introduction" section), the outcome shows that face masks disproportionally affect facial emotional recognition: the most recognizable (close to the ceiling level of performance, Fig. 4) were neutral expression, fear, and happiness, whereas disgust, sadness, and angriness turned out to be least recognizable. As this analysis is beyond the focus of the present study, the outcome of post-hoc pair-wise comparisons (two-tailed Tukey HSD, multiplicity adjusted) is provided in Supplementary Material (Tables S1–S2). As seen from Table 1 summarizing the outcome of the least squares mean analysis (expressions with no differences in recognition are marked by the same letter), the most recognizable were neutral expressions and fear (without any difference between them, both marked by A),

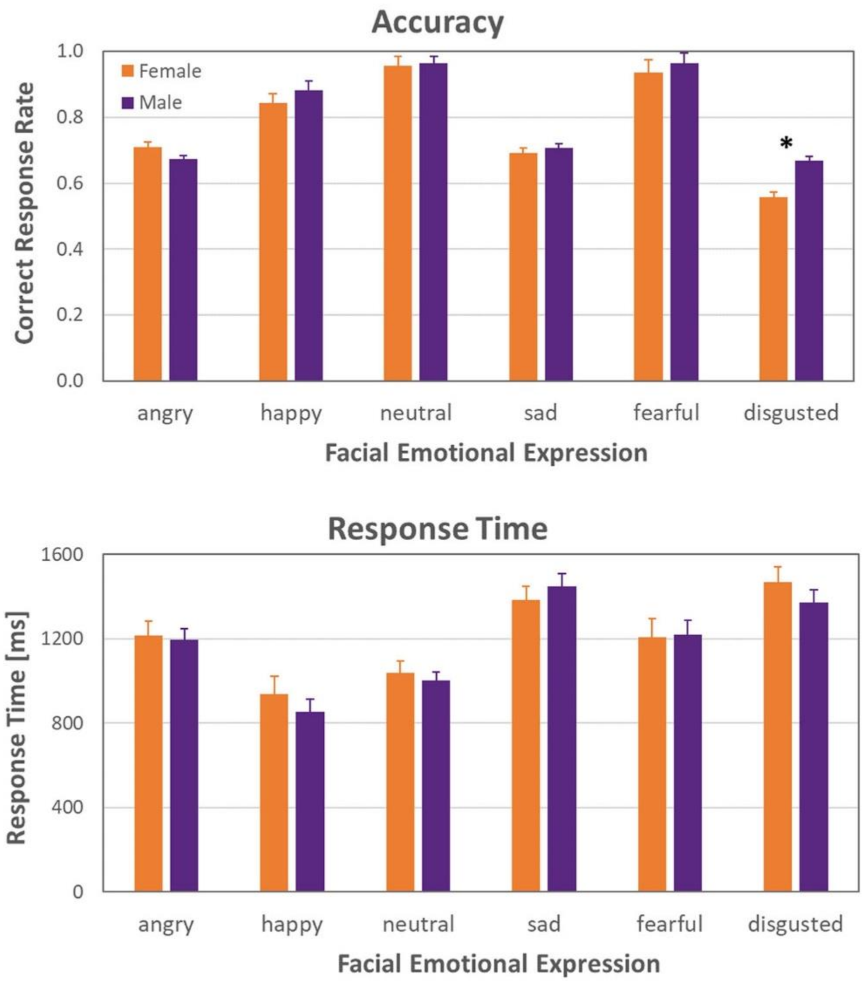

Fig. 4 Gender impact on reading emotions in masked faces. Mean correct response rate (top panel) and mean response time, RT (bottom panel) for recognition of facial emotions hidden behind a mask in female (orange) and male (violet) participants. Vertical bars represent ±SEM. Asterisks indicate significant differences ($p < 0.05$).

followed by happiness (marked by B), and then by sadness and anger (without any difference between them, both marked by C). Disgust was the most poorly recognizable emotion.

Contrary to our expectations, males were more proficient than females in recognition of disgust (males, 0.61 ± 0.12, and females, 0.56 ± 0.19; $t(49) = 3.34$, $p = 0.044$, corrected, $p = 0.007$, uncorrected; Tukey HSD corrected, two-tailed; effect size Cohen's $d = 0.954$). As seen in Fig. 4, no gender differences occurred for all other emotions. A further analysis (performed separately for female and male faces) showed that mostly female faces behind a mask contributed to hitches in disgust recognition in both female and male beholders (Fig. 5). Both female and male participants recognized disgust in female masked faces substantially poorer than in male faces (for females, Wilcoxon signed-rank test, $z = 3.59$, $p < 0.0003$, two-tailed, effect size $d = 2.063$; for males, $z = 3.50$, $p < 0.0005$; two-tailed, effect size $d = 1.888$). As expected, males excelled on recognition of disgust in female faces and tended to be more proficient in male faces (for female faces, Mann–Whitney test, $U = 231$, $p = 0.039$; for male faces, $U = 247$, $p = 0.072$).

Table 1. Least squares mean rates for recognition of emotions behind a mask.

Emotion		Least squares mean
Neutral	A	0.960
Fearful	A	0.949
Happy	B	0.862
Sad	C	0.700
Angry	C	0.691
Disgusted	D	0.613

Note: Top to bottom, the most to least recognizable emotions; emotions with no significant differences in recognition are marked by the same letter.

Response time

Individual response time (RT) values for correct responses were submitted to a two-way mixed-model ANOVA with the within-subject factor Emotional Expression (angry, fearful, neutral, disgusted, happy, and sad) and between-subject factor Observer Gender (female/male). Note, the analysis of RT plays only a secondary role, since participants had been asked to respond as soon as possible after the stimulus offset. A main effect of Gender was not significant ($F(1,245) = 1.22$, $p = 0.270$, n.s.), whereas a main effect of Emotional Expression was highly significant ($F(5,245) = 57.33$, $p < 0.0001$; effect size, $\eta^2 = 0.539$). As seen in Fig. 4, in accord with the recognition accuracy analysis, the fastest responses were given for neutral expression, fear, and happiness, while RTs for disgust and sadness were longer. A Gender by Emotion interaction failed to reach significance ($F(5,245) = 0.97$, $p = 0.436$, n.s.). Pair-wise comparisons did not reveal any gender differences in RT for all emotions.

DISCUSSION

This work was aimed at investigation of gender impact on the recognition of facial emotions hidden behind a mask. The outcome indicates that: (i) Masks hamper recognition (both accuracy and RT) of emotions in a different way: while some emotions such as happiness, fear, and neutral expressions remain rather well recognizable even when a face is hidden behind a mask, others such as anger, sadness and, in particular, disgust are poorly recognizable. This is in close agreement with previous research[2,5]. (ii) Contrary to our expectations, however, males were, in general, more proficient in facial emotion recognition, in particular, in recognition of disgust behind a mask, than females. A large body of earlier studies analyzing gender impact on reading

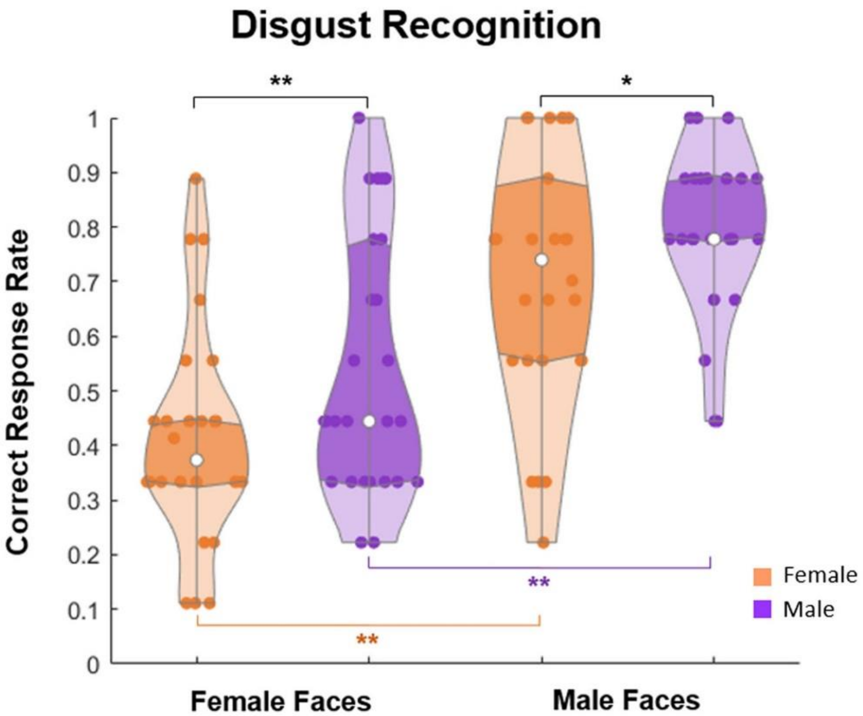

Fig. 5 Violin plot of disgust recognition rates in masked female and male faces. Mean correct response rate for recognition of disgust hidden behind a mask in female (orange) and male (violet) participants separately for female and male posers. Vertical bars represent ±SEM. Double asterisks indicate significant differences ($p < 0.05$), single asterisk indicates a tendency ($p = 0.07$).

covered faces has been conducted online with samples heavily predominated by females. Comparison of gender differences in unbalanced samples may result in paradoxical statistical outcomes. A few studies (with designs balanced in respect to gender) either report the absence of gender differences[14,17], or reveal female superiority in reading covered faces[43]. In particular, women are reported to show a better performance for subtle expressions such as surprise and sadness, both in masked and whole-face conditions, and men excel in recognition of fear, especially in masked faces[20]. Research on reading language of the eyes as assessed by the RMET also implies female superiority in reading masked faces[45]. However, it was not the case in the present study. Noteworthy, males are reported to be more proficient than females in recognition of emojis (especially negative ones), while females are better in recognition of natural facial expressions[56]. The lack of fine-grained structure in emojis appears to be more favorable for males. This strategy may be also more profitable for males while reading covered by masks faces. (iii) Furthermore, compared to masked male faces, disgust represented in female faces is particularly poorly recognizable by both female and male beholders. These items will be discussed further in turn.

Why is disgust in masked faces recognized so poorly?

It is widely believed that the eyes represent the window to the soul[45]. Yet, in the same vein as previous research, the present findings indicate that (i) not all emotions are equally affected by face masks covering the lower portion of a face, and (ii) digital superimposing masks on photographs of faces consistently results in a substantial decrease in inferring sadness and disgust as well as their perceived intensity and confidence in recognition[9–27]. The most probable reason for this is that disgust is expressed primarily by the lower part of a face, namely, by a mouth and a nose[3,4]. In particular, disgust expressions are predominately comprised of the nose wrinkle, lip corner pullers, and lower lip depressor[34,57,58]. In accord with this, longer fixation on the mouth positively ties with recognition accuracy of disgust (as well as anger)[59]. Furthermore, disgust recognition benefits more than other basic emotions from audiovisual information as compared with video-only or audio-only conditions[60]. An area of the eyes and surrounding regions may be rather comparable when expressing sadness, disgust, and anger, sharing similar activation of muscles of the upper face part (Fig. 2). This may lead to perceptual errors of mistaking these emotions for one another[9,14,21,23].

Why do males excel in disgust recognition? Why is disgust less recognizable in female faces?

Recognition of disgust is heavily affected by a face mask in both female and male observers, albeit it is easily recognizable by healthy people in unmasked faces[9,14]. The present study shows that disgust recognition is affected in women more severely than in men. One may ask why males are more proficient in reading disgust in covered faces. One possible explanation would be that females and males use different gender-dependent perceptual strategies. For example, eye tracking indicates that females look at the eyes before looking at the mouth for angry, happy, and surprised, but not for disgusted, fearful or sad facial expressions[61]. When information from a mouth is absent (hidden behind a mask), this strategy may be inefficient for disgust recognition. Different perceptual styles (either global/holistic or local) may also account for gender differences in reading disgust in masked faces. It is believed that females possess a rather holistic perceptual style, whereas males a rather local one with an effortful piecemeal analysis of facial features and cues[51,62–67]. Obviously, face covering more heavily affects the holistic style requiring appearance of faces in their entirety, whereas the local information processing style allows extracting some subtle cues pointing to disgust in the upper part of faces. This is in line with the study in Japanese individuals revealing that people who are capable of inferring complex mental states of others from *subtle* cues may be less susceptible to the negative impact of mask wearing[25]. Moreover, individuals with a higher empathic concern demonstrate higher recognition level for disgust in masked faces[29]. Reportedly, women not only experience emotional disgust more often, but also spend more time attending to disgust facial expressions than men[68]. In our opinion, however, aversive behavior toward disgust seems to be more plausible. In line with this, as compared to female SZ patients, male individuals with SZ excel in recognition of disgust in unmasked faces[69]. Apparently, this agrees with the present findings indicating that reading disgust in masked female faces may be more demanding than in male faces, and for female as compared to male observers. One possible account for this may be that female posers express disgust even to a greater degree by the lower part of a face than male posers as well as even less by the upper part of a face. These assumptions, however, call for further experimental support.

Reading covered faces in mental and neurological disorders

As mentioned earlier, reading covered faces may be particularly challenging for individuals with mental, neurological, neurodevelopmental, and psychosomatic disorders[2]. However, experimental evidence is sparse. Among patients with MDD, SZ, bipolar disorder (BD), and TD individuals, patients with MDD and SZ exhibit most difficulties in identifying subtle (but not intense) expressions of happiness[70]. While masks heavily impact recognition of happiness and sadness in TD and ASD persons, reading of anger is unaffected in both groups. Yet, disgust recognition in covered by masks faces is similarly diminished in both groups[71]. In the absence of high levels of comorbid alexithymia (difficulties in identifying and describing emotions experienced by oneself or others), no evidence is reported for deficient emotion recognition with masked faces in ASD[72]. By contrast, healthy individuals with higher scores on the AQ-10 (the 10-item Autism Spectrum Quotient) are less accurate and confident in facial expression recognition, perceiving emotional expressions as less intense[12]. Yet, another study in TD individuals reveals that reading emotions in masked faces is unrelated to alexithymia as assessed by the 20-item Toronto Alexithymia Scale as well as to autistic traits expression as measured by the Autism Spectrum Quotient[23]. Individuals with developmental prosopagnosia (DP, a neurodevelopmental condition characterized by lifelong deficits in face recognition of neural and genetic origins[73]) exhibit the same level of facial emotion recognition of unmasked faces as neurotypical controls, but demonstrate deficits in subtle emotion recognition in masked faces, in particular, mistaking happiness for neutral expression[74]. Facial emotion recognition is affected by masks in cognitively unimpaired relapsing-remitting patients with multiple sclerosis (MS); these patients also exhibit selective impairments in recognition of fear both in unmasked and masked faces[75].

In a nutshell, the primary novel outcome of the present study indicates that males are not over-performed by female peers in reading basic emotions in covered by masks faces. In particular, reading disgust in masked faces is more demanding for females than for males, and for female than for male faces expressing disgust. These findings may help to explain gender/sex differences in disgust recognition that is of substantial value for understanding and treatment of mental disorders. Disgust is considered *the forgotten emotion of psychiatry*[76] that *explains everything*[77]. Moreover, disgust is one of the primal emotions that define a uniquely human social cognitive domain[57,58]. Most important, a wide range of mental disorders (anxiety disorders, obsessive-compulsive disorder (OCD), specific phobias, depression, eating disorders, and body dysmorphia) are characterized by alterations in expression and/or recognition of disgust. In response to images (non-face, scenic) eliciting disgust, individuals with SZ exhibit alterations in functional magnetic resonance imaging (fMRI) brain activation, in particular, hyperactivation of the right temporal cortex[78]. In response to briefly exposed facial disgust expressions, reduced fMRI activation of the insula is reported in patients with SZ; moreover, this activation is positively linked to social loneliness and negatively tied with agreeableness[79]. For understanding the value of disgust for mental health, many exciting research avenues remain to be explored.

DATA AVAILABILITY

The data supporting the conclusions of this paper are either included in the paper or will be made available by the authors upon request to any qualified researcher.

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AUTHOR CONTRIBUTIONS

Conceived and designed the study experiments: M.A.P. and A.N.S. Performed testing: J.M. Analyzed the data: J.M., A.N.S., and M.A.P. Contributed materials/analysis tools: M.A.P., C.C.C., A.N.S., and A.J.F. Participant recruitment: J.M. Wrote the paper: M.A.P., A.N.S., and J.M. All co-authors contributed to the writing and editing. Supervision and administration of the whole project: M.A.P.

