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# Reading language of the eyes

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ABSTRACT

The need for assessment of social skills in clinical and neurotypical populations has led to the widespread, and still increasing use of the 'Reading the Mind in the Eyes Test' (RMET) developed more than two decades ago by Simon Baron-Cohen and colleagues for evaluation of social cognition in autism. By analyzing most recent clinical and brain imaging data, we illuminate a set of factors decisive for using the RMET. Converging evidence indicates: (i) In neurotypical individuals, RMET scores are tightly correlated with other social skills (empathy, emotional intelligence, and body language reading); (ii) The RMET assesses recognition of facial affect, but also heavily relies on receptive language skills, semantic knowledge, and memory; (iii) RMET performance is underwritten by the large-scale ensembles of neural networks inside and well-outside the social brain; (iv) The RMET is limited in its capacity to differentiate between neuropsychiatric conditions as well as between stages and severity of a single disorder, though it reliably distinguishes individuals with altered social cognition or elevated pathological traits from neurotypical persons; (v) Merely gender (as a social construct) rather than neurobiological sex influences performance on the RMET; (vi) RMET scores do not substantially decline in healthy aging, and they are higher with higher education level, cognitive abilities, literacy, and mental well-being; (vii) Accuracy on the RMET, and engagement of the social brain, are greater when emotions are expressed and recognized by individuals with similar cultural/ethnic background. Further research is required to better inform usage of the RMET as a tool for swift and reliable examination of social cognition. In light of comparable visual input from the RMET images and faces covered by masks due to COVID-19 regulations, the analysis is of value for keeping efficient social interaction during the current pandemic, in particular, in professional settings related to social communication.

## 1. Introduction

Over half a century (albeit foremost over the last two decades marked by increasing efforts in Social Neuroscience), the growing need to experimentally assess social cognition (our ability to perceive and understand emotions, drives, and desires of our counterparts) in neurotypical individuals as well as in a wide range of psychiatric, neurological, and psychosomatic conditions has led to developing novel tools. These tests meet the requirements to be easy-to-administer, reliable and ecologically valid. Among a few examples are the point-light technique for assessment of body and face language reading (Johansson, 1973; Bassili, 1978, 1979; Atkinson et al., 2012; de Gelder et al., 2010; Sokolov et al., 2011, 2020; Krüger et al., 2013; Bidet-Ildei et al., 2020; Isernia et al., 2020; see Pavlova, 2012, 2017a,b; Pelphrey et al., 2014) and newly created Face-n-Food and Face-n-Thing images and paradigms for swift inspections of the sensitivity to faces (Pavlova et al., 2015, 2016, 2017, 2018, 2020, 2021; Proverbio and Galli, 2016; Rolf et al., 2020; Kubon et al., 2021). A large, and still increasing, number of clinical, developmental, brain imaging and normative studies have implemented the Reading the Mind in the Eyes Test, RMET (for earlier reviews, see Kirkland et al., 2013; Girli, 2014; Olderbak et al., 2015; Baron-Cohen, 2017; Peñuelas-Calvo et al., 2019; Kittel et al., 2021).

The original version of the RMET had been introduced by Simon Baron-Cohen and colleagues (Baron-Cohen et al., 1997) to evaluate mindreading abilities in adults with autism spectrum disorder (ASD). The test requires matching of visual information from photographs of a

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pair of eyes (primarily taken from UK newspapers) along with the surrounding part of a face (including hair style and make-up) and a pair of words describing affective or mental states (one correct and the other incorrect). Autistic individuals demonstrated a lower performance level than unaffected typically developing individuals and a clinical cohort with Tourette syndrome. The RMET had been reported to possess good convergent validity with Happé 's Strange Stories (a test assessing theory of mind, ToM, cognitive abilities; Happé, 1994), and discriminant validity with a basic emotion recognition task based on Ekman's photographs (Baron-Cohen et al., 1997). The initial version consisted of 25 black-and-white photographs of female and male gazes with a forced choice between two words referring to semantically opposite affective states (e.g., 'relaxed-worried' or 'certain-uncertain'). As *riposte* to critics pointing to some limitations of the initial version, a revised version of the RMET (Baron-Cohen et al., 2001a) increased the number of items (to 36 instead of 25) and response options per item (to 4 instead of 2). For instance, instead of an initial alternative between 'serious (correct)--playful (incorrect)', participants had to decide between 'serious (correct)-ashamed-alarmed-bewildered (all three incorrect)'. The intention behind it was to increase the level of difficulty and individual variability by avoiding a near-the-ceiling level of performance. The authors also used more complex visual images for reducing responses based on rather simple cues such as gaze directions (e.g., 'noticing you'/'ignoring you' or 'far away focus'/'near focus'). They balanced the RMET in terms of gender of depicted images (19 female and 17 male posers). Furthermore, they included a glossary of all the verbal affective state terms to diminish the influence of language knowledge, as in the initial version, options for responses often included rather uncommon words.

This version of the RMET (Baron-Cohen et al., 2001a) became one of the most frequently used tools in assessing social capabilities not only in clinical practice, but also in neurotypical individuals. Our recent PUBMED search with key words '*Reading the Mind in the Eyes Test*' yielded almost 600 results with a drastically increasing number per year over the last decade: from 10 in 2010 to a peak of 78 in 2021 (Fig. 1). The interest rapidly increased during the COVID-19 pandemic (2020-2021), since mandatory face covering by masks left the same amount of information for non-verbal social cognition as the RMET did (Pavlova and Sokolov, 2022). In accord with this, most recent experimenthal evidence indicates that RMET performance predicts accuracy of facial affect recognition of masked faces, whereas the Tromsø Social Intelligence Scale (TSIS) does not (Swain et al., 2022).

The test has been translated into many languages including Arabic (Hünefeldt et al., 2021), Bengali (Rudra et al., 2016), Bosnian (Schmidt and Zachariae, 2009), Brasilian version (Sanvicente-Vieira et al., 2014), French (Prevost et al., 2014), German (Bölte, 2005; Pfaltz et al., 2013), Italian (Vellante et al., 2013), Japanese (Kunihira et al., 2006; Adams et al., 2010), Persian (Khorashad et al., 2015), Romanian (Miu et al., 2012), Russian (Kholmogorova et al., 2015), Spanish (Fernández-Abascal et al., 2013), Swedish (Hallerbäck et al., 2009), and Turkish (Girli, 2014). Shortened RMETs for developmental studies, such as a 28-item version for children (Baron-Cohen et al., 2001b), a 24-item version for adolescents (Holt et al., 2014), a 24-item test (Schroeter et al., 2018) as well as 10- and 21-item modifications for older adults (Lee et al., 2020; Chander et al., 2020) have also been implemented. In an effort to increase the ecological validity of the task for young participants, the RME of Children Test (RME-C-T) had been developed using photos of children's gazes (Pahnke et al., 2020).

Curiously, even the Cat Emotion Test (CET), a version of the RMET with cat eyes replacing the original human images (Fig. 2), has been recently developed to be applied in clinical settings (Eddy and Hansen, 2020). This may be beneficial, in particular, for examination of autistic people often displaying lower brain activity for human, but not animal faces (Whyte et al., 2016). RMET and CET performance are found to be differentially affected by executive functions and signs of psychopathology. Moreover, schizotypal personality traits and empathy (assessed by the Interpersonal Reactivity Index, IRI) predict RMET but not CET

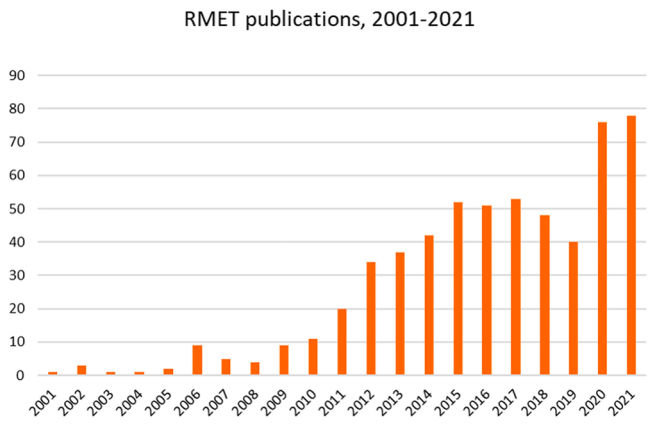


**Fig. 1.** Number of publications per year between 2001 and 2021 as the outcome of PUBMED search with key words 'Reading the Mind in the Eyes Test', RMET.

accuracy (Eddy and Hansen, 2020). Anthropomorphic images may be more acceptable for autistic people as they often prefer non-human (such as animals, avatars, robots or cartoons) over human social agents and avoid human counterparts. On a newly developed Cartoon Reading the Mind in the Eyes (CRME) version of the standard RMET (Fig. 3), adults scoring above the clinical cutoff for autistic traits on the Autism Quotient (AQ; Baron-Cohen et al., 2001c) do not differ from individuals with the lowest level of autistic traits, whereas the groups differ on the standard RMET (Atherton and Cross, 2022). Presumably, in cartoons, featural cues are more expressive or even exaggerated.

The RMET has a number of benefits for assessment of social cognition in clinical settings over widely used questionnaires often based on subjective self-evaluations. Foremost, the test is easy to administer, in particular, in a paper-and-pencil form. Yet even the modified version of the test has been criticized for heavy reliance on language proficiency and vocabulary comprehension (Olderbak et al., 2015; Kittel et al., 2021). There are also several disputable issues regarding the RMET visual input: (i) *Imbalance in item valence*. Nearly 100 studies have examined whether performance on the RMET varies with item valence, and the outcome depends on cultural differences. The number of visual images of different valence, i.e., the proportion of positive, negative, and neutral affective states is reported to be unequal: among 36 items of the RMET, 12 represent negative, 8 positive, and 16 neutral complex affective states (Harkness et al., 2010). Most recently, in a group of 164 raters, valence categories on the RMET were shown to be rather subjective, exhibiting a U-shaped association with RMET performance. Items with more pronounced valence (negative or positive) were stronger knotted with better performance than neutral items (Hudson et al., 2020). (ii) *Imbalance in item gender by valence*. The RMET appears unbalanced in regard to the number of female/male posers with distinct emotional valence: among 16 neutral images, 7 are represented by females; among 8 positive images, 5 portrayed females; but among 12 negative images, 5 display females (Harkness et al., 2010; see also Olderbak et al., 2015). This is of importance, since gender of a poser is known to affect the perception of emotional valence. In general, male posers tend to be rated as more emotionally negative than female posers (e.g., Korb et al., 2022). This was also shown for images used in the German version of the RMET (Kynast and Schroeter, 2018), though in German participants, the link between gender of a poser and emotional valence is reported to be modulated by age: older male posers are estimated as expressing more negative emotions, and male posers are estimated older than female posers. (iii) *Limited standardization of visual input*. Relatively poor internal consistency of the RMET is elicited by limited standardization of visual information available such as different gaze directions, face angles, and illumination (Vellante et al., 2013; Khorashad et al., 2015; Olderbak et al., 2015). For example,