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The authors declare no competing interests.

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2.1.1 Supplementary tables

Table S1. Pairwise comparisons (Tukey HSD, two-tailed, multiplicity adjusted) for an ANOVA main effect of Emotional expression recognition.

Emotion Pair		t value	P
Anger	Happy	- 7,25	< 0.001
Anger	Neutral	- 11,44	< 0.001
Anger	Sad	- 0,38	0.999
Anger	Fear	- 10,96	< 0.001
Anger	Disgust	3,29	0.015
Happy	Neutral	- 4,19	< 0.001
Happy	Sad	6,87	< 0.001
Happy	Fear	- 3,71	0.004
Happy	Disgust	10,54	< 0.001
Neutral	Sad	11,07	< 0.001
Neutral	Fear	0,48	0.997
Neutral	Disgust	14,73	< 0.001
Sad	Fear	- 10,58	< 0.001
Sad	Disgust	3,67	0.004
Fear	Disgust	14,25	< 0.001

Table S2. Consolidated matrix of statistical differences (two-tailed HSD *p*-values, multiplicity adjusted) between emotion expressions as provided in Table S1

	Neutral	Fear	Happy	Sad	Anger	Disgust
Neutral		0.997	< 0.001	< 0.001	< 0.001	< 0.001
Fear	0.997		0.004	< 0.001	< 0.001	< 0.001
Happy	< 0.001	0.004		< 0.001	< 0.001	< 0.001
Sad	< 0.001	< 0.001	< 0.001		0.999	0.004
Anger	< 0.001	< 0.001	< 0.001	0.999		0.015
Disgust	< 0.001	< 0.001	< 0.001	0.004	0.015	

Significant values are given in green.

2.2 Reading language of the eyes in female depression

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Feature Article

Reading language of the eyes in female depression

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Aberrations in non-verbal social cognition have been reported to coincide with major depressive disorder. Yet little is known about the role of the eyes. To fill this gap, the present study explores whether and, if so, how reading language of the eyes is altered in depression. For this purpose, patients and person-by-person matched typically developing individuals were administered the Emotions in Masked Faces task and Reading the Mind in the Eyes Test, modified, both of which contained a comparable amount of visual information available. For achieving group homogeneity, we set a focus on females as major depressive disorder displays a gender-specific profile. The findings show that facial masks selectively affect inferring emotions: recognition of sadness and anger are more heavily compromised in major depressive disorder as compared with typically developing controls, whereas the recognition of fear, happiness, and neutral expressions remains unhindered. Disgust, *the forgotten emotion of psychiatry*, is the least recognizable emotion in both groups. On the Reading the Mind in the Eyes Test patients exhibit lower accuracy on positive expressions than their typically developing peers, but do not differ on negative items. In both depressive and typically developing individuals, the ability to recognize emotions behind a mask and performance on the Reading the Mind in the Eyes Test are linked to each other in processing speed, but not recognition accuracy. The outcome provides a blueprint for understanding the complexities of reading language of the eyes within and beyond the COVID-19 pandemic.

Key words: face covering; emotions; major depressive disorder; female depression; masked faces; mental health; RMET.

Introduction

Non-verbal communication is based on various body cues such as posture, eye contact, and facial expressions, which play a pivotal role in social interaction (de Gelder 2006; Tamietto et al. 2007; van den Stock et al. 2007; de Gelder et al. 2010; Atkinson et al. 2012; Pavlova 2012; Bidet-Ildei et al. 2020; Kret et al. 2020; Sokolov et al. 2020; Pavlova and Sokolov 2022a, b; Pavlova et al. 2022, 2023b) by influencing the interpretation of spoken language (Wilms et al. 2022). An Arabic proverb wisely suggests *"Eyes speak louder than tongues,"* underscoring significance of the eyes in conveying unspoken messages. It seems obvious that at least a basic understanding of non-verbal communication is of immense value for adaptive social integration and interaction, as non-verbal information may either be used to add nuances or even completely change the meaning of what is (or is not) being said.

Non-verbal social cognition is well-known to be impaired in a wide range of mental, neurological, and neurodevelopmental disorders. Major depressive disorder (MDD) has also been associated with aberrant social and interpersonal functioning (Koelkebeck et al. 2018; Langenbach et al. 2023). Deficits in social cognition may contribute to the development and maintenance of interpersonal difficulties in MDD. However, as revealed by several meta-analytic reviews, the outcome of the experimental studies on emotion recognition in MDD is rather controversial, with the effect sizes being rather small, and some studies underpowered (Demenescu et al. 2010; Dalili et al. 2015; Krause et al. 2021).

MDD is a prevalent mental condition with significant impact on individuals' well-being and societal functioning. It is classified by the World Health Organization (WHO) as one of the most common psychiatric disorders and is ranked as one of the leading causes of the number of years lost due to disability (World Health Organization 2020). MDD is characterized by symptoms such as mood deterioration, indifference, sleep disturbances, and diminished appetite (Caroleo et al. 2019; Yang et al. 2022). As most mental conditions, MDD is gender (a social construct reflecting social norms, roles, biases, and practices)- and sex (a neurobiological construct)-specific, possessing a skewed ratio. Gender disparities are evident in MDD diagnosis, with females twice as likely to be diagnosed, and in symptom profiles (Friedrich 2017; Salk et al. 2017). Males are found to have worse insight into their disease and more often exhibit feelings of angriness, irritation, and frustration (Sabic et al. 2021) as well as risky and escaping behaviors such as substance abuse and promiscuity (Cavanagh et al. 2016; Herreen et al. 2022). Females show a more conventional clinical picture with depressed mood and disturbances of sleep and appetite (Cavanagh et al. 2017; Sabic et al. 2021), along with excessive self-reproach and diminished libido (Smith et al. 2008). Understanding gender/sex-specific manifestations, in particular, in social cognition, might be of particular value for tailored interventions and treatment approaches.

With isolation during the COVID-19 pandemic exacerbating loneliness, a strong association was revealed between loneliness and depressive and anxiety disorders (Steen et al. 2022). MDD often presents in a synergistic relationship with loneliness, with each predicting the other (Cacioppo et al. 2006). Moreover, loneliness may impede the recovery of MDD patients (van den Brink et al. 2018). Loneliness by itself was found to be indicative of deficits in emotion recognition (Okruszek et al. 2024).

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Fig. 1. A female poser expressing 6 basic emotions. Faces are shown under full-face (top) and covered-by-mask conditions (bottom row). From Carbon (2020), Frontiers Psychology, the Creative Commons Attribution [CC BY] license (https://creativecommons.org/licenses/by/4.0/). These images are presented for illustrative purposes only and have not been used as experimental material here.

Fig. 2. An example of images used in the RMET. From Baron-Cohen et al. (2001). J Child Psychol Psychiatry. Copyright ©2003 by John Wiley and Sons Inc, reprinted with permission of the publisher.

The COVID-19 pandemic adds further complexity to social cognition due to widespread mandatory mask usage. Yet, aberrant facial affect recognition caused by facial masks remains in the focus of attention within and beyond the pandemic, as face masks find ubiquitous use in medicine, where they pose a hurdle in patient-healthcare provider communication, for example, in dental practice. Masks not only reduce the overall amount of facial information available, but also introduce perceptual biases and prejudices affecting person-to-person social interaction at large (Leder et al. 2022; Pavlova and Sokolov 2022a; Pavlova et al. 2023a, b). Face masks do not lead to equally deficient recognition of all emotions: sadness and disgust are most heavily affected (Carbon 2020; Bani et al. 2021; Noyes et al. 2021; Blazhenkova et al. 2022; Grahlow et al. 2022; Grenville and Dwyer 2022; Kastendieck et al. 2022; Kim et al. 2022; Leder et al. 2022; Maiorana et al. 2022; Proverbio and Cerri 2022; Rinck et al. 2022; Tsantani et al. 2022; Verroca et al. 2022; Gil and Le Bigot 2023; Ikeda 2023; Proverbio et al. 2023; Ventura et al. 2023; Thomas and Caharel 2024), whereas neutral expressions (Carbon 2020; Noyes et al. 2021; Cooper et al. 2022; Leder et al. 2022; Rinck et al. 2022; Gil and Le Bigot 2023), fear (Carbon 2020; Bani et al. 2021; Leder et al. 2022; Verroca et al. 2022; Thomas and Caharel 2024), and happiness (Maiorana et al. 2022) appear to be most resistant to mask wearing. This differential impact of medical masks on inferring emotions reflects a weight of facial landmarks: The lower part of a face is considered indispensable mainly for the recognition of disgust, the upper portion for anger and fear, and both for surprise and sadness (Bassili 1979; Wegrzyn et al. 2017). Facial landmarks relevant to emotion recognition are often related not only to the upper or lower part of the face, but specifically to the eyes and mouth (Wegrzyn et al. 2017; Bozkurt et al. 2024), with the nose regarded rather as a distracting element as it provides little information (Fujihara et al. 2023) and is fixated upon most often by anxious individuals (Green and Guo 2018).

Covering faces with masks leaves a comparable amount of visual information for face reading as the Reading the Mind in the Eyes Test (RMET), which contains a set of photographs of the eyes along with the surrounding part of a face (Baron-Cohen et al. 2001; for review, see Pavlova and Sokolov 2022a, b). Indeed, in a sample heavily predominated by females (88 males, 133 females), the RMET was found to predict affect recognition accuracy in masked faces (Swain et al. 2022). Considering well-documented (relatively small, but persistent) female proficiency in reading language of the eyes as assessed by the RMET (Baron-Cohen et al. 2015; Pavlova and Sokolov 2022a, b), one can expect females to also excel in reading emotions in faces covered by masks. However, the outcome of studies (mostly conducted online with samples predominated by females) is controversial, either revealing female advantage (Grundmann et al. 2021; Huc et al. 2023) or not (Carbon et al. 2022; Kim et al. 2022). By contrast, in a recent face-to-face study, typically developing (TD) males are found to be more proficient in emotion recognition, in particular, in inferring disgust, *the forgotten emotion of psychiatry* (Phillips et al. 1998), than their female peers (Pavlova et al. 2023b). Overall, females rate negative emotions covered by masks as more negative and positive emotions as more positive than males (Calbi et al. 2021). People with mental wellness issues, namely, high stress scores, are less accurate in inferring fear from faces covered by masks. In addition, under high perceived stress, males are slower (albeit females are faster) in recognizing happiness in masked faces (Huc et al. 2023).

Reading covered faces may be particularly challenging for individuals with MDD who have been characterized by aberrant social cognition already in the pre-pandemic period (Pavlova and Sokolov 2022b). To our knowledge, only a handful of studies have addressed this issue, and the outcome is rather inconclusive. In a relatively small and inhomogeneous sample of MDD patients ($n = 19$; 15 females, 4 males), masked happiness expressed with low (but not with high) intensity elicits difficulties in recognition as compared with unmasked faces as well as with TD controls ($n = 28$; 23 females, 5 males) and patients with bipolar disorder (BD; $n = 13$; 5 females, 8 males) (Escelsior et al. 2022).

The present work was directed at investigating reading of emotional expressions in faces covered by masks in female individuals with MDD. We set a focus on female MDD for several reasons, the primary of which was achieving group homogeneity. In addition, as mentioned above, (i) MDD is a gender/sex-specific mental disorder that presumably displays a gender-specific profile in social cognition; and (ii) with a high probability, the gender of beholders impacts the reading of covered faces, at least, the ability to infer specific emotions such as disgust (Pavlova et al. 2023b).

We intended to clarify (i) whether the recognition of facial affect in masked faces is impaired in female MDD; and (ii) whether and, if so, how the ability to infer emotions in masked faces is tied to reading language of the eyes as assessed by the RMET. Several reports point to difficulties of MDD patients, in particular, women (Wright et al. 2009), in recognizing sadness and anger even in unmasked full-seen faces as well as specific attitudes to social cues in angry and sad faces (Leyman et al. 2007; Dai and Feng 2009; Duque and Vázquez 2015; Branco et al. 2018; Kudinova et al. 2018; Flechsenhar et al. 2024). Therefore, we expected the perception of these emotional expressions would be particularly affected in faces covered by a mask. Moreover, as covering faces with masks leaves a comparable amount of information for face reading as the RMET (Pavlova and Sokolov 2022a, b), we anticipated to find a tie between reading emotions behind a mask and RMET performance. Finally, based on earlier evidence (Pavlova et al. 2023b), we also expected to find altered disgust recognition in MDD.

Materials and methods

Participants

In total, 61 female participants were engaged in the study. Thirty-one patients with MDD were recruited from the inpatient units at the Department of Psychiatry and Psychotherapy, University Hospital, Eberhard Karls University of Tübingen, Baden-Württemberg, Germany. The sample size was estimated prior to the study based on the requirements of statistical data processing, and was calculated considering possible dropouts. Twelve patients were diagnosed with a moderate episode of recurrent MDD (International Statistical Classification of Diseases and Related Health Problems, 10th Edition, ICD-10, F33.1), 12 with a severe episode of recurrent MDD (F33.2), 1 patient with a moderate depressive episode (F32.1), and 5 with a severe depressive episode without psychotic symptoms (F32.2). In the course of treatment, one patient was additionally diagnosed with paranoid schizophrenia (F20.0) and, therefore, was excluded from further data processing. In the final sample, 30 MDD patients were aged 37.07 ± 12.75 years (mean $\pm$ standard deviation, SD; median, Mdn, 33.5 years, 95% confidence interval, CI [32.31, 41.83]; age range, 19–58 years). The average time from the first diagnosis was 9.93 ± 9.43 years (Mdn, 8 years; 95% CI [6.41; 13.45]). Exclusion criteria comprised preterm birth (<37 gestation weeks), severe organic diseases and comorbid psychiatric conditions such as attention deficit hyperactivity disorder. Seventeen out of 30 patients had one or more comorbid disorders such as social phobia and alcohol abuse (Table S1, Supplementary Material). Twenty-six out of 30 patients were under routine medical drug treatment: All of them received antidepressants (including tricyclic and tetracyclic antidepressants, selective serotonin reuptake inhibitors, or serotonin and norepinephrine reuptake inhibitors). In addition, some patients received antipsychotics (13 individuals), mood stabilizers (1), neuroleptics (1), or opioids (1).

The data sets of 30 TD females, person-by-person matched for age with MDD patients, were used as a control. They were aged 36.80 ± 13.12 years (Mdn, 33.00 years, 95% CI [31.90, 41.70]). None of them had a history of neurological or mental disorders including MDD, schizophrenia, autism spectrum disorders, and regular intake of medication. They were recruited from the local community.

No age difference was found between the MDD and TD groups (Mann–Whitney test, $U = 435.50$, $P = 0.834$, 2-tailed, n.s.). As performance on the RMET (German version; see section below) requires language command of high proficiency, German as native language was used as one of the inclusion criteria. All observers had normal or corrected-to-normal vision. Participants were tested individually, and were naïve as to the purpose of the study. None had previous experience with such displays and tasks. The study was conducted in line with the Declaration of Helsinki and approved by the local Ethics Committee at the Medical School, Eberhard Karls University of Tübingen. Informed written consent was obtained from all participants. Participation was voluntary and the data sets were processed anonymously. Participants received a monetary reward for their participation.

Emotions in Masked Faces (EMF) task

The task is described in detail elsewhere (Pavlova et al. 2023b). The original photographs used as stimuli in the task were taken with project-specific permission from the MPI FACES database (Ebner et al. 2010; Fig. 1). Beige face masks were subsequently superimposed with a graphics editor on all faces and adapted individually to properly fit a face (Carbon 2020). Frontal photographs of 6 (3 female/3 male) Caucasians were used from 3 distinct age groups (young, middle, and older). Each depicted person displayed 6 basic emotional states (anger, disgust, fear, happiness, sadness, and neutrality). Realistic shadow effects were added to improve the naturalistic impression of the images. The stimulus set consisted of 36 images (6 emotions $\times$ 2 genders $\times$ 3 age groups) and was repeated 3 times per session, resulting in a total of 108 trials. The faces were not shown without a mask to avoid possible passive learning effects. For the EMF task, only 2 responses (1 correct and 1 incorrect) rather than all possible 6 alternative responses for emotion recognition were used in order to reduce the efforts needed for semantic comprehension and a runtime of the task as a whole, both of which are welcome in examination of patients. The response alternatives were chosen based primarily on the emotion confusion data (Carbon 2020; Carbon et al. 2022): *angry—disgusted*, *fearful—sad*, and *neutral—happy*.