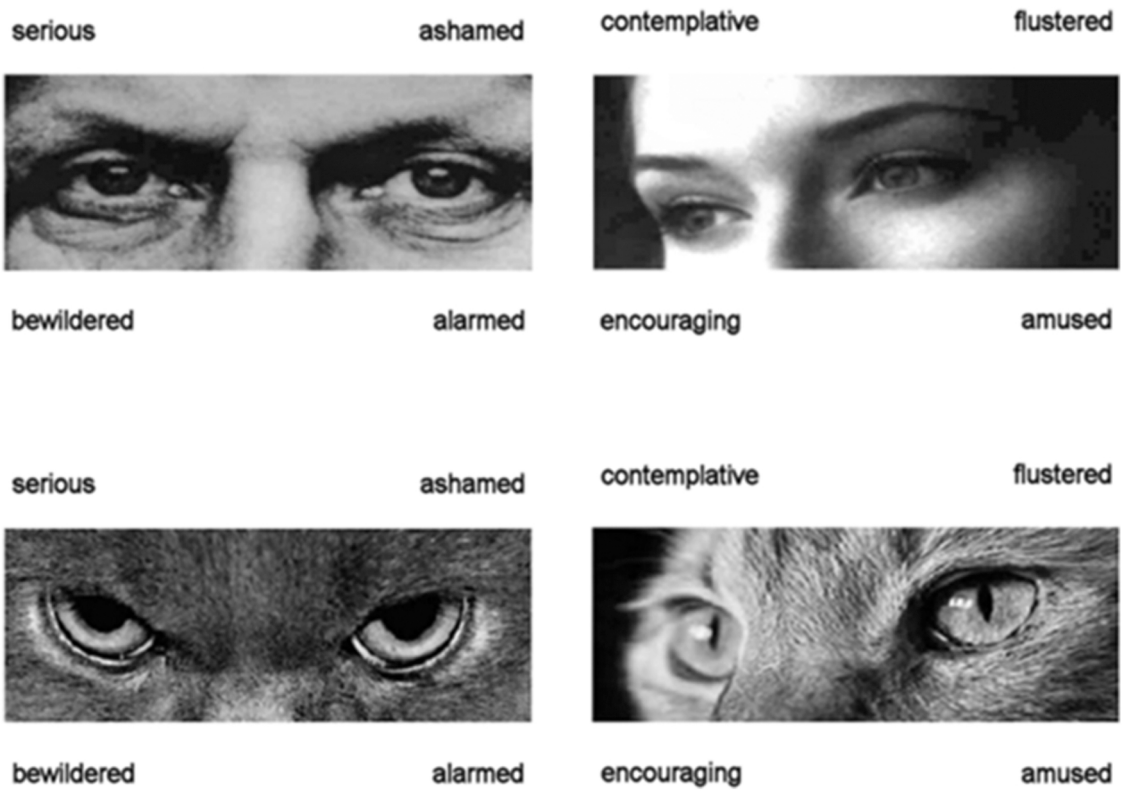


**Fig. 2.** Examples of images used in the standard RMET (top row) and in the Cat Emotion Test (CAT; bottom row). Correct responses are 'serious' for the images on the left, and 'contemplative' for the images on the right. From Eddy and Hansen, 2020. Predictors of performance on the Reading the Mind in the Eyes Test. *PLoS One, Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/4.0/)*.

modifications of an image in illumination lead to altered performance on this item (Hallerbäck et al., 2009). In addition, the visual images had been selected from newspapers in the United Kingdom about 25 years ago, and, therefore, may be outdated. Furthermore, how we read complex mental states may be derived from basic visual signals: simple opposing features such as eye widening and narrowing signal not only basic emotions, e.g., fear versus disgust, but also complex mental states, e.g., awe versus suspicion (Lee and Anderson, 2017). There are also several points regarding the psychometric characteristics of the RMET (Harkness et al., 2010; Ragsdale and Foley, 2011; Vellante et al., 2013; Khorashad et al., 2015; Olderbak et al., 2015) and multidimensionality of the response outcome (Olderbak et al., 2015). Besides, the data sets obtained are often not normally distributed (Söderstrand and Almkvist, 2012; Vellante et al., 2013). Recent work indicates great individual differences on the RMET within a non-clinical population along with limitations of the test to reliably capture differences between high performers (Black, 2019). All these issues call for a more sensitive tool. However, the principal question is *what does the RMET truly measure*?

## 2. Validity: what does the RMET assess?

The RMET had been conceptualized as a test tapping ToM, i.e., as a tool that is relatively free of general non-social cognitive capabilities (Baron-Cohen et al., 1997). The RMET has been often referred to as a measure of affective ToM, i.e., the inference of complex emotional states (e.g., Rosso and Riolfo, 2020; Gallant et al., 2020). Yet the test also requires the attribution of non-emotional mental states, and, therefore, cognitive ToM abilities (Shamay-Tsoory et al., 2010). Some experimental evidence suggests that the RMET assesses lower-level emotion recognition rather than higher-level ToM (Oakley et al., 2016). The RMET is considered by its creators to evaluate both processes (Vellante et al., 2013; Baron-Cohen et al., 2015).

The architects of the RMET reported a lack of correlations between the RMET and general IQ (intelligence quotient) scores in a large group of pooled together sub-groups of students, individuals with ASD, neurotypical controls, and IQ-matched controls (Baron-Cohen et al., 2001a). Yet later, verbal IQ was reported to contribute to the variance on the RMET (Golan and Baron-Cohen, 2006; Peterson and Miller, 2012; Del Valle Rubido et al., 2018), whereas some aspects of face processing (as measured by the Cambridge Face Memory Test) do not (Peterson and Miller, 2012). A recent meta-analysis of 18 studies using the RMET in neurotypical population (including children) shows that RMET performance is dependent on both general and verbal IQ (Peñuelas-Calvo et al., 2019). In 117 adults in Turkey, level of education was found to significantly affect RMET scoring (Yıldırım et al., 2011).

As already mentioned above (Section 1), the RMET heavily relies on proficient language command and vocabulary comprehension (Olderbak et al., 2015; Kittel et al., 2021). Recent studies in children point to associations between the RMET-C, fluid intelligence and receptive language (Rosso and Riolfo, 2020). Language (spelling/reading) skills in neurotypical young adults (students) with and without brain concussion (Gallant and Good, 2020), and the Author Recognition Test, a measure of lifetime exposure to literary fiction (Kidd and Castano, 2013; Panero et al., 2016) predict RMET scores. After reading metaphorical as opposed to literal sentences, RMET scores are higher (Bowes and Katz, 2015). Across individuals with early Alzheimer's disease (from subjective cognitive impairment through mild cognitive impairment (MCI) to early dementia), RMET scores are related to episodic and working memory as well as verbal fluency (Yildirim et al., 2020a).

At the same time, the RMET has been shown to be predictive of emotion perception from whole-seen faces (Guastella et al., 2010; Petroni et al., 2011; Kittel et al., 2021). Moreover, significant correlations are reported between the RMET and Emotional Accuracy Test (EAT, which uses natural facial expressions and defines the recognition as the match between the emotion ratings of a target and a perceiver) and Geneva Emotion Recognition Test (GERT), as well as with verbal IQ

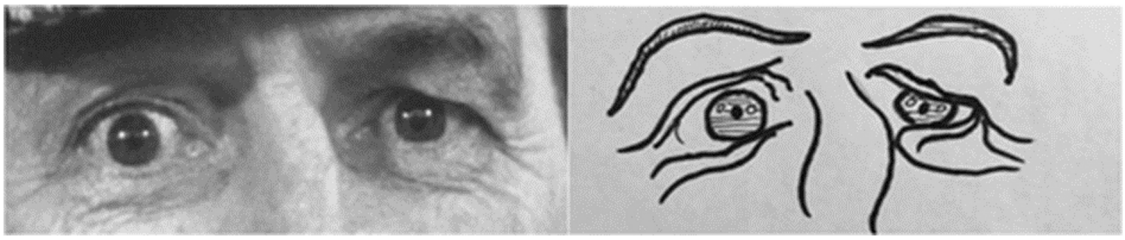

**Fig. 3.** Examples of images from the RMET and Cartoon Reading the Mind in the Eyes (CRME), a cartoon version of the standard RMET. Both images express '*panic*', and the correct response is 'panicked' along with 3 foils (jealous, arrogant, and hateful). From Atherton and Cross, 2022. Reading the mind in cartoon eyes: Comparing human versus cartoon emotion recognition in those with high and low levels of autistic traits. *Psychological Reports, Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/4.0/)*.

(Israelashvili et al., 2021). Our ability to obtain social information from the eyes is linked to self-reported empathy and artistic attitudes (Guariglia et al., 2015; Olderbak and Wilhelm, 2017; Eddy and Hansen, 2020) as well as to emotional intelligence as assessed by the Mayer-Salovey-Caruso Emotional Intelligence Test (Megías-Robles et al., 2020). In 200 Korean adults, RMET performance is associated with alexithymia (the inability to identify emotions in the self) assessed by the Korean version of the 20-item Toronto Alexithymia Scale, TAS-20 K, and individuals with poor RMET performance are more likely to express aggression (Lee et al., 2020). RMET scores are negatively correlated with social anxiety (Alvi et al., 2020; Berg et al., 2021). Individualism is not related to reading in the eyes, whereas collectivism is positively related to RMET scores in Palestinian, but not in Italian or German adolescents (Hünefeldt et al., 2021). While students of play-acting show significantly higher RMET scores than students of dance performance, the difference between play-acting and psychological students is marginal (Schmidt et al., 2021). The authors of this study speculate that dancers appear to be less concerned with others' emotional states that may be related to an 'inward' focus requested by this particular art. Our explanation would be that face information is simply more substantial for actors, whereas for dancers, body language may be of crucial value.