Participants were administered a computer version of the task by using the Presentation software (Neurobehavioral Systems, Inc, Albany, California, United States of America). The stimuli subtended a visual angle of $9.8° \times 9.8°$ at an observation distance of 70 cm. They were presented in a pseudo-randomized order, one at a time for 2 s in 3 runs separated by short breaks. Upon image offset, 2 words (correct and incorrect responses) appeared on the right and left sides of a black screen. The correct response position varied randomly across trials. Participants were asked to respond as accurately but also as fast as possible once a response screen was on, with a time limit of 5 s. For each trial, they had

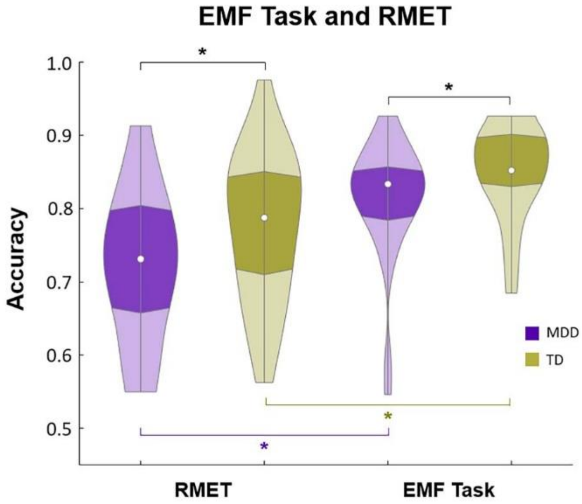

Fig. 3. Violin plots of accuracy on the RMET-M and EMF task in MDD (left violin plots, violet) and TD (right violin plots, olive green) females. Asterisks indicate significant differences ($P < 0.05$).

to indicate a displayed emotion by pressing the respective key on the side of a correct response. Once a response was given or the time limit elapsed, a white fixation cross appeared for a duration varying between 1.5 and 2 s prior to the next trial. Trials with missed responses were not repeated. The number of such trials in both tasks and participant groups was negligible: On the EMF task, 0.600 ± 1.163 responses were missed in MDD (Mdn, 0; 95% CI [0.166; 1.034]; not more than 5 by a single participant) and 0.452 ± 0.624 responses in TD (Mdn, 0; 95% CI [0.219; 0.685]; not more than 2 by a single participant). Instructions were carefully explained to participants and their understanding had been proven with pre-testing (about 10 trials), which had been performed under supervision of an examiner. No immediate feedback was given regarding performance.

Reading the Mind in the Eyes Test, modified

The original task is described in detail elsewhere (Baron-Cohen et al. 2001; for review, see Pavlova and Sokolov 2022b). In this study, a computer version of the RMET (M, modified; Pavlova et al. 2022) was administered. In short, the original version of the RMET consists of the eye portions of 36 monochrome photographs of female and male faces expressing a certain mental or affective state. On each trial, participants have to choose 1 of 4 alternative adjectives that best corresponds to the image. For the RMET-M, we reduced the 4 adjectives to 2 (correct/incorrect), so that the focus was shifted away from linguistic comprehension. For example, for an image in Fig. 2, beholders had to decide whether the person was alarmed (*besorgt*, incorrect) or serious (*ernst*, correct). The reduction of alternative responses also led to a shorter trial duration. In addition, instead of the original 36 images, 16 photographs were selected to compose a balanced set of stimuli containing an equal number of depictions of each gender (8 female/8 male images) and positive and negative expressions (8 positive/8 negative).

On the basis of previous research with the standard RMET version (Isernia et al. 2020), photographs, for which the task was most difficult, were kept to retain individual variability. Each session consisted of 80 trials (16 photographs × 5 repetitions) shown in a pseudo-randomized order, with each image displayed for 2 s, after which the 2 adjectives (correct and incorrect responses) appeared on the left and right of a black screen. The correct response position varied randomly across trials. Participants were asked to respond as accurately, but also as fast as possible during a time limit of 12 s. After each response, during an interstimulus interval that randomly varied between 2 and 3 s, a white fixation cross was displayed in the center of the screen. If participants failed to respond, the next trial started automatically. On the RMET-M, 0.100 ± 0.403 responses were missed in the MDD group (Mdn, 0; 95% CI [−0.050, 0.250]; not more than 2 by a single participant), while no misses occurred in the TD group. Completion of both the EMF task and RMET-M took about 30–35 min per participant.

Data analysis

Prior to statistical data processing, all data sets were routinely analyzed for normality of distribution using the Shapiro–Wilk test with subsequent use of either parametric (for normally distributed data) or nonparametric statistics. For non-normally distributed data sets, additionally to means and SDs, Mdns and 95% CIs are reported. Inferential statistics was performed by mixed-model analyses of variance, ANOVAs, and post hoc pairwise comparisons with the software package JMP (Version 16.2; SAS Institute, Cary, North Carolina, United States of America). Nonparametric statistics (Mann–Whitney and Wilcoxon signed rank tests) was computed for between- and within-group comparisons, respectively, with MATLAB (version 2023a; MathWorks, Inc, Natick, Massachusetts, United States of America).

Results

Recognition accuracy

The individual average correct response rates for the EMF task and RMET-M were submitted to a 2-way mixed-model ANOVA with the within-subject factor Task (EMF/RMET) and between-subject factor Disorder (Yes/No). A main effect of Task was highly significant ($F(1,58) = 35.61$, $P < 0.001$; effect size, *eta-squared* $\eta^2 = 0.380$), with more accurate responses on the EMF task than on RMET-M. As expected, a main effect of Disorder was also significant ($F(1,58) = 10.32$, $P = 0.002$; effect size, $\eta^2 = 0.151$), with patients performing generally less accurately. A Disorder by Task interaction was nonsignificant ($F(1,58) = 0.43$, $P = 0.515$; n.s.).

In both MDD and TD, the EMF task turned out to be a less difficult task than RMET-M: accuracy was lower on the RMET-M (Wilcoxon signed rank test, for MDD, $z = -3.65$, $P = 0.001$; for TD, $z = -3.18$, $P = 0.003$, 2-tailed; here and further false positive rate [FDR] corrected for multiple comparisons; Fig. 3). As expected, pairwise comparisons between TD and MDD females revealed a significant difference in RMET-M performance (0.721 ± 0.101 and 0.774 ± 0.099, for MDD and TD, respectively; $t(58) = 2.06$, $P = 0.022$, one-tailed; effect size, Cohen's $d = 0.53$). The difference between MDD and TD females on the EMF task was also significant (MDD, 0.812 ± 0.082; Mdn, 0.833, 95% CI [0.782; 0.842]; TD, 0.847 ± 0.063; Mdn, 0.852; 95% CI [0.823; 0.871]; Mann–Whitney test, $U = 314$, $P = 0.023$; one-tailed, effect-size, $d = 0.54$).

Emotion recognition on EMF task

In order to take a closer look at performance on different emotions on the EMF task, the individual accuracy rates for each emotion were submitted to a 2-way mixed-model ANOVA with the within-subject factor Emotion (Angry, Fearful, Neutral, Disgusted, Happy, and Sad) and between-subject factor Disorder (Yes/No). A main effect of Emotion was highly significant ($F(5,288) = 59.95$, $P < 0.001$; effect size, $\eta^2 = 0.508$). A main effect of Disorder was also significant ($F(1,288) = 9.67$, $P = 0.002$; effect size, $\eta^2 = 0.143$), with MDD patients performing generally worse than TD participants. An

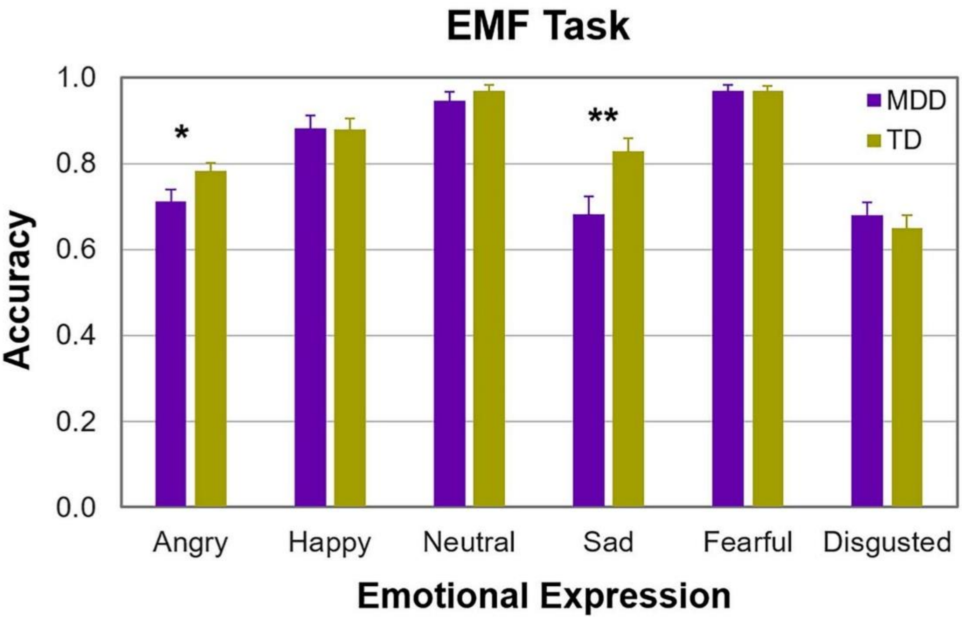

Fig. 4. Recognition accuracy of facial emotions on the EMF task in MDD (left bars, violet) and TD (right bars, olive green) females. Vertical bars represent ±SEM. Double asterisks indicate significant differences ($P < 0.05$), and single asterisk indicates a tendency ($P = 0.07$).

Emotion by Disorder interaction was significant as well ($F(5,288) = 4.71$, $P < 0.001$; effect size, $\eta^2 = 0.075$), indicating uneven differences in recognition of diverse emotions between MDD and TD.

As expected, pairwise group comparisons of accuracy for each emotion revealed that MDD females experience more difficulties in recognition of sadness in masked faces (MDD, 0.681 ± 0.225; TD, 0.830 ± 0.162; Mdn, 0.889; 95% CI [0.769; 0.891]; Mann–Whitney test, $U = 265.5$, $P = 0.018$, corrected [$P = 0.003$, uncorrected], one-tailed; effect size, $d = 0.75$). MDD patients also tend to be less accurate in recognition of anger (MDD, 0.711 ± 0.159; Mdn, 0.750, 95% CI [0.652; 0.770]; TD, 0.783 ± 0.104; Mdn, 0.833; 95% CI [0.745; 0.822]; $U = 316$, $P = 0.072$, corrected [$P = 0.024$, uncorrected]; one-tailed). No difference was found in recognition of all other emotional expressions behind a mask: happiness (MDD, 0.881 ± 0.165; Mdn, 0.944, 95% CI [0.819; 0.943]; TD, 0.880 ± 0.134; Mdn, 0.889; 95% CI [0.830; 0.930]; $U = 405.50$, $P = 0.732$, here and further 2-tailed, n.s.), neutral expressions (MDD, 0.946 ± 0.108; Mdn, 1.000, 95% CI [0.906; 0.986]; TD, 0.969 ± 0.075; Mdn, 1.000; 95% CI [0.941; 0.997]; $U = 377$, $P = 0.570$, n.s.), and fear (MDD, 0.970 ± 0.065; Mdn, 1.000, 95% CI [0.946; 0.994]; TD, 0.970 ± 0.054; Mdn, 1.000; 95% CI [0.950; 0.990]; $U = 445.50$, $P = 0.952$, n.s.).

Based on our previous findings (Pavlova et al. 2023b), we also expected to find alterations in disgust recognition in MDD. However, no difference was found in recognition accuracy of disgust in MDD as compared with TD (MDD, 0.680 ± 0.162; TD, 0.650 ± 0.159; $t(58) = 0.72$, $P = 0.310$, one-tailed, n.s.), most likely because disgust was poorly recognized even in TD. Indeed, as seen from Fig. 4 and indicated by the Steel–Dwass test (Table S2, Supplementary Material), disgust was the least recognizable emotion in TD, whereas fearful and neutral expressions were the most recognizable ones. In MDD, recognition accuracy did not differ between disgust, sadness, and anger. Recognition accuracy of happiness, fear, and neutral expressions in masked faces was close to the ceiling level and did not differ from each other as well (Table S2, Supplementary Material). The findings, therefore, show that face masks disproportionally affect facial emotional recognition not only in TD individuals (Pavlova et al. 2023b), but also in MDD females.

Even for the least recognizable masked emotions (sadness and disgust), recognition rates were above chance level in both MDD patients (sadness, $t(29) = 4.43$, $P < 0.001$; disgust, $t(29) = 8.52$, $P < 0.001$; 2-tailed tests throughout) and controls (sadness, $z = 4.65$, $P < 0.001$; disgust, $t(29) = 5.16$, $P < 0.001$).

RMET-M accuracy on positive and negative expressions

The individual accuracy rates separately for positive and negative expressions on the RMET-M were submitted to a 2-way mixed-model ANOVA with a within-subject factor Expression (Positive/Negative) and a between-subject factor Disorder (Yes/No). Information about recognition accuracy of positive and negative expressions was corrupted in the data sets of two participants. A main effect of Disorder was significant ($F(1,56) = 4.44$, $P = 0.040$; effect size, $\eta^2 = 0.073$). A main effect of Expression ($F(1,56) = 1.19$, $P = 0.279$, n.s.) as well as an Expression by Disorder interaction ($F(1,56) = 1.64$, $P = 0.206$, n.s.) were nonsignificant. As seen from Fig. 5, pairwise group comparisons indicated that MDD females were less accurate than their TD peers in recognition of positive expressions ($t(56) = 2.74$, $P = 0.032$, 2-tailed; corrected, effect size, $d = 0.72$), but no difference was found in recognition of negative expressions ($t(56) = 0.55$, $P = 0.782$, n.s.). All other pairwise differences were nonsignificant.

Response time

The detailed analysis of response time (RT) is provided in Supplementary Material. The main outcome is that, by contrast with recognition accuracy, MDD and TD females did not differ from each other in RT to different emotions on the EMF task. No difference in RT was found even for emotions on which MDD females were less accurate than their TD peers. Despite the difference in recognition accuracy, MDD and TD females did not differ in RT to positive and negative expressions on the RMET-M.

Relationship between EMF task and RMET-M

As covering faces with a mask leaves a comparable amount of visual information for face reading as the RMET (Pavlova and

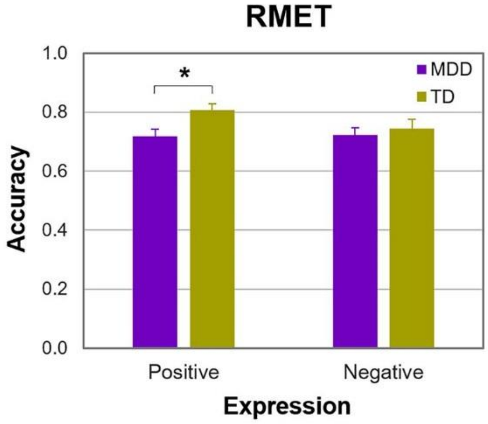

Fig. 5. Recognition accuracy for positive and negative expressions on the RMET-M in MDD (left bars, violet) and TD females (right bars, olive green). Vertical bars represent ±SEM. Asterisk indicates a significant difference ($P = 0.032$).

Sokolov 2022a, b), we expected to find a tie between emotion recognition behind a mask as assessed by the EMF task and RMET-M. For recognition accuracy, no significant correlation was found between these tasks either in MDD patients (Spearman's *rho*, $\rho(28) = 0.244$, $P = 0.195$, n.s.) or TD controls ($\rho(28) = 0.045$, $P = 0.813$; n.s.), whereas RT on the EMF task was positively linked to RT on the RMET-M both in MDD (Pearson's product moment correlation, $r(28) = 0.615$, $P < 0.001$) and in TD ($\rho(26) = 0.771$, $P < 0.001$) females (Fig. 6).