A growing body of evidence shows that compared with placebo, intranasal administration of the neuropeptide oxytocin (OXT, *love hormone*, an evolutionarily ancient neuropeptide known to facilitate social cognition, Tillman et al., 2019) promotes RMET performance (Domes et al., 2007; Weisman et al., 2015; but cf. Radke and Brujin, 2015). This is the case in young men for difficult (but not for easy) items as well as in individuals with lower empathy scores (Feeser et al., 2015), and low socioeconomic status (Sun et al., 2020). Genetic variations in the oxytocin receptor gene (OXTR) are related to RMET scores (Lucht et al., 2013). OXT administration also increases RMET scores in schizophrenia (Woolley et al., 2014; but see Brambilla et al., 2016), people with severe alexithymia (Luminet et al., 2011), males with depression (Pincus et al., 2010; MacDonald et al., 2013), and individuals with and without a history of childhood maltreatment (Riem et al., 2014; Schwaiger et al., 2019). In women with maternal love withdrawal, OXT also enhances brain activation in the superior temporal sulcus (STS), a central part of the social brain, and the insula during RMET performance (Riem et al., 2014).

Few studies report the link between the RMET and several aspects of body language reading such as inferring emotions through point-light displays representing human locomotion in a non-clinical adult population and 7- to 12-year-olds (Alaerts et al., 2011; Miller and Saygin, 2013; Rice et al., 2016). Yet recent work indicates that this bond is gender-specific, occurring in females solely (Isernia et al., 2020; Fig. 4). Given that general IQ is occasionally reported to be related to body language reading (inferring emotions through point-light body language, Mazzoni et al., 2020), visual processing of neutral body motion (Rutherford and Troje, 2012; Keane et al., 2018) and the RMET, it appears plausible to assume that a more general factor such as intellectual capacity may underlie both RMET performance and body reading. The most recent meta-analysis indicates that the RMET is more strongly related to emotion perception than other ToM assessments (Kittel et al., 2021) operating rather as an emotion (or affect) perception measure.

In sum, it appears that at least two core factors profoundly affect RMET performance: on one side, language skills (language comprehension, vocabulary, verbal fluency, etc.) and, on the other side, the sensitivity to non-verbal emotional signals such as facial affect reading. This is of particular value for examination of distinct clinical populations, since scarcity in RMET scoring may stem not only from poor visual social cognition, but simply from deficits in language capabilities and semantic, episodic, and working memory. Further illumination of '*what the RMET truly measures*' comes from cumulative brain imaging evidence.

## 3. Neural circuits supporting performance on the RMET

Brain imaging and lesion studies provide further insights into the origins of the RMET outcome. The initial functional magnetic resonance imaging (fMRI) study conducted by the RMET creators indicated involvement of the pivotal areas of the social brain such as the right STS and amygdala, as well as a number of the prefrontal regions that may be engaged in language comprehension and decision making (Baron-Cohen et al., 1999). Increased activation in the amygdala, however, is reportedly absent in ASD (Baron-Cohen et al., 1999).

### 3.1. Neuroanatomy of RMET performance

RMET performance is correlated with the grey matter volumes of the dorsomedial prefrontal cortex (dmPFC), inferior parietal lobule (IPL), precuneus, and temporoparietal junction (TPJ) in the left hemisphere (Sato et al., 2016). The grey matter density in the left posterior STS (pSTS) and functional connectivity between the pSTS and amygdala also predict RMET scores (Yin et al., 2018). RMET performance is correlated with fractional anisotropy of the right-hemispheric uncinate fasciculus, an association fiber tract connecting the right frontal and anterior temporal lobes, which support decision making and social behavior (Coad et al., 2020; Fig. 5).

As indicated by voxel-based morphometry, RMET deficits in Lewy body dementia and Alzheimer's disease are associated with grey matter atrophy in the inferior frontal and orbitofrontal cortices, TPJ, precuneus, fusiform gyrus and insula (Heitz et al., 2016). In multiple sclerosis (MS), RMET scores are knotted with white matter volumes in the bilateral parietal and temporal cortices as well as with the cingulate grey matter volume (Chalah et al., 2017). Across ASD, attention-deficit/hyperactivity disorder (ADHD), and obsessive-compulsive disorder (OCD), smaller amygdala/hippocampal volumes are associated with lower RMET scores (Baribeau et al., 2019).

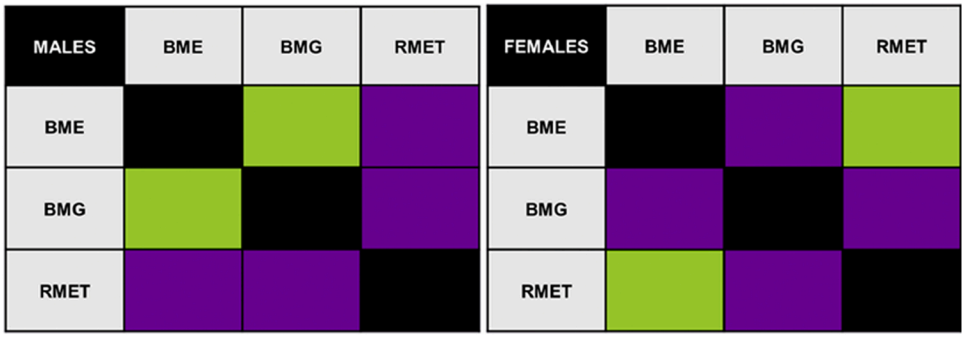


**Fig. 4.** Correlation matrices between accuracy of performance (correct response rate) on emotion (BME) and gender (BMG) recognition through point-light body motion, and the RMET. Significant correlations (Pearson product moment correlation; $p < 0.05$) are color-coded by green, non-significant correlation by violet. In females only (right matrix), RMET scoring is significantly bonded with body language reading. From Isernia et al., 2020. Untangling the ties between social cognition and body motion: gender impact. *Front. Psychology*, *Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/4.0/)*.