In MDD, accuracy rate on the EMF task (but not on the RMET-M; $\rho(28) = -0.188$, $P = 0.320$, n.s.) was negatively associated with chronological age ($\rho(28) = -0.562$, $P = 0.001$). In TD, neither accuracy on the RMET-M nor on EMF task was linked to chronological age ($\rho(28) = 0.045$, $P = 0.813$, n.s.; $\rho(28) = -0.206$, $P = 0.275$, n.s., respectively).

Discussion

This work was aimed at examination of facial affect recognition in masked faces in female MDD. The outcome indicates that patients with MDD experience more difficulties in the recognition of sadness behind a mask and tend to be less accurate in recognition of masked anger than their person-by-person matched TD peers. Furthermore, as faces covered by masks and the RMET-M provide comparable information to interpret facial expressions, we asked (i) whether and, if so, how the ability to read the language of the eyes, as assessed by the RMET-M, is altered in female MDD; and (ii) whether there is a tight link between face reading in masked faces and RMET-M performance in MDD. The findings reveal that MDD females exhibit more difficulties on the EMF task as well as on RMET-M as compared with TD individuals. However, the abilities to infer emotions behind a mask and RMET-M performance were linked to each other in terms of processing speed, but not recognition accuracy. These findings will be discussed further in turn.

Emotions behind a mask

The outcome of the study nicely dovetails with previous findings as well as with our earlier work involving young TD males and females (Pavlova and Sokolov 2022a; Pavlova et al. 2022, 2023b) demonstrating the disproportionate impact of face masks on emotion recognition. The study provides novel insights by showing that facial masks disproportionally affect inferring emotions in female MDD, leaving happiness, neutral expressions, and fear almost at the ceiling recognition level. Most importantly, as compared with their TD peers, females with MDD experience more difficulties in the recognition of sadness and anger.

Previous research suggests that individuals with MDD struggle with accurately identifying sadness and anger even in unmasked faces (Flechsenhar et al. 2024). Moreover, MDD individuals exhibit specific attitudes toward social cues in full-seen angry and sad faces (Leyman et al. 2007; Dai and Feng 2009). As compared to TD, patients with MDD show a negative attentional bias toward sad faces in attentional maintenance indices (first fixation duration and total fixation time), which is positively linked to the severity of symptoms (Duque and Vázquez 2015). MDD individuals overestimate the intensity of anger in faces, what may lead to erroneous interpretation of social cues (Branco et al. 2018). Women (but not men) with MDD are less accurate in recognizing fearful and sad faces, which they likely misinterpret as angry (Wright et al. 2009). Furthermore, in women with MDD, pupillary reactivity is observed in response to negative emotional expressions (sadness and anger), but not to positive emotions (Kudinova et al. 2018). Electroencephalographic studies indicate the reduced brain response to threatening (angry) faces in MDD (Foti et al. 2010). In addition, although effective recognition of sadness requires visual input from both the upper and lower face parts (Bassili 1979; Wegrzyn et al. 2017), depressed individuals orient their gaze overall less to the eyes and mouth than their TD peers (Bodenschatz et al. 2020). This type of behavior is also found in anxious individuals (Green and Guo 2018) and is thought to be a social avoidance strategy (Fiquer et al. 2018; Bodenschatz et al. 2020; Suslow et al. 2024). This leads to the assumption that sadness and anger possess a special status, at least, in female MDD.

Based on our previous considerations (Pavlova et al. 2023b), we expected to find alterations in disgust recognition in female MDD. It is suggested that MDD is associated with an imbalance of specific self- and other-blaming emotions rather than a general increase in negative emotions. More specifically, individuals with MDD (in a sample predominated by females) exhibit increased self-contempt as well as reduced disgust toward others (Zahn et al. 2015). Contrary to our expectations, no difference was observed in recognition accuracy of disgust in MDD as compared with TD, most likely because disgust was rather poorly recognized even in neurotypical females. Possible reasons for poor recognition of disgust, *the forgotten emotion of psychiatry* (Phillips et al. 1998), were discussed in detail earlier (Pavlova et al. 2023b). In brief, the most probable cause is that disgust is expressed primarily by the lower part of a face (Bassili 1979; Langbehn et al. 2022). In particular, disgust expressions are comprised of nose wrinkles, lip corner pullers, and lower lip depressor (Rozin et al. 1994; Langbehn et al. 2022). Furthermore, facial mimicry around the eyes may be rather akin for sadness, disgust, and anger, sharing similar activation of muscles (see Fig. 1). This may lead to perceptual errors, for example, of mistaking these emotions for one another (Carbon 2020; Carbon et al. 2022; Rinck et al. 2022; Verroca et al. 2022). Our earlier work indicated that TD females had more difficulties with disgust recognition behind a mask than their male peers (Pavlova et al. 2023b). Moreover, in masked faces, healthy individuals with higher empathic concern demonstrate a higher recognition level of disgust (Shepherd and Rippon 2023). Overall, TD women not only experience emotional disgust more often (Kraines et al. 2017), but may also exhibit aversive reactions toward potentially disgusted faces, which could further hinder recognition.

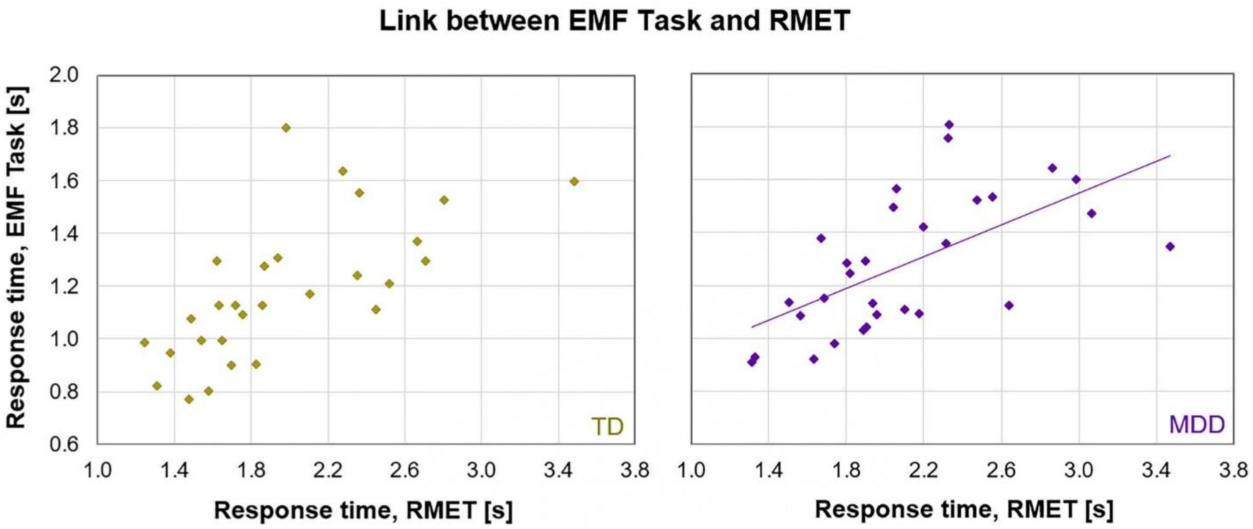

Fig. 6. Relationship between processing speed on the EMF task and RMET-M. Significant nonlinear correlation ($P < 0.001$) was found between RT on the RMET-M and EMF task in TD individuals (left panel, olive green), whereas significant linear correlation ($P < 0.001$) in MDD (right panel, violet).

RMET in depression

The present findings reveal a weakened ability for reading language of the eyes as assessed by the RMET-M in female MDD as compared to TD, and that this deficit stems primarily from a reduced capacity to infer positive expressions. Previous evidence on the RMET in MDD is not only sparse, but rather controversial (for review, see Pavlova and Sokolov 2022b). Reportedly, no difference occurs between MDD patients and healthy controls, and only MDD individuals who experienced childhood maltreatment, such as emotional abuse and neglect, score poorly on the RMET (Simon et al. 2019). Patients with MDD ($n = 37$, 20 females) and social anxiety disorder (SAD) exhibit no differences on the RMET, but perform worse on the Faux Pas Task tapping Theory of Mind as compared with SAD and controls (Maleki et al. 2020). On the Persian version of the RMET, patients with MDD ($n = 56$, 26 females) and stimulant-induced depressive disorder (SIDD; $n = 54$, 17 females) score lower, almost all of them under 22 points (with a maximal score of 36), with no difference between the groups (Razeghian Jahromi et al. 2024). RMET scores of Chinese patients with MDD ($n = 20$, 14 females) are lower than those of healthy controls, but significantly higher than those of individuals with BD (Chang et al. 2024). Several studies with MDD patients in Turkey also resulted in controversial outcomes. Individuals with MDD ($n = 68$, 51 females) do not differ from healthy controls ($n = 93$, 50 females) on the overall RMET scores as well as on negative, positive, and neutral items (Aydın et al. 2024). On the same wavelength, no difference on the RMET was found between MDD ($n = 55$, 37 females) and TD ($n = 50$, 45 females) (Cetin et al. 2021). On the other hand, MDD patients ($n = 55$; 12 females; MDD duration about 1 year) were significantly worse on the Turkish version of the RMET-revised than healthy controls ($n = 54$; 13 females) (Durmaz and Baykan 2020). Comparing these findings with the outcome of this study, it is of importance to bear in mind that the modified version of the RMET (RMET-M) [featuring 16 of the most difficult images, 2 (correct/incorrect) response options, and an equal number of both female/male (8/8) and positive/negative (8/8) expressions (**Methods**)] was used here. Furthermore, the experimental procedures were different: Instead of using each item only once in a session as in the RMET, here each of the 16 items appeared 5 times in a pseudo-randomized order to increase reliability of the collected data.

Relationship between RMET and EMF task

As faces covered by masks and the RMET contain comparable information for reading faces, we expected that face reading in masked faces (as assessed by the EMF task) and RMET performance might be intimately tied. Yet in both MDD and TD, inferring facial emotions behind a mask and reading language of the eyes as assessed by the RMET were linked to each other in terms of processing speed, but not recognition accuracy. The analysis reveals that for both MDD and TD females, the RMET turned out to be more challenging than the EMF task, potentially leading to greater variability in strategies and problem solving. Although the visual input is comparable, the tasks fundamentally differ in their nature: inferring basic emotions versus more intricate mental states.

Social cognition in MDD

Recent work on face pareidolia (our ability to see faces where there are none) in MDD indicates that patients exhibit intact sensitivity to faces in face-like non-face images (Kubon et al. 2021, 2023). This outcome agrees well with some previous studies indicating that social cognition deficits in MDD are less pronounced as compared to other neuropsychiatric disorders (Weightman et al. 2014). However, alternative perspectives point to substantial deficits in social cognition and their possible causal connection to symptom severity (Langenbach et al. 2023). As to facial affect, some studies report alterations, particularly a *negative bias*, a tendency to interpret ambiguous, neutral expressions or emotions more negatively and preferentially attend to negative information (Surguladze et al. 2004; Bourke et al. 2010; Csukly et al. 2011; Tong et al. 2020; Akhapkin et al. 2021; Nakamura et al. 2022), whereas other groups report no substantial deficits in processing of facial affect (Bediou et al. 2005; Joormann and Gotlib 2006; Gollan et al. 2010; Seidel et al. 2010; Monferrer et al. 2023). As proposed earlier, individuals with MDD may be particularly sensitive to social signals before the disease onset: Those with high sensitivity (or even with over-sensitivity) to social signals in combination with low psychological defense may be more prone to depression

(Kubon et al. 2021). Strictly speaking, individuals with MDD may be rather competent in perceiving and understanding of counterparts, but employ maladaptive strategies when dealing with social agents/signals or challenging situations indicated by these signals. Therefore, even if facial emotion perception in MDD appears *biased*, this is more likely to be the result of deeply rooted maladaptive cognitive strategies rather than *poor sensitivity* to social signals per se.

Considering the impact of the COVID-19 pandemic, which has affected face-to-face social interaction due to mandatory face-mask wearing (Pavlova and Sokolov 2022a), the present findings may be of special importance for maintaining effective social interaction in females with MDD. Yet, the findings are valuable also beyond the pandemic, as face masks are of universal use in medical practice, where they are known to negatively impact patient-healthcare provider communication and interaction (Wong et al. 2013; Wiesmann et al. 2021). Our study contributes to this outcome by demonstrating that recognition of certain emotions behind a mask, in particular, subtle ones such as sadness, represents a considerable challenge for females with MDD. A deeper understanding of reading language of the eyes in MDD calls for future tailored experimental work in male depression.

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Author contributions

Jonas Moosavi (Data curation, Formal analysis, Investigation, Visualization, Writing – original draft), Annika Resch (Data curation, Investigation), Alessandro Lecchi (Data curation, Investigation), Alexander N. Sokolov (Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing), Andreas J. Fallgatter (Funding acquisition, Resources, Writing – review & editing), and Marina A. Pavlova (Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing).

Supplementary material

Supplementary material is available at *Cerebral Cortex* online.

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Conflict of interest statement: None declared.

Data availability

The data supporting the conclusions of this paper are either included in the paper or will be made available by the authors upon reasonable request to any qualified researcher.

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2.2.1 Supplementary material

Table S1. Comorbidity

	Comorbidities (ICD-10 Code)
P02	Problems related to life-management difficulty (Z73)
P03	Social phobias (F40.1)
P04	Mental and behavioral disorders due to use of cannabinoids Harmful use (F12.1)
P06	Eating disorder, unspecified (F50.9) Problems related to life-management difficulty (Z73)
P07	Social phobias (F40.1)
P08	Panic disorder [episodic paroxysmal anxiety] (F41.0) Emotionally unstable personality disorder: Borderline (F60.31)
P09	Social phobias (F40.1) Predominantly compulsive acts [obsessional rituals] (F42.1)
P11	Mixed and other personality disorders (F61) Obsessive-compulsive disorder (42) Mental and behavioral disorders due to use of alcohol Harmful use (F10.1)
P13	Depersonalization-derealization syndrome (F48.1)
P19	Problems related to life-management difficulty (Z73) Mental and behavioral disorders due to use of sedatives or hypnotics Dependence syndrome (F13.2)
P20	Anxious [avoidant] personality disorder (F60.6)
P21	Post-traumatic stress disorder (F43.1) Mental and behavioral disorders due to use of tobacco Dependence syndrome (F17.2)
P22	Mental and behavioral disorders due to use of tobacco Dependence syndrome (F17.2)
P25	Mental and behavioral disorders due to use of opioids Harmful use (F11.1) Mental and behavioral disorders due to use of alcohol Harmful use (F10.1)
P26	Social phobias (F40.1)
P27	Anankastic personality disorder (F60.5)
P29	Mixed obsessional thoughts and acts (F42.2)

Table S2. Pairwise Steel-Dwass comparisons of recognition accuracy on the EMF task in MDD and TD

Emotion	Linking Letter	Median	Lower 95% CI	Upper 95% CI	*P*
MDD					
fearful	A	1.00	0.95	0.99	0.986
neutral	A	1.00	0.91	0.99	0.633
happy	A	0.94	0.82	0.94	0.001
angry	B	0.75	0.65	0.77	0.997
sad	B	0.67	0.60	0.77	0.999
disgusted	B	0.67	0.62	0.74	
TD					
fearful	A	1.00	0.95	0.99	0.983
neutral	A	1.00	0.94	1.00	0.004
happy	B	0.89	0.82	0.93	0.806
sad	B	0.89	0.77	0.89	0.505
angry	B	0.83	0.75	0.83	0.003
disgusted	C	0.67	0.58	0.70	

Note: *P*-values indicate differences in recognition accuracy for a preceding and subsequent emotion. Emotions are ordered according to their recognizability from the most to the least recognizable. The same letters indicate no difference in recognition between a preceding and subsequent emotion.

SUPPLEMENTARY RESULTS

Response Time

The individual correct response time (RT) for the RMET-M and EMF task were submitted to a two-way mixed-model ANOVA with the within-subject factor Task (RMET/EMF) and between-subject factor Disorder (Yes/No). A main effect of Task was significant ($F(1,56) = 227.28$, $p < 0.001$; effect size, $\eta^2 = 0.80$) as well as a main effect of Disorder ($F(1,56) = 4.78$, $p = 0.033$; $\eta^2 = 0.08$), with generally longer RTs in patients. A Disorder by Task interaction was nonsignificant ($F(1,56) = 0.09$, $p = 0.763$; n.s.). In both MDD and TD, shorter RTs on the EMF task are in line with their higher accuracy rates on the task, pointing to the RMET-M as the more difficult task (MDD, $t(29) = 10.86$, $p < 0.001$, $d = 1.74$; TD, Wilcoxon signed-rank test, $z = 4.62$, $p < 0.001$, $d = 3.59$; here and further two-tailed and false discovery rate [FDR] corrected for multiple comparisons).