### 3.2. Functional brain imaging during the RMET

Activation of the pSTS is uncovered by fMRI during the RMET in early, mid-adolescence, and young adulthood, whereas in early adolescence the dmPFC, IFG and temporal lobe are engaged (Moor et al., 2012). This outcome generally agrees with a longitudinal fMRI analysis in 12- to 19-year-olds revealing stability of test-retest correlations in the STS and IFG in the right hemisphere, yet decreasing activation in the bilateral dmPFC and right IFG with age (Overgaauw et al., 2015). Conjunction analysis points to overlapping activity in the IFG, precentral gyrus, and superior frontal gyrus of the left hemisphere across three tasks: the RMET, Reading the Mind in the Voice, and Intentional Causal Attribution task (Thye et al., 2018). After cognitive-based compassion training, neurotypical individuals exhibit increased scores on the RMET accompanied by an increased fMRI activation in the IFG and dmPFC (Mascaro et al., 2013).

Male violent offenders with conduct disorder and antisocial personality disorder (with and without signs of schizophrenia) exhibit higher levels of fMRI activation in the left prefrontal and temporo-parietal regions, right fusiform gyrus and right dorsolateral prefrontal cortex, and reduced activation in the left amygdala while completing the RMET (Schiffer et al., 2017). This outcome further illuminates RMET dependence on the circuits underwriting language skills. The severity of sexual abuse and emotional neglect is related to an increased activation of the left IFG during the RMET, which is also associated with an activation in the right insula and superior temporal gyrus, STG (van Schie et al., 2017). Compared to placebo, OXT administration in individuals with depression led to increased activation in the superior middle frontal gyrus and insula (Pincus et al., 2010). Attachment-related stress induction results in reduction of activation in the left pSTS, IFG, and TPJ during the RMET, while the middle frontal gyrus and anterior insula demonstrate greater functional connectivity to the pSTS in the left hemisphere (Nolte et al., 2013).

### 3.3. Lesion studies and the RMET

In patients with traumatic brain injury, whole-brain voxel-based lesion symptom mapping (VLSM) indicates that the Brodmann Area (BA) 47 in the left IFG, a region known to be heavily involved into verbal fluency and semantic working memory, along with adjacent rostral aspects of the arcuate fasciculus are crucial for RMET performance (Dal Monte et al., 2014). Of note, verbal fluency and general memory were the only deficient cognitive domains in these patients. Parcel-based lesion-symptom mapping (PLSM), white-matter tract-wise statistical analysis (TSA) and disconnectome symptom mapping (DSM) in stroke patients reveal that low RMET scores are associated with damage to the right posterior frontal gyrus and insula as well as with dysconnectivity in white-matter tracts between frontal and temporo-parietal regions (Domínguez et al., 2019).

## 4. The RMET in clinical settings: diagnostic validity

### 4.1. The RMET in autism

The RMET (Baron-Cohen et al., 1997, 2001a) was initially developed for a swift examination in ASD of one aspect (namely, inferring affective states) of a rather complex multifaceted construct such as ToM. By now, the most replicable and robust finding is that individuals with ASD exhibit difficulties on the RMET (Baribeau et al., 2015; Lombardo et al., 2016; Baron-Cohen, 2017; Del Valle Rubido et al., 2018; Peñuelas-Calvo et al., 2019; Baltazar et al., 2021). This finding is observable across cultures occurring, for example, in children from Kolkata, India (Rudra et al., 2016). In the neurotypical population, lower RMET scores are found in individuals with higher autistic traits (Gökçen et al., 2014). Individuals are at low risk of ASD if they perform at a threshold of at least 70% (or higher) of correct responses for easy RMET items as well as items with positive valence (Baltazar et al., 2021). Yet, the RMET does not differentiate between broad autism phenotype (BAP, *a set of traits in people who show autistic tendencies such as problems with communication and social skills but do not meet the DSM IV-TR diagnostic criteria for autism*) and Non-BAP (Camodeca, 2019). ASD is characterized by an imbalance of excitatory and inhibitory neurotransmission with higher glutamine (Gln) and lower γ-aminobutyric acid (GABA). Whereas a negative association occurs between the RMET and Gln levels, RMET scores are positively tied with GABA levels (Cochran et al., 2015).

The RMET became a popular tool for detecting alterations in social cognition in clinical settings. As postulated by Simon Baron-Cohen (Baron-Cohen, Am J Psychiatry 174:1, p. 2, 2017), '*…individual differences in reading the mind in the eyes are not just a function of our biology, as postnatal social experience likely amplifies these prenatal determinants. For this reason, we should expect that impaired performance on this test might be observed in a range of clinical groups, not just in autism, for diverse reasons.*' At least two issues concerning diagnostic validity of the RMET must be accurately considered: (i) the capability to differentiate between distinct neuropsychiatric, neurological and neurodevelopmental conditions. In other words, one asks whether the RMET represents a sufficient instrument for uncovering the specificity of social cognitive profiles, and may serve as a kind of diagnostic tool; and (ii) the capacity to discriminate between clinical and non-clinical populations. We discuss these issues in turn.