Pairwise group comparisons show no significant difference in RT on the RMET-M (MDD, 2.11 ± 0.52 (here and throughout in seconds); TD, 1.97 ± 0.53, Mdn, 1.84, 95% CI [1.77; 2.18]; Mann-Whitney test, $U = 346$, $p = 0.254$; n.s.). The difference between MDD and TD on the EMF task was also nonsignificant (MDD, 1.28 ± 0.26; TD, 1.18 ± 0.27; $t(56) = 1.48$, $p = 0.145$; n.s.).

Response time on EMF task

In order to examine processing speed for distinct emotions in MDD and TD individuals, the individual correct RT for each emotion on the EMF task were submitted to a two-way mixed-model ANOVA with the within-subject factor Emotion (Angry, Fearful, Neutral, Disgusted, Happy, and Sad) and between-subject factor Disorder (Yes/No). Main effects of both Emotion ($F(5,280) = 73.14$, $p < 0.001$, $\eta^2 = 0.57$) and Disorder were highly significant ($F(5,280) = 21.53$, p

< 0.001, $\eta^2 = 0.28$). Yet, an Emotion by Disease interaction was nonsignificant ($F(5,280) = 0.49$, $p = 0.785$; n.s.).

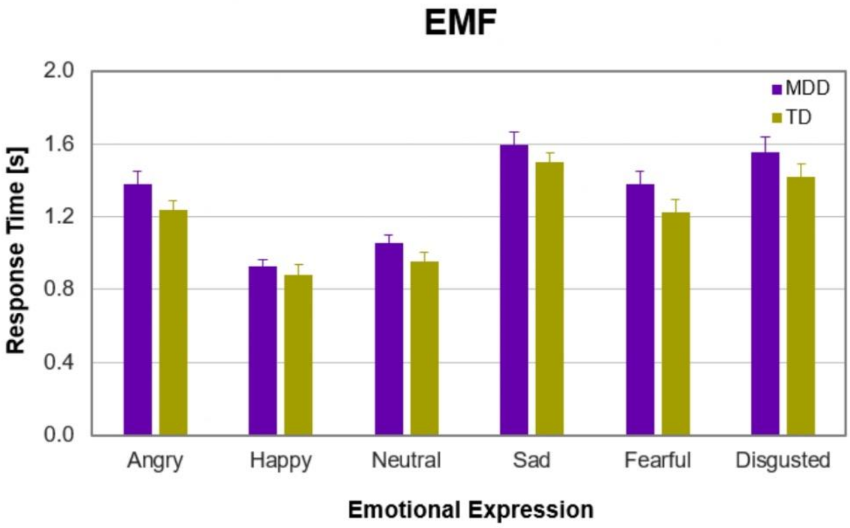

Figure S1. Response times of correct responses for facial emotions on the EMF task in MDD (left bars in all pairs, violet) and TD (right bars in all pairs, olive green) females. Vertical bars represent ±SEM. No difference between MDD and TD for each single emotion was found.

Post-hoc pairwise comparisons for each emotion show no significant differences in RT between the MDD and TD groups for all emotional expressions (Fig. S1): angry (MDD, 1.38 ± 0.38; TD, 1.23 ± 0.30; $t(56) = 1.60$, $p = 0.226$, two-tailed tests throughout, n.s.), happy (MDD, 0.92 ± 0.20; Mdn, 0.88, 95% CI [0.85; 1.00]; TD, 0.88 ± 0.26; Mdn, 0.82; 95% CI [0.78; 0.98]; $U = 341$, $p = 0.222$, n.s.), neutral (MDD, 1.05 ± 0.25; Mdn, 0.97, 95% CI [0.96; 1.15]; TD, 0.95 ± 0.27; Mdn, 0.89; 95% CI [0.85; 1.06]; $U = 313.5$, $p = 0.099$, n.s.), sad (MDD, 1.60 ± 0.40; TD, 1.50 ± 0.38; $t(56) = 0.97$, $p = 0.337$, n.s.), fearful (MDD, 1.38 ± 0.37; TD, 1.22 ± 0.37; Mdn, 1.20; 95% CI [1.08; 1.36]; $U = 302$, $p = 0.067$, n.s.), and disgusted (MDD, 1.55 ± 0.44; Mdn, 1.54; 95% CI [1.39; 1.72]; TD, 1.42 ± 0.38; $U = 344$, $p = 0.242$, n.s.).

Response time on RMET-M

The individual RT for correct responses to positive and negative items on the RMET-M were submitted to a two-way mixed-model ANOVA with the within-subject factor Expression (Positive/Negative) and between-subject factor Disorder (Yes/No). Main effects of both Disorder ($F(1,56) = 5.66$, $p = 0.021$, $\eta^2 = 0.09$) and Expression ($F(1,56) = 8.98$, $p = 0.041$, $\eta^2 = 0.14$) were significant. An Expression by Disorder interaction was nonsignificant ($F(1,56) = 0.51$, $p = 0.478$, n.s.).

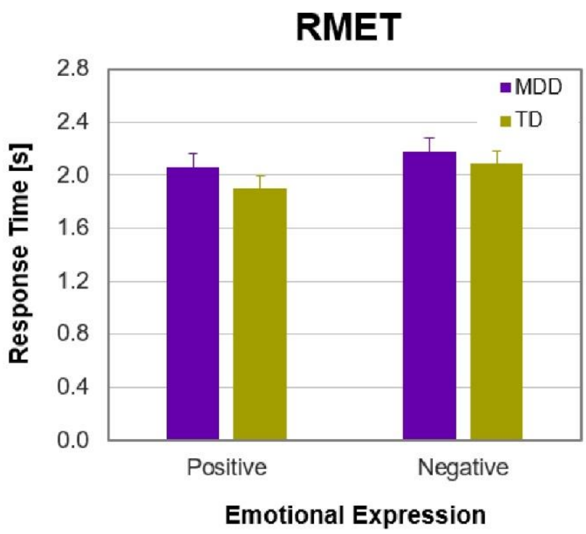

Figure S2. Response times of correct responses for positive and negative expressions on the RMET-M in MDD (left bars in both pairs, violet) and TD females (right bars in both pairs, olive green). Vertical bars represent ±SEM. No difference in RT either for positive or negative expressions was found.

Post-hoc pairwise RT comparisons revealed neither significant differences for positive expressions ($U = 351$, $p = 0.285$, n.s.) nor for negative expressions ($U = 348$, $p = 0.267$, n.s.) between MDD and TD females (Fig. S2).

Recognition accuracy in moderate and severe MDD

In order to determine whether MDD severity affects recognition, individual accuracy rates of patients with moderate (N = 13) and severe (N = 17) MDD were submitted to a two-way mixed-model ANOVA with the within-subject factor Task (RMET/EMF) and between-subject factor MDD Severity (Moderate/Severe). This analysis indicated that in our sample of MDD patients, both a main effect of MDD Severity ($F(1,28) = 2.21$, $p = 0.148$, n.s.) as well as a Task by MDD Severity interaction ($F(1,28) = 0.13$, $p = 0.723$, n.s.) were not significant. However, as the sample sizes for both sub-groups with moderate and severe MDD were relatively small, this finding should be taken with caution.

2.3 'The mirror of the soul?' Inferring sadness in the eyes

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'The mirror of the soul?' Inferring sadness in the eyes

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The eyes are widely regarded as the mirror of the soul, providing reliable nonverbal information about drives, feelings, and intentions of others. However, it is unclear how accurate emotion recognition is when only the eyes are visible and whether inferring of emotions is altered across healthy adulthood. To fill this gap, the present piece of research was directed at comparing the ability to infer basic emotions in two groups of typically developing females that differed in age. We set a focus on females seeking group homogeneity. In a face-to-face study, in a two-alternative forced choice paradigm (2AFC), participants had to indicate emotions for faces covered by masks. The outcome reveals that although the recognition pattern is similar in both groups, inferring sadness in the eyes substantially improves with age. Inference of sadness is not only more accurate and less variable in older participants, but also positively correlates with age from early through mid-adulthood. Moreover, reading sadness (and anger) is more challenging in the eyes of male posers. A possible impact of poser gender and cultural background, both in expressing and inferring sadness in the eyes, is highlighted.

Keywords Basic emotions, Sadness, Reading emotions in the eyes, Face covering, Poser gender, COVID-19

The eyes are believed to be the windows to the soul, delivering nonverbal, reliable information about emotional states and personal traits of a social counterpart. In other words, one can understand a person's emotions, intentions, drives and desires by simply looking into his or her eyes. This view had been recently questioned in the context of the COVID-19 pandemic, leading to mandatory mask wearing that leaves primarily the information from the eyes available for social communication and interaction. Indeed, how accurate is emotion recognition when only the eyes are visible? Recent studies repeatedly report that reading emotions behind a mask remains efficient for some basic expressions such as happiness, but inferring other emotions such as disgust and sadness may be heavily affected[1–16]. Yet, cultural differences in emotional expressions as well as some methodological issues, such as the limitations of online research, may substantially contribute to inconsistency and low replicability of some findings, for instance, for anger recognition[17–19].

Pre-pandemic abilities for reading language of the eyes, as assessed by the Reading the Mind in the Eyes Test (RMET[20]; with visual input comparable with masked faces; for review see[21]), are shown to improve during the pandemic in female adults, as well as male and female adolescents[22]. In line with this, experience in viewing people wearing face masks leads to better emotion recognition in Brazilian and Swiss preschoolers aged 4 to 6 years[23]. This suggests a kind of implicit or passive learning. On the other hand, a comparison of emotion recognition in two independent groups of participants in May 2020 and July 2021 suggests that even after more than a year of the COVID-19 pandemic, masks remain a burden for recognizing emotions[5]. At the same time, individuals who self-reportedly are more practiced in watching and regularly interacting with people wearing masks are more effective and confident in recognizing facial expressions[5]. On the same wavelength, the face-specific event-related potentials (ERPs, N170 and P2) are reported to be affected by mask wearing, and the impact is more pronounced in individuals with less experience with masked faces[24]. Therefore, as expected[17], the brain appears to adapt to some constraints in decoding social input.

The question arises, whether inferring facial affect from the eyes improves with life experience. By contrast with other cognitive abilities such as working memory, nonverbal social cognition is believed to remain relatively intact with age[25,26]. Recent research indicates a lack of deterioration or even an improvement in reading language of the eyes as assessed by the RMET in healthy aging[27,28]. In accordance with this, as compared to younger people (aged 18–33 years), older adults (aged 51–83 years) exhibit equal accuracy and difficulties in inferring happiness, sadness, and disgust in masked faces[29]. The effect of masks on emotion recognition (anger, fear, contempt, and

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sadness) in dynamic facial expressions does not differ between younger (18–30 years) and older (65–85 years) adults[30].

It is largely unknown whether inferring emotions from the eyes is altered across more comparable intervals of the lifespan, namely, from young adulthood to middle age. To fill this gap, the present piece of research was directed at the assessment of inferring basic emotions in two groups of typically developing (TD) individuals that differ in age. In search of group homogeneity, a focus has been set on female participants, as gender differences are reported in recognition of emotions in masked faces[19,31,32].

Materials and methods

Participants

Twenty-five female TD participants (Group 1) were recruited in February–March 2023 to examine gender differences in inferring emotions in masked faces[19]. Thirty TD female participants (Group 2) were engaged as controls for our earlier study in females with major depressive disorder (MDD) from April 2023 until February 2024[33]. None of them had head injuries, a history of mental disorders, or regular medication. They were recruited from the local community. Participants of Group 1 were aged 22.28 ± 3.34 years (mean±standard deviation, SD; median, Mdn, 22 years, 95% confidence interval, CI [21.74; 22.82]), and those of Group 2 were aged 36.80 ± 13.12 years (Mdn, 33 years, 95% CI [31.90; 41.70]), with a significant age difference between the groups (Mann–Whitney test, $U = 106.0$, $p < 0.001$, two-tailed). German as a native language was used as one of the inclusion criteria. As cultural background affects emotion recognition in masked faces[34], one of our inclusion criteria was growing up and permanently living in Germany. All observers had normal or corrected-to-normal vision. They were tested individually and were naïve as to the purpose of the study. The study was conducted in line with the Declaration of Helsinki and approved by the local Ethics Committee at the Medical School, Eberhard Karls University of Tübingen. Informed written consent was obtained from all participants. Participation was voluntary and the data was processed anonymously.

Emotions in masked faces (EMF) task

The stimuli and task are described in detail elsewhere[19]. In brief, photographs of six (three female and three male) Caucasians from three distinct age groups (young, middle, and older age), were taken from the Max Planck Institute FACES database[35] with permission (see Fig. 1). Each depicted person displayed six emotional states (anger, disgust, fear, happiness, sadness, and neutral expressions; a surgical face mask was applied to all faces). This resulted in 36 images and a total of 108 trials (6 emotions × 2 genders × 3 age groups × 3 runs). Two alternative (correct/incorrect) responses for each trial were used, which were chosen based on the emotion confusion data[1,5]: *angry—disgusted, fearful—sad,* and *neutral—happy.* On each trial, in a two-alternative forced choice paradigm (2AFC), participants had to indicate the correct emotion. For avoiding possible implicit learning effects, only masked faces were used. Participants were administered a computer version of the EMF task by using Presentation software (Neurobehavioral Systems, Inc., Albany, CA, USA). The stimuli were presented in a pseudo-randomized order, one at a time for 2 s, in three runs separated by short breaks. Upon image offset, a correct and incorrect response appeared on the right and left sides of a screen. Participants were asked to respond as accurately as possible. Participants were carefully instructed and their understanding had been proven with pre-testing (about ten trials) performed under supervision of an examiner. No immediate feedback was provided. The testing lasted for about 15–20 min per person.

Figure 1. A female poser expressing six basic emotions. Faces are shown under full-face (top) and covered-by-mask conditions (bottom row). From Carbon[1], the Creative Commons Attribution [CC BY] license. These images are presented for illustrative purposes only, and have not been used as experimental material in the present study.

Data processing and analysis

All data sets were checked for normality of distribution by means of the Shapiro–Wilk test. For non-normally distributed data, additionally to means and SDs, Mdns and 95% CIs were reported. For normally distributed data, a linear Pearson correlation was calculated, whereas for non-normally distributed data, a non-linear Spearman correlation was used. Inferential statistics was performed by analyses of variance (ANOVAs) and pairwise comparisons with the software package JMP (version 16; SAS Institute, Cary, NC, USA). Non-parametric statistics was performed using MATLAB (version 2023a; MathWorks, Inc., Natick, MA, USA).

Results

Recognition accuracy

Individual correct response rates for each emotion of the EMF task were submitted to a two-way mixed-model ANOVA with the within-subject factor Emotion (angry, happy, neutral, sad, fearful, disgusted) and between-subject factor Group (Group 1/Group 2). As expected, a main effect of Emotion was highly significant ($F(5,316) = 62.74$, $p < 0.001$, effect size, *eta-squared* $\eta^2 = 0.54$). A main effect of Group ($F(1,316) = 0.004$, $p = 0.951$, n.s.) as well as a Group by Emotion interaction ($F(5,316) = 1.78$, $p = 0.116$, n.s.) were not significant.

Both Groups 1 and 2 exhibited a similar uneven pattern of emotion recognition: inferring facial affect in the eyes was rather accurate for fear, neutral expressions, and happiness, whereas it was less precise for disgust and sadness. This outcome indicates the replicability of our earlier findings[19].

As seen in Fig. 2, pairwise comparisons revealed a significant difference between the groups in inferring sadness (Group 1, 0.691 ± 0.193; Group 2, 0.830 ± 0.162, Mdn, 0.889, 95% CI [0.769; 0.890]; $U = 201$, $p = 0.018$, here and further false discovery rate [FDR] corrected for multiple comparisons [$p = 0.003$, uncorrected] and two-tailed, effect size, Cohen's $d = 0.86$). The difference in inferring anger (Group 1, 0.709 ± 0.146; Group 2, 0.783 ± 0.104, Mdn, 0.833, 95% CI [0.745; 0.822]; $U = 257$, $p = 0.047$, uncorrected, $d = 0.56$) and disgust (Group 1, 0.558 ± 0.165; Group 2, 0.650 ± 0.159; $t(53) = 2.09$, $p = 0.041$, uncorrected, $d = 0.57$) was also significant, but did not survive corrections for multiple comparisons and only tended to reach significance (anger, $p = 0.094$; disgust, $p = 0.094$). For other emotions, no significant differences in recognition accuracy were revealed between Group 1 and Group 2 (Table S1, Supplementary Material). This finding suggests that in inferring subtle emotions such as sadness in the eyes, experience obtained with age may be of substantial advantage.

Link of EMF task with age

Although the overall recognition rate tended to positively correlate with chronological age (Spearman's rho, $\rho(53) = 0.261$, $p = 0.054$), only sadness showed a significant non-linear positive link with age ($\rho(53) = 0.280$, $p = 0.039$). As seen in Fig. 3, younger women exhibited rather high variability in inferring sadness. Interestingly, recognition of sadness and disgust was non-linearly correlated with each other in our sample of female TD participants ($\rho(53) = 0.308$, $p = 0.022$).

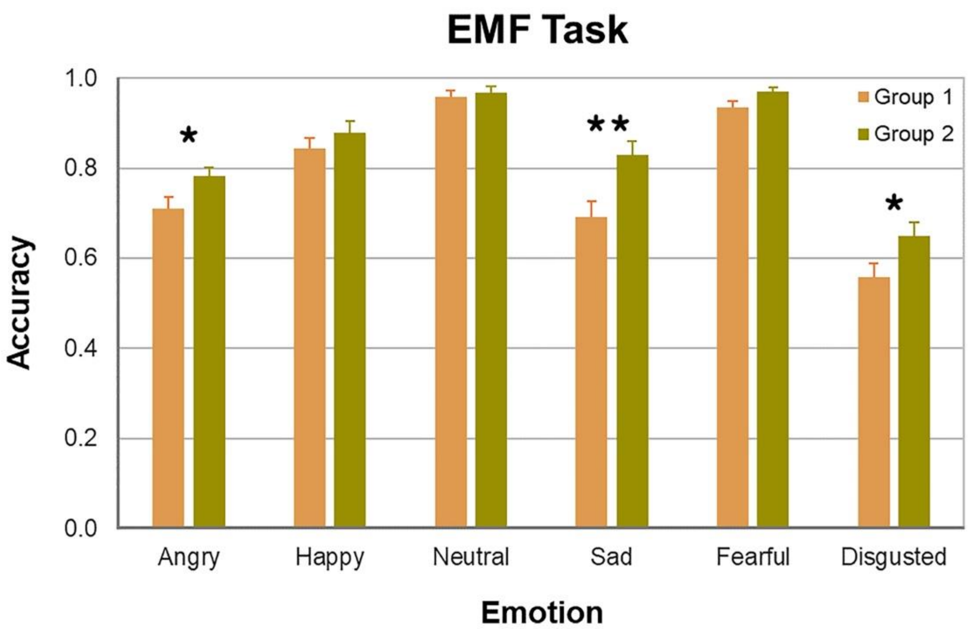

Figure 2. Recognition accuracy of facial emotions on the EMF task for Group 1 (apricot, from Pavlova et al.[19]) and Group 2 (olive green; from Moosavi et al.[33]). Vertical bars represent ± SEM. Double asterisk indicates a significant difference ($p < 0.05$), single asterisks a tendency ($0.05 < p < 0.1$).

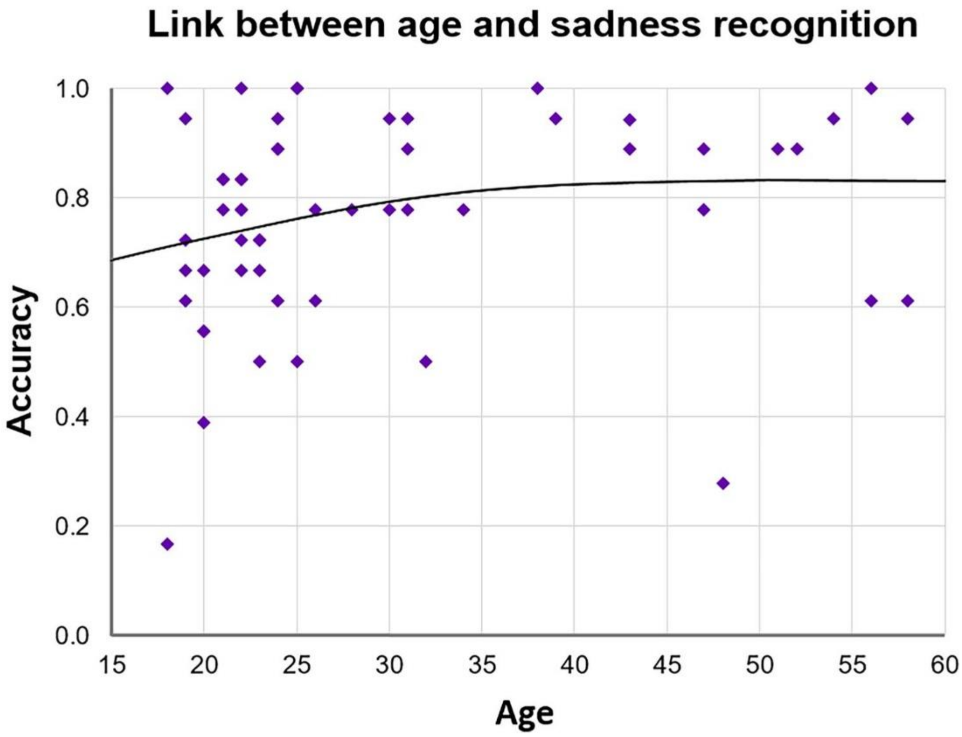

Figure 3. Link between inferring sadness on the EMF task and age. Significant positive non-linear Spearman correlation ($p = 0.039$) was found between recognition accuracy of sadness and age.

Recognition accuracy for male and female posers

Individual correct response rates were submitted to a two-way repeated measures ANOVA with the within-subject factors Emotion (angry, happy, neutral, sad, fearful, disgusted) and Gender of Poser (female/male). [Information about the gender of posers was corrupted in the data sets of two participants.] A main effect of Gender of Poser was not significant ($F(1,516) = 0.94$, $p = 0.333$, n.s.). A main effect of Emotion was highly significant ($F(5,516) = 80.92$, $p < 0.001$, effect size, $\eta^2 = 0.61$) with a significant Gender by Emotion interaction ($F(5,516) = 14.31$, $p < 0.001$, $\eta^2 = 0.21$).

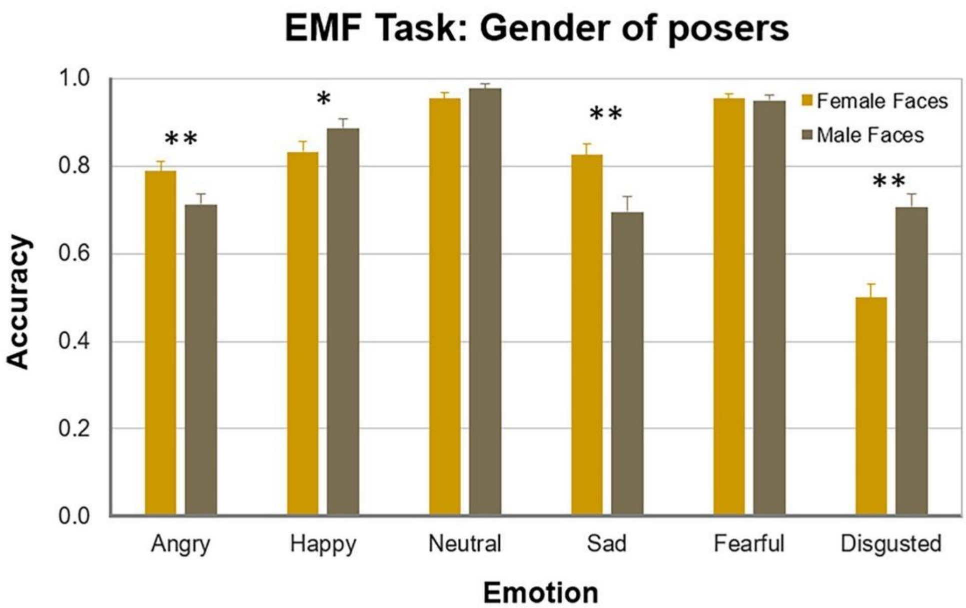

Figure 4. Recognition accuracy of facial emotions on the EMF task for female faces (yellow mustard) and male (olive grey) faces in TD females. Vertical bars represent ± SEM. Double asterisks indicate significant differences ($p < 0.05$), single asterisk a tendency.

As seen in Fig. 4, inferring sadness in the eyes of females was more accurate compared to male posers (Wilcoxon signed-rank test, $z = 3.45$, $p = 0.003$; here and further two-tailed and FDR corrected for multiple comparisons; Cohen's $d = 1.08$). Inferring anger ($z = 2.48$, $p = 0.028$, $d = 0.72$) was also better in female eyes. By contrast, disgust was, and happiness tended to be, better recognizable in the eyes of males (disgust, $z = 4.40$, $p < 0.001$, $d = 1.52$; happiness, $z = 1.95$, $p = 0.077$). Inferring neutral expressions and fear did not depend on the gender of the poser (Table S2, Supplementary Material).

For female posers, sadness recognition tended to positively correlate ($\rho(51) = 0.243$; $p = 0.077$), whereas disgust recognition positively correlated ($\rho(51) = 0.355$, $p = 0.008$) with beholder age. For male posers, recognition of fear ($\rho(51) = 0.326$, $p = 0.016$) and anger ($\rho(51) = 0.278$; $p = 0.041$) positively correlated with age.

Discussion

The main outcome of the study indicates that when visual input from the eyes only is available, in healthy women, recognition of such a subtle emotional expression as sadness substantially improves across the lifespan, from young to mid-adulthood. It appears that improvement in inferring sadness in female eyes primarily contributes to this result, as sadness recognition in the eyes of male posers does not correlate with age. At first glance, it may appear paradoxical, as masks have a more pronounced impact on inferring sadness in the eyes of males compared to females.

Several factors may potentially contribute to this outcome. First of all, although both the upper (the eyes and surrounding part of a face) and lower parts of a face are believed to essentially contribute to sadness recognition[36,37], its recognition accuracy as well as perceived intensity and confidence in recognition are severely affected by masks[1–16,38]. This leads to the conclusion that not only visual information revealed in the eyes is necessary for efficient sadness recognition. This outcome appears startling, as the eyes are traditionally believed to be particularly vital for sadness recognition. In the Facial Action Coding System (FACS[39]), most facial action units (AUs) engaged in sadness expression come from the eye region: AU1, inner eyebrow raiser; AU4, brow furrower; AU43, upper eyelid lower; AU64, eyes down, and only AU15, lip corner depressor is beyond the eye region[40].

Second, expression of emotions in the eyes is/may be gender-dependent. Social norms often encourage women to be more emotionally expressive, while men are typically socialized to exhibit less emotional variability[41]. This societal influence likely contributes to differences in recognition accuracy, as women, for example, are more prone to use their cheek-raisers while smiling than men, resulting in a smile that appears more genuine (also known as a true or Duchenne smile[42]). This nicely dovetails with the present findings as far as poorer recognition of sadness (and anger) in male posers may be explained by a lower intensity of sadness in the male eyes. By contrast, however, disgust and happiness tend to be better recognizable in male eyes, which questions the greater poignancy of females in all emotional expressions.

In addition, as pointed out earlier[17], in face images routinely used in experimental settings and face databases, facial emotions are displayed by professionals who have been (i) asked and (ii) trained to express emotions. These expressions may turn out to be rather different from the natural feelings we experience and express in real life. In naturalistic environments, we are usually quite far from extreme affect demonstrations.

The ability to express (and read) emotions in the eyes had been plentifully reflected in poetry, for instance, for the eyes expressing hatred, '*As if there were four, though they are three, stare at him hungrily*' (Alexander S. Pushkin, The Tale of Tsar Saltan, 1831; translated by Marina A. Pavlova).

Third, cultural/ethnical background in emotion expression and experience may contribute to the efficiency of emotion recognition in the eyes as well[18]. For instance, face masks hamper recognition of happiness in U.S. Americans but not in Japanese individuals, suggesting a higher sensitivity of Japanese people to information available in the eyes[34]. Individualism is reported to be associated with better recognition of (unmasked) happiness but poorer recognition of (unmasked) sadness[43]. On the other hand, in a U.S. sample, Asian-born participants exhibit the lowest sadness recognition accuracy compared to both Asian Americans and European Americans[44]. In light of these findings, the present outcome has to be taken with caution, as both expression of sadness

Figure 5. Pronounced differences in expression of sadness within the same cultural background. The images are taken from the MPI FACES database (Ebner et al.[35]; public domain). These images are presented for illustrative purposes only, and have not been used as experimental material in the present study.

through the eyes (faces were taken from the Max Planck Institute FACES database, German posers[35]) as well as inferring of sadness in the eyes by German beholders may reflect specific cultural particularities. As seen in Fig. 5, however, even within the same culture, individual differences in expression of sadness (also by the eyes) may be rather pronounced.

In a nutshell, the present findings suggest that in inferring subtle emotional expressions (such as sadness) in the eyes, experience obtained with age, from young through middle healthy adulthood, may be of substantial benefit. At the same time, sadness recognition may be modulated by estrogen receptor gene polymorphisms[45]. In young women, recognition accuracy of sadness (and disgust) is higher in the follicular phase (with lower levels of estrogen and progesterone) than in the menstrual phase[46,47]. Overall, females are recently reported to be faster than males in sadness recognition; moreover, both female and male observers are more accurate in inferring sadness in female as compared with male faces[48]. A better understanding of possible alterations in reading emotions in the eyes with age calls for future tailored work in male observers.

Data availability
Data is provided within the manuscript or supplementary information files.

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Author contributions
J.M. performed testing, analyzed the data, recruited participants, wrote the manuscript. A.R. recruited participants and performed testing. A.N.S. analyzed the data and wrote the manuscript. A.J.F. contributed materials/analysis tools. M.A.P. designed the study, recruited participants, analyzed the data, and wrote the manuscript. All co-authors contributed to the writing and editing.

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The authors declare no competing interests.

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2.3.1 Supplementary material

Table S1. Recognition accuracy: group comparison

	Group 1			Group 2					
	Mean	Mdn	95% CI	Mean	Mdn	95% CI	Mann-Whitney *U* / *t* - test	*P* uncorr.	*P* corr.
anger	0.71 ± 0.15			0.78 ± 0.10	0.83	[0.75; 0.82]	*U* = 257	0.047**	0.094*
happiness	0.84 ± 0.14	0.89	[0.79; 0.89]	0.88 ± 0.13	0.89	[0.83; 0.93]	*U* = 282	0.165	0.198
neutral	0.96 ± 0.08	1.00	[0.93; 0.99]	0.97 ± 0.08	1.00	[0.94; 1.00]	*U* = 340	0.555	0.555
sadness	0.69 ± 0.19			0.83 ± 0.16	0.89	[0.77; 0.89]	*U* = 201	0.003**	0.018**
fear	0.94 ± 0.07	0.94	[0.91; 0.96]	0.97 ± 0.05	1.00	[0.95; 0.99]	*U* = 269	0.075*	0.112
disgust	0.56 ± 0.17			0.65 ± 0.16			$t(53) = 2.09$	0.041**	0.094*

Table S2. Recognition accuracy for male and female posers

	female faces			male faces				
	Mean	Mdn	95% CI	Mean	Mdn	95% CI	Wilcoxon signed-rank test, *z*	*P* corr.
anger	0.79 ± 0.16	0.78	[0.75; 0.83]	0.71 ± 0.17	0.78	[0.67; 0.76]	2.48	0.028**
happiness	0.83 ± 0.18	0.89	[0.78; 0.88]	0.89 ± 0.16	0.89	[0.84; 0.93]	1.95	0.077*
neutral	0.95 ± 0.10	1.00	[0.93; 0.98]	0.98 ± 0.07	1.00	[0.96; 1.00]	1.54	0.149
sadness	0.83 ± 0.18	0.89	[0.78; 0.88]	0.70 ± 0.26	0.78	[0.62; 0.77]	3.45	0.003**
fear	0.95 ± 0.08	1.00	[0.93; 0.98]	0.95 ± 0.09	1.00	[0.93; 0.98]	0.23	0.818
disgust	0.50 ± 0.22			0.71 ± 0.23	0.78	[0.64; 0.77]	4.40	< 0.001**

Note: For non-normally distributed data, additionally to means and SDs, Mdns and 95% CIs are reported.
Double asterisks indicate significant differences ($p < 0.05$), single asterisks indicate a tendency ($0.05 < p < 0.1$).