### 4.2. RMET discriminability between neuropsychiatric conditions

Most recent cross-disorder systematic reviews, meta-analyses and experimental work reveal no difference in RMET performance between ASD and schizophrenia spectrum disorders (SSD) (Fernandes et al., 2018; Oliver et al., 2021; Altschuler et al., 2021; but see Guastella et al., 2013; Chen et al., 2017 for limitations of using the RMET in SSD). Likewise, no difference on the RMET was found between remitted patients with schizophrenia, schizoaffective and bipolar disorders

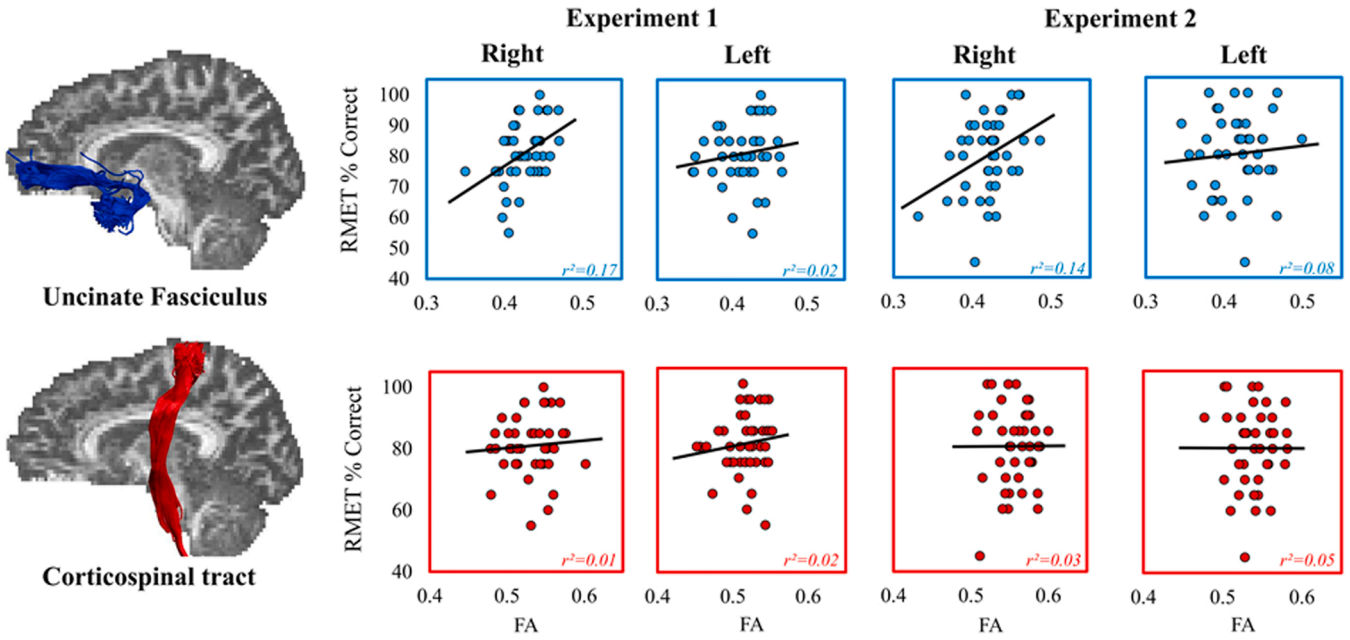


**Fig. 5.** The link between fractional anisotropy (FA) in the uncinate fasciculi (UF), marked in blue (top row) and corticospinal tracts (CST), marked in red (bottom row) and scoring on emotional items of the RMET in 42 neurotypical adults (9 males) aged 19–40 years (exp. 1), and in 44 adults (14 males) aged 18–34 years (exp. 2). Best fitting linear regression lines are displayed on each scatter plot. In both experiments, significant correlation occurs between the RMET accuracy and FA of the right (but not left) UF. From Coad et al., 2020. Structural connections support emotional connections: uncinate fasciculu microstructure is related to the ability to decode facial emotion expressions. *Neuropsychologia, Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/4.0/).*

(Dehelean et al., 2021). Individuals with ASD and alexithymia do not differ from each other on RMET scoring, though ASD individuals (solely) demonstrate deficient performance on the Movie for Assessment of Social Cognition (MASC) (Oakley et al., 2016, but see Rødgaard et al., 2019). Patients with major depressive disorder (MDD) and social anxiety disorder (SAD) exhibit no difference on the RMET, whereas on the Faux Pas Task tapping reasoning aspects of ToM, individuals with MDD show weaker performance as compared with individuals with SAD and controls (Maleki et al., 2020). This outcome suggests that either the RMET poorly differentiates between these neuropsychiatric conditions or deficits on the RMET have similar cross-diagnosis origins.

RMET scores in individuals at high risk for psychosis and with first-episode psychosis (FEP) as well as in patients with FEP and chronic patients with schizophrenia are comparable albeit lower than in controls (García-Fernández et al., 2020; Kim et al., 2020). This suggests that the standard RMET does not discriminate between the stage and severity of these conditions. The RMET also does not discriminate patients with early Alzheimer's disease from individuals with early Lewy body dementia (Heitz et al., 2016). Yet children with ASD, ADHD, OCD, and neurotypical controls differ in RMET accuracy (Baribeau et al., 2019): Individuals with ASD and ADHD exhibit the poorest performance on items with positive valence, whereas over-performance of individuals with OCD on the RMET suggests their hypersensitivity to social signals. Children 11–17 years old with Tourette syndrome exhibit similar difficulties on the RMET as those with ASD (Pérez-Vigil et al., 2021). Yet a systematic review and meta-analysis of 13 cross-sectional studies indicates that RMET scoring of individuals with MDD is weaker than in those with borderline personality disorder (BPD) (Richman and Unoka, 2015). This difference is modulated by valence of items: positive items elicit more incorrect responses in MDD, while individuals with BPD score lower on neutral items. The recent revised version of the RMET (RMET-CV-R) used in illiterate respondents (less than 5 years of schooling) over 60 years old in rural communities in China discriminates well between treatment-naïve and treated patients with chronic schizophrenia (Deng et al., 2021).