3 GENERAL DISCUSSION

By investigating the impact of gender, age, and mental disorder, the experimental studies presented in this dissertation collectively advance our understanding of the ability to infer emotions and mental states from the eyes. To this end, we examined (1) gender impact on inferring emotions from the eyes in masked faces in the young neurotypical population (Pavlova et al., 2023b); (2) age-related changes in inferring emotions from the eyes in TD females (Moosavi et al., 2024a); and (3) reading language of the eyes in female patients with MDD (Moosavi et al., 2024b). By revealing strengths and weaknesses in inferring emotions from the eyes, the synthesis of the findings across this work provides a blueprint to investigate profiles of social cognition abilities in distinct mental disorders.

Two paradigms, the EMF task and the RMET, which provide comparable visual input from the eyes, were used: the EMF task throughout all three studies, and the RMET for additional examination of patients with MDD. As described earlier (Introduction, Section **1.1 Facial emotion recognition**), the EMF task comprises images of masked faces expressing basic emotions (e.g., happiness, sadness, disgust, and anger), while the RMET comprises photographs of the eye portions of faces expressing a certain mental or affective state.

With the fairly recently sparked interest in the impact of face masks (**Fig. 1**, Introduction), caused by the COVID-19 pandemic, most research was conducted online, which enabled safe and effective collection of data. However, this approach has a number of methodological limitations regarding verification of those participating, their task comprehension, and participant diligence. Additionally, online samples are usually predominated by females, creating a substantial barrier for proper gender comparison. Unbalanced design when participants are not matched with respect to gender and differ in sample size (e.g., a sample of females or TD individuals is twice or even larger than a sample of males or patients) may lead to paradoxical statistical outcomes and preclude appropriate generalization of findings (Isernia et al., 2020). While most previous studies suffered from these limitations, the present work was conducted face-to-face with balanced and carefully matched samples of participants in each group.

The outcome of all three studies (Pavlova et al., 2023b; Moosavi et al., 2024a; Moosavi et al., 2024b) indicates that both TD males and females, as well as MDD females, demonstrate an uneven profile of reading emotions in the eyes, with some emotions affected by masks more severely than others. Indeed, while eyes are often called '*the window to the soul*' or even *'the mirror of the soul'*, experimental work (including the outcome of the present studies) demonstrates that not all emotions can be recognized equally well from the eyes only. This aligns with previous research showing that emotion recognition varies across different facial regions, with some expressions being more affected by occlusion than others (Carbon, 2020; Bani et al., 2021; Carbon et al., 2022; Grahlow et al., 2022; Grenville and Dwyer, 2022; Langbehn et al., 2022; Proverbio and Cerri, 2022; Kim et al., 2022a; Maiorana et al., 2022; Rinck et al., 2022; Proverbio et al., 2023; Ventura et al., 2023a; Abutalebi et al., 2024; Ikeda, 2024; Mastorogianni et al., 2024; Waizman et al., 2025; Wickline et al., 2025).

3.1 Emotion-specific gender impact

It is well-recognized that males and females may differ in inferring emotions through the eyes and facial emotion expression (Hall et al., 2010; Sullivan et al., 2017; Abbruzzese et al., 2019; Fan et al., 2021). The present work contributes to clarification of gender impact on reading language of the eyes. Our study (Pavlova et al., 2023b) is one of the earliest face-to-face examinations of emotion recognition in masked faces with a sample balanced in gender and age. Conducting research in a face-to-face setting, as done in the present study, enhances the validity of findings by ensuring controlled testing conditions, standardized task administration, and real-time monitoring of participant engagement.

Previous (mostly online) research resulted in contradictory outcome in regard to gender differences in inferring emotions from masked faces, either revealing a female advantage (Grundmann et al., 2021; Huc et al., 2023) or not (Carbon et al., 2022; Kim et al., 2022a; Fuchs et al., 2024). Our findings indicate that, in contrast to widespread beliefs favoring women, young TD males outperform their female peers in recognition of several negative emotions. Females are more strongly affected by face masks in disgust recognition, even more so in faces of congruent gender, compared to their male peers. One possible explanation might be a greater sensitivity to threat-related emotions in males, since anger and disgust are both associated with potential threats or contaminants. Gender-specific findings are particularly relevant as they provide an important foundation for research on mental disorders, such as MDD, which often exhibit gender disparities in prevalence, manifestation (Schuch et al., 2014; Qin et al., 2020; Sabic et al., 2021), and social cognition (Landman-Peeters et al., 2005; Li et al., 2015).

Disgust, in particular, has been largely underexplored and is considered '*the forgotten emotion of psychiatry*' (Phillips et al., 1998), despite its relevance in conditions such as obsessive-compulsive disorder, social anxiety, and mood disorders (McKay and Olatunji, 2009; Davey, 2011; Knowles et al., 2019; Lenk et al., 2019; Amoroso et al., 2020; Tolchinsky et al., 2024). Given the observed gender differences in disgust recognition, future research should examine whether they reflect underlying cognitive or affective biases that may contribute to gender-specific vulnerabilities in psychiatric conditions.

The present evidence on the uneven/selective impact of gender on emotion recognition in the eyes dovetails with reading dynamic body language: young TD females show superior recognition of some emotions in body language, while males demonstrate enhanced recognition of others (Sokolov et al., 2011; Krüger et al., 2013). In other words, the gender impact may be profoundly modulated by emotion.

In addition, the gender effects in inferring of emotions in faces covered by masks suggest an interaction of different cognitive processing strategies with the visual input. Holistic processing, which may be more common in females (Rennels and Cummings, 2013; Østergaard Knudsen et al., 2021), becomes less effective when only eyes are visible. On the contrary, featural/local face processing, which may be more common in males (Rennels and Cummings, 2013), appears to be more tolerant to the absence of the whole Gestalt. Presumably, this strategy leads to more advantageous processing of information obtained from the eyes only, and therefore allows more efficient reading of emotions in masked faces.

For a deeper understanding of the gender differences in reading in the eyes, one needs to examine the biological and socio-cultural origins of face processing. The ability of females to recognize facial affect may have evolved as a requirement for understanding and responding to the needs of offspring, as well as navigating complex social dynamics within groups (Archer, 2019). More often the socio-cultural factors, which shape gender differences in face processing, are stressed (Weber et al., 2014; Asperholm et al., 2019), which traditionally encourage women to develop skills necessary for caregiving (Chaplin, 2015). The malleability of these skills becomes evident when examining cross-cultural studies. In countries with higher gender equality, the gender differences in face memory and recognition observed in lower equality countries seem to disappear (Mishra et al., 2019). This demonstrates how external developmental factors profoundly shape social cognition. In general, females show superior performance on social cognition tasks across cultures (Baron-Cohen et al., 2001; Hansen, 2011; Kirkland et al., 2013; Pavlova and Sokolov, 2022ab; McDonald and Kanske, 2023; Vaskinn et al., 2024).

Strictly speaking, gender differences in social cognition are often characterized by modest effect sizes and context-specific manifestations. Our findings contribute to the understanding of how gender influences social cognitive processes, particularly in clinical contexts. Rather than a simple binary predictor of social cognitive abilities, gender functions as a modulating factor that interacts with both developmental and pathological processes. Mental conditions can fundamentally transform social information processing patterns, and most of them exhibit highly gender-specific prevalence rates and manifestations (Seedat et al., 2009; Eaton et al., 2012; Riecher-Rössler, 2017; Green et al., 2018; Maestre-Miquel et al., 2021; Otten et al., 2021), suggesting that gender may play a crucial role in vulnerability to and expression of psychopathology.

Understanding these complex interactions requires careful consideration of both neurotypical and clinical populations. Research in neurotypical individuals provides an essential baseline against which to interpret clinical findings – without this foundation, researchers risk conflating disorder-related effects with typical gender differences. Furthermore, investigating how gender modulates social cognition in clinical populations may provide valuable insights into the etiological factors contributing to these conditions. Such understanding is crucial for developing more targeted and effective interventions that account for both gender-specific and disorder-specific aspects of social cognitive deficits.

3.2 Effect of experience on inferring of emotions

Understanding gender impact on emotion recognition provides a foundation for exploring how these abilities evolve with experience gained across different life periods. In general, as with many other cognitive skills such as working memory, one can expect that the ability for facial emotion recognition ability may decline with age. Social cognition, however, seems to remain largely intact with age (Natelson Love et al., 2016; Reiter et al., 2017; Stietz et al., 2021; Grainger et al., 2022). In line with this, reading language of the eyes as assessed by the RMET in healthy aging has been found to be little affected by age or even to improve (Dodell-Feder et al., 2020; Yıldırım et al., 2020). Older adults (51-83 years) had been reported to show reduced accuracy in identifying emotions such as anger, sadness, and fear compared to younger adults (18-33 years) (Faustmann et al., 2022). Similarly, recognition of emotions in masked faces (particularly for expressions of anger and fear) had been found to be more challenging for older adults (Faustmann et al., 2022; Slessor et al., 2022).

It is largely unknown whether inferring emotions from the eyes is altered across more comparable intervals of the lifespan, namely, from young to mid-adulthood. Our second study fills this gap by investigating whether, and if so how, inferring emotions from the eyes improves across mid-adulthood (Moosavi et al., 2024a). The outcome reveals that healthy women demonstrate a substantial improvement in inferring subtle emotions such as sadness from the eyes. In addition, recognition of other negative emotions (namely, anger and disgust) also tends to sharpen with age.

An age-related negativity bias might, at least in part, account for these results. The negativity bias (Baumeister et al., 2001) refers to the tendency to give greater weight to negative information compared to positive information in one's environment. The developmental trajectory of such a bias is subject to contradictory reports (Norris, 2019), and recent literature reports the opposite effect, sometimes termed "*positivity effect*" (Carstensen and DeLiema, 2018; Sparks and Ledgerwood, 2018; Fields et al., 2022).

The other, more reasonable, explanation for the observed improvement in inferring sadness from the eyes is the accumulation of emotional experience and a heightened sensitivity to this particular emotion. With age, people are exposed to a wider range of emotional experiences, particularly those involving loss, adversity, and empathy-driven social interactions. This may lead to increased familiarity with sadness and, accordingly, to a more refined recognition ability. Sadness is considered to be a subtle emotion, often conveyed through delicate shifts in gaze, brow positioning, and micro-expressions (Gollan et al., 2013; Girard et al., 2015). Unlike high-arousal emotions such as anger or fear, which produce more overt facial markers, sadness requires a more refined sensitivity to be detectable. This makes the observed improvement in its recognition even more striking, as it suggests an experience-based enhancement in the ability to process complex, subtle emotions.

3.3 Reading language of the eyes in MDD

The findings on age and gender differences in typical development provide valuable context for understanding the outcome regarding inferring emotions from the eyes in clinical populations, particularly in female MDD.

3.3.1 Selective deficits in reading in the eyes in MDD

The findings of our third study (Moosavi et al., 2024b) show that female patients with MDD exhibit an uneven profile in inferring emotions in masked faces as well as in reading mental states of others as assessed by the RMET. MDD patients demonstrate selective deficits with difficulties in recognition of such negative emotions as sadness and anger in masked faces, while they maintain the same, rather high recognition level of happiness, neutral expressions, and fear similarly to their TD peers. Likewise, MDD differentially affects inferring mental states of others as assessed by the RMET: patients exhibit difficulties in reading of mental states with positive valence, but did not differ in recognition accuracy from person-by-person matched TD controls in inferring mental states with negative valence.

It is vital to emphasize, however, that despite the selective impairments, female MDD patients demonstrated remarkably preserved emotion recognition abilities overall, with performance consistently above chance level across all basic emotions. This largely intact capability represents a notable strength in the MDD cognitive profile and stands in contrast to other mental conditions, such as SZ, where patients show a global deficit in inferring social signals from the eyes (Resch et al., 2024). These findings lead to a more nuanced understanding of emotional processing in MDD. More specifically, MDD patients seem to perceive social signals accurately, but they differ in processing and interpretation of these signals (Steger and Kashdan, 2010; Kaletsch et al., 2015; Kubon et al., 2021; 2023).

The distinctive pattern of performance on the RMET and EMF task indicates that emotional processing deficits in female MDD manifest across different social cognitive tasks, as the RMET requires more complex cognitive processing, while the EMF task taps recognition of basic emotions. In MDD, alterations in brain activity related to emotional processing have been observed, which may contribute to the task-specific nature of observed deficits (Teng et al., 2024).

The selectivity of deficits in reading of social signals in females with MDD raises the question of whether, and if so, how this ability is affected in other mental disorders. In SZ, gender differences in hostility bias and ToM, which are present in neurotypical individuals, are generally concealed (Kubota et al., 2022), as well as advantages of TD males over females in reasoning, problem solving, and working memory (Zhang et al., 2017). Women with bipolar disorder are, unlike TD women, not outperforming their male peers on visual and auditory emotion recognition tasks (Vaskinn et al., 2007) and on the RMET in general (Navarra-Ventura et al., 2021). The latter is also the case in autism spectrum disorder (ASD) (Baron-Cohen et al., 2015; Pavlova and Sokolov, 2022b). These findings suggest that gender is not a fixed predictor of social cognitive abilities, but instead a flexible factor that changes with mental health conditions.

3.3.2 Link between recognition of emotions and mental states

While in MDD patients (as well as in TD controls) no link was found between recognition accuracy on the EMF task and RMET, response time (processing speed) on both tasks was related to each other. This suggests that MDD and TD individuals rely on rather similar visual cues when inferring basic emotions and when reading mental states of others. In other words, individuals who are proficient in extracting visual information from the eyes for basic emotion recognition are also rather fast in processing visual input for more complex inferring of mental states of others. A lack of association between these two tasks in terms of recognition accuracy suggests *distinct* latent neurocognitive mechanisms underwriting these tasks, such as accumulation of sensory evidence for decision making, decision thresholds, and criteria (Moosavi et al., 2024b; Resch et al., 2024). In other words, for each MDD and TD individual, reading sophisticated mental states may be, to a different degree, more demanding than inferring basic emotions. This individual variability is reflected in the absence of the link in recognition accuracy between these tasks.

3.3.3 Clinical implications

The deficits in the ability to read emotions or complex mental states in the eyes could have several clinically relevant implications. Firstly, the impairments can lead to difficulties in social interactions and interpersonal relationships, potentially exacerbating social isolation and reinforcing depressive thought patterns. This is especially relevant for healthcare settings, where service providers might wear face masks most of the time, or in times of public health crisis, as in the recent COVID-19 pandemic. Secondly, as the degree of the negativity bias in emotional processing in MDD appears to be state-dependent, changes in the negativity bias could reflect fluctuations in depressive symptom severity. Consequently, it holds potential relevance for diagnostic or treatment strategies, as reductions in the bias might indicate treatment response or remission (Münkler et al., 2025). This is especially the case for the specific pattern in emotion recognition impairment, which could be explored as a marker of MDD severity or treatment success (Liu et al., 2021).

3.4 Brain mechanisms of inferring emotion in the eyes

The neural mechanisms underlying emotion recognition from the eyes involve distributed networks extending beyond traditional social brain circuits. Research demonstrates the crucial role of key regions including the superior temporal sulcus, amygdala, and prefrontal areas (Baron-Cohen et al., 1999). The structural and functional connectivity between these regions, particularly through the right uncinate fasciculus, predicts performance on the RMET (Coad et al., 2020). However, even in TD individuals, only a handful of studies deal with brain activity during emotion recognition in masked faces (Pavlova and Sokolov, 2022ab), and such studies are absent in MDD.

Recent functional magnetic resonance imaging (fMRI) work in neurotypical individuals reveals increased activation in the posterior cingulate cortex, fusiform gyrus, and insular cortex when processing emotional expressions partially obscured by masks. Notably, for sad expressions, increased activation in the insula and inferior frontal gyrus was found for masked compared to unmasked sad faces (Waizman et al., 2024, **Fig. 4**). This suggests that the brain employs additional neural resources to compensate for reduced visual information, particularly when processing sadness.

Further brain imaging evidence indicates recruitment of additional neural mechanisms and resources, with stronger fMRI activation observed in the occipito-temporal areas (right fusiform face area and bilateral occipital face area) when viewing masked faces as compared with unmasked faces (Abutalebi et al., 2024, **Fig. 4**). Furthermore, a stronger correlation of fMRI activation was found between the right occipital face area and areas involved in sensory integration, such as the parietal regions, when processing masked faces, suggesting increased cognitive effort for recognizing emotions when facial cues are limited (Abutalebi et al., 2024).

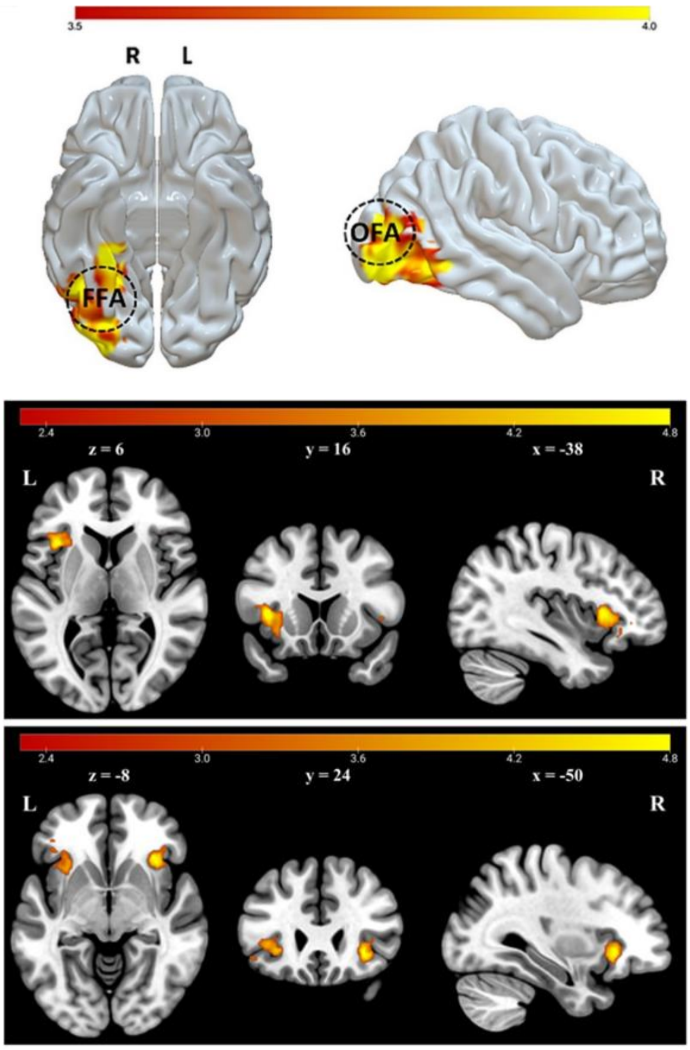

Figure 4. FMRI brain activation during processing of masked and unmasked faces. Upper: Two 3D brain renderings, with significant activations for the masked > unmasked contrasts. The left image shows activation in the right fusiform face area (labeled "FFA") and the right image shows activation in the occipital face area (labeled "OFA"). Activations are shown with t-values (3.5-4.0) as indicated by the color bar. From Abutalebi et al. (2024). On the brain struggles to recognize basic facial emotions with face masks: an fMRI study. *Front. Psychol*. 15:1339592. doi: 10.3389/fpsyg.2024.1339592; the Creative Commons Attribution [CC BY] license. **Lower:** Two rows of fMRI slices, with each row presenting axial, coronal, and sagittal views. Activations appear in yellow-orange regions primarily in the insula and inferior frontal gyrus orbital part. These activations represent the sad masked > sad unmasked contrast based on a sample of 23 fathers and 18 children. Activations are shown with t-values (2.4-4.8) as indicated by the color bar. From Waizman et al. (2024). Behavioral and neural evidence for difficulty recognizing masked emotional faces. *Emotion*. Advance online publication. doi: 10.1037/emo0001444; Copyright © 2024 by American Psychological Association, with permission.

In MDD, increased fMRI activation patterns in the frontal regions and temporal areas is typically observed during emotion recognition tasks (Ternovoy et al., 2023). Particularly relevant to our findings, individuals with MDD show distinct activation patterns when processing positive emotional stimuli, marked by hyperactivity in the medial frontal and temporal regions (Gou et al., 2023). TD individuals with higher levels of depressive symptoms show greater activation in the insula and inferior frontal gyrus when recognizing masked sad facial expressions (Waizman et al., 2024), hinting at a potential neural mechanism behind depression-specific alterations.

Gender-specific differences add another layer of complexity, as women with depression show distinct activation patterns during the processing of both positive and negative emotional expressions (Kustubayeva et al., 2023). While these neural patterns offer insights into potential mechanisms, understanding the relationship between altered brain activation and deficits in reading in the eyes needs more targeted investigations, which account for mental status, gender, and experience.

It is important to note that the fMRI methodology employed in these studies has inherent limitations. While fMRI provides high spatial resolution for identifying brain regions underpinning emotion recognition, it does not provide any temporal information needed to capture information processing rapidly unfolding in time. Future research employing magnetoencephalography that offers high temporal resolution is needed to track neural dynamics of emotion recognition processes. This approach would help to elucidate whether alterations in inferring of social signals in MDD rely on early or rather late processing mechanisms.

3.5 Future Directions

The findings on deficits in reading emotions in the eyes suggest potential impact on daily social functioning. Future work needs to be done to clarify whether improving emotion recognition skills could enhance treatment outcomes for MDD patients, as the causal relationship between social cognition deficits and MDD symptoms remains unclear (Langenbach et al. 2023). Effective compensatory strategies may demonstrate such a causal connection by improving quality of life parameters, and further studies should investigate whether specific cognitive training approaches, such as digital or real-world social interaction exercises, can mitigate deficits in inferring social signals in the eyes. A focus should also be set on how mask wearing affects different age groups, as the recognition strategy of older adults may be impacted by masks differently (Noh and Isaacowitz, 2014; Caroppo et al., 2017). Given the observed differences in sadness recognition between younger and middle-aged females, it would be valuable to explore whether such changes extend to individuals with MDD.

For a deeper understanding of MDD, it would be insightful to compare patterns of nonverbal social cognitive abilities across other mental health conditions such as ASD and SZ. ASD individuals display difficulties in reading social signals, particularly when it comes to interpreting others' mental states (Baron-Cohen et al., 2015). However, unlike MDD, social-cognitive deficits in ASD appear to be more pervasive rather than selective (Pavlova and Sokolov, 2022b). In male SZ, as noted earlier, patients exhibit global deficits in recognizing facial emotions in masked faces compared to selective impairments in MDD (Resch et al., 2024). However, no differences in RMET performance are reported between ASD and SZ individuals (Fernandes et al., 2018; Oliver et al., 2021; Altschuler et al., 2021; for review, see Pavlova and Sokolov, 2022b). Uncovering profiles of social cognitive abilities in distinct mental disorders helps to clarify whether social cognitive deficits are of specific character for a particular disorder.

Neurotypical females tend to outperform males in reading the eyes across cultures (Baron-Cohen et al., 2001; Kirkland et al., 2013; Pavlova and Sokolov, 2022ab), but there are also opposite reports (Mar et al., 2006; Nettle and Linde, 2008; Olderbak et al., 2015; Isernia et al., 2020; Lee et al., 2020; Megías-Robles et al., 2020; Kynast et al., 2021; Pavlova and Sokolov, 2022b). In closer examination, the differences in reading in the eyes may be driven by social and cultural factors rather than by biological sex (Vonk et al., 2016; Pavlova and Sokolov, 2022ab). For example, gender identity rather than biological sex was found to be predictive of the ability to read in the eyes (Kung, 2020; Pavlova and Sokolov, 2022ab), while testosterone administration in young females does not impact their RMET performance (Carré et al., 2015; Pavlova and Sokolov, 2022ab). These findings highlight the need for future research to disentangle the effects of gender identity, hormonal influences, and sociocultural expectations in shaping the ability to read in the eyes, particularly in psychiatric conditions like MDD.

With a large part of MDD literature focusing on females (Swetlitz, 2021), future research needs to put a stronger focus on the impact of MDD on social cognition in males.

Although males are less likely to develop MDD, they arguably exhibit a more severe symptom profile (Sabic et al., 2021; Swetlitz, 2021) and are potentially underdiagnosed (Sabic et al., 2021). Expanding research would help identify whether possible social cognitive impairments in male MDD follow patterns and profiles that differ from those observed in females. This will help to clarify whether gender-specific intervention strategies are warranted.

All three studies taken together reveal how recognition of facial affect through the eyes emerges from a dynamic interplay of gender, experience, and mental conditions. The findings underscore how constrained visual input serves as a methodological lens for examining the differential effects of psychopathology, developmental trajectories, and gender-specific processing strategies on emotion recognition. Collectively, these studies demonstrate that human processing and interpretation of emotional expressions cannot be reduced to simplistic universal patterns or isolated explanatory factors. Rather, emotion recognition depends on the interaction of multiple variables, beginning with fundamental visual processing constraints.

The single term to characterize the general outcome of this work would be '*selectivity*'. Indeed, wearing masks *selectively* affects emotion recognition, leading to difficulties in inferring some emotion, but leaving recognition of other facial expressions intact. Gender of beholder *selectively* impacts inferring emotions from the eyes. Enrichment of visual experience from young to mid-adulthood leads to *selective* improvements in reading (subtle and negative) emotion. Finally, female patients with MDD exhibit *selective* impairments in inferring social signals from the eyes.

Limited facial cues do not uniformly impair emotion recognition but rather serve as a catalyst, amplifying underlying processing differences and thus making them more visible. This uncovers reading language of the eyes as a complex, adaptive cognitive process influenced by the interplay of bottom-up perceptual processes and top-down cognitive strategies, with facial input constraints offering a unique lens for understanding both typical and atypical emotion processing. These findings are particularly valuable for understanding nonverbal social cognition, suggesting that the ability to read the language of the eyes may serve as a potential marker for mental health conditions.

4 SUMMARY

The present work investigates factors shaping how we read the language of the eyes, focusing on the impact of gender, experience, and the specificity of mental conditions such as MDD. Two paradigms were implemented in this study: The Emotion recognition in Masked Faces (EMF) task and RMET, which provide a comparable amount of information from the eyes. While most previous studies suffered such limitations of online experimenting as a lack of control over settings and female predominance, this work was conducted face-to-face. The outcome of the first study that included a sample of TD individuals balanced in gender, indicates that both males and females demonstrate an uneven profile of emotion recognition, with some emotions affected by masks more severely than others. Contrary to our expectations, however, males were more sensitive to subtle emotional signals transmitted through the eyes. On disgust recognition, *the forgotten emotion of psychiatry*, a notable effect of masks was found on females exhibiting lower accuracy. These findings are particularly relevant for research on mental disorders such as MDD, which shows gender disparities in prevalence, manifestation, and social cognition. The second study reveals that recognition of subtle emotions, in particular sadness, improves with experience through early to mid-adulthood in TD females. Finally, the third study in female MDD indicates that reading language of the eyes is affected selectively rather than globally: Recognition of subtle negative emotions (such as sadness and disgust) covered by masks as well as interpretation of the eyes' expressions with positive valence are more heavily compromised. Selective impairments in emotion recognition differ markedly from global deficits in other clinical populations such as SZ. In both MDD and TD individuals, emotion recognition behind a mask and performance on the RMET are linked to each other in processing speed, but not recognition accuracy, suggesting a commonality in the encoding of visual input. Overall, by identifying gender- and experience-related patterns, this work suggests the ability for reading language of the eyes may serve as a marker of mental conditions such as MDD. Moreover, distinct patterns of deficits in reading language of the eyes across mental disorders enhances understanding of nonverbal social cognition, informing the development of diagnostic tools, remediation programs, and tailored interventions within and beyond the context of the COVID-19 pandemic.

5 ZUSAMMENFASSUNG

Die vorliegende Arbeit beleuchtet Faktoren, die das Lesen der „Sprache der Augen“ beeinflussen, mit Fokus auf Geschlecht, Erfahrung und psychiatrischem Befund, wie schwere Depression (MDD). Zwei Paradigmen wurden genutzt: Emotionserkennung in Gesichtern mit Mund-Nasen-Schutz (EMF) und der RMET, die vergleichbare Informationen aus Augenpartien liefern. Während frühere Studien oft unter Einschränkungen von Online-Experimenten wie mangelnder Kontrolle und weiblicher Überrepräsentation litten, wurde diese Untersuchung in Präsenz durchgeführt. Die 1. Studie, welche eine geschlechter-ausgewogene TD-Stichprobe nutzt, zeigt, dass sowohl Männer als auch Frauen ungleichmäßige Profile in der Emotionserkennung haben, wobei der Mund-Nasen-Schutz die Emotionen unterschiedlich stark beeinträchtigt. Unerwarteterweise reagierten Männer sensibler auf subtile emotionale Signale in den Augen. Bei der Erkennung von Ekel, *der vergessenen Emotion der Psychiatrie*, zeigten Frauen eine geringere Genauigkeit. Diese Ergebnisse sind besonders relevant für die Erforschung psychischer Erkrankungen wie MDD, die geschlechtsspezifische Unterschiede in Prävalenz, klinischer Manifestation und sozialer Kognition aufweisen. Die 2. Studie zeigt, dass die Erkennung subtiler Emotionen, insbesondere Traurigkeit, bei TD-Frauen mit zunehmender Erfahrung im frühen bis mittleren Erwachsenenalter verbessert wird. Bei Frauen mit MDD (3. Studie) ist das Erkennen von Emotionen aus den Augen nicht global, sondern selektiv beeinträchtigt: Besonders betroffen sind negative Emotionen (wie Traurigkeit und Ekel) hinter Masken sowie positive Augenausdrücke beim RMET. Solche selektiven Defizite unterscheiden sich deutlich von globalen Beeinträchtigungen bei anderen Krankheitsbildern wie SZ. Sowohl bei MDD- als auch bei TD-Personen sind das Emotionserkennen hinter Masken und die RMET-Leistung in der Verarbeitungsgeschwindigkeit, nicht jedoch in der Erkennungsgenauigkeit, miteinander verknüpft, was auf eine ähnliche visuelle Enkodierung hindeutet. Insgesamt legt die Arbeit nahe, dass die Fähigkeit, Emotionen aus den Augen zu lesen, ein Marker für psychische Erkrankungen wie MDD sein könnte. Zudem hilft das Verständnis spezifischer Defizitmuster bei verschiedenen psychischen Störungen, die nonverbale soziale Kognition besser zu erfassen, und unterstützt die Entwicklung diagnostischer Werkzeuge, Interventionsprogramme und therapeutischer Ansätze im und außerhalb des Kontexts der COVID-19-Pandemie.

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7 DECLARATIONS OF CONTRIBUTION

Emotions behind a mask: the value of disgust. Schizophrenia (2023), 9(1), 58.

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Conceived and designed the study experiments: M.A.P. and A.N.S. Performed testing: J.M. Analyzed the data: J.M., A.N.S., and M.A.P. Contributed materials/analysis tools: M.A.P., C.C.C., A.N.S., and A.J.F. Participant recruitment: J.M. Wrote the paper: M.A.P., A.N.S., and J.M. All co-authors contributed to the writing and editing. Supervision and administration of the whole project: M.A.P.

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J.M. performed testing, analyzed the data, recruited participants, wrote the manuscript. A.R. recruited participants and performed testing. A.N.S. analyzed the data and wrote the manuscript. A.J.F. contributed materials/analysis tools. M.A.P. designed the study, recruited participants, analyzed the data, and wrote the manuscript. All co-authors contributed to the writing and editing.

Reading language of the eyes in female depression. Cerebral Cortex (2024), 34(7), bhae253.

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I hereby confirm that I have written this doctoral thesis on my own and have not used any sources other than those indicated by me.

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