### 4.3. RMET discriminability between clinical and non-clinical populations

Apart from ASD, contrasting findings are reported on the RMET's diagnostic validity for discrimination of clinical from non-clinical populations. In a large sample of males ($N = 1000$; age range, 18–78 years), higher psychopathic traits are negatively related to RMET (Short Forms A and B) scores (Carroll et al., 2021). Patients with schizophrenia score lower on the RMET than neurotypical controls or first-degree relatives (Varela et al., 2021). By contrast, no difference occurs between adults with MDD and controls, and only persons with MDD who were maltreated (i.e., reported emotional abuse and neglect) in childhood score poorly on the RMET (Simon et al., 2019). Female adolescents with non-suicidal self-injury (NSSI, most of whom are diagnosed with MDD) do not exhibit difficulties on the RMET (Tekden et al., 2021). The RMET does not discriminate adolescents with ADHD from their neurotypical peers (Çiray et al., 2022). Patients with BPD are reported to perform better than controls, in particular, on neutral RMET items (Fertuck et al., 2009), though the opposite effect is reported in females with BPD (Tay et al., 2017; Cyrkot et al., 2021). Individuals with bipolar disorder (BD) and unipolar depression (UD) perform worse on the RMET than controls: patients with BD display more difficulties on items with positive valence, whereas patients with UD with negative valence (Espinós et al., 2018). Patients with SAD score lower on the RMET than neurotypical controls (Maleki et al., 2020; Küçükparlak et al., 2021). Children with fetal alcohol spectrum disorder (Stevens et al., 2017) and individuals with alcohol dependence (Nandrino et al., 2014) exhibit deficits on the RMET. Females with cocaine addiction display deficits on negative items (Sanvicente-Vieira et al., 2017). Sexually abused female adolescents score lower on the RMET (Gundogdu and Eroglu, 2021). Patients with serious eating disorders (in a sample predominated by females, 85.1%) perform worse on the RMET (Boscoe et al., 2021). Young females with a high body mass index (BMI) show worse RMET performance compared to their counterparts, whereas the opposite outcome is reported in older women (Balter et al., 2021).

The RMET scores are lower than in controls in a wide range of neurological and neurodegenerative disorders: for example, in patients

with multiple sclerosis (Cotter et al., 2016) and epilepsy (Stewart et al., 2016). Unsurprisingly, patients with behavioral variant frontotemporal dementia (bvFTD; Pardini et al., 2013; Schroeter et al., 2018) and Lewy body dementia (Heitz et al., 2016) experience difficulties on the RMET. Older individuals with MCI exhibit lower performance level on the RMET along with poorer everyday skills (such as paying bills) assessed by the Revised Cambridge Behavioral Inventory (Michaelian et al., 2019).

De novo Parkinson's disease (PD) patients (Orso et al., 2020), non-demented PD patients (Tsuruya et al., 2011) and PD individuals with freezing of gait (Raffo De Ferrari et al., 2015) are all deficient on the RMET. Yet patients with early PD (Romosan et al., 2019) as well as patients with spinal muscular atrophy (Mix et al., 2021) are reported to be unimpaired. The RMET also points to a socio-cognitive aspect of other movement disorders, such as Huntington's disease (Bayliss et al., 2019) or amyotrophic lateral sclerosis (ALS, a rapidly progressive neurodegenerative disease) with difference between cognitively intact and executively impaired patients (Burke et al., 2016).

To summarize the clinical findings analyzed in this section, poorer RMET performance in a wide range of neuropsychiatric, neurological and neurodegenerative conditions leads to an assumption that the RMET is rather limited in discrimination between most of them. One possible account might be that deficits in social cognition in all these conditions are non-specific for a single condition. Instead deficits are of similar origins across conditions.

Notably, the RMET may be quite challenging for individuals not only with neuropsychiatric, neurological, and neurodevelopmental conditions characterized by alterations in social cognition, but also for individuals with other cognitive deficits such as limited attentional resources. In unison with brain imaging, the data in patients imply that not only intact communication within the large-scale neural networks underpinning veridical reading in the eyes, but a proper functioning of the neural circuits supporting attentional capacity, working memory, and decision making is required for efficient RMET performance.

## 5. Gender/sex impact on the RMET

Already initial reports (Baron-Cohen et al., 1997, 2001a) indicate a tendency of females to excel on the RMET. This outcome was confirmed in a number of subsequent studies in neurotypical individuals (e.g., Schiffer et al., 2013; Baron-Cohen et al., 2015; Megías-Robles et al., 2020; Kynast et al., 2021) including data of our own collaborative group (Isernia et al., 2020). Yet a lack of gender differences (Mar et al., 2006; Olderbak et al., 2015; Lee et al., 2020) or male advantage (Nettle and Liddle, 2008) are also documented. A meta-analysis in adults from 10 countries (including USA, UK, Germany, Italy, and Argentina) illuminates a small but consistent effect of female superiority: using both fixed and random effects models, the mean weighted effect size was $g = 0.177$, $p < 0.001$ (Kirkland et al., 2013). This superiority appears to be rather independent of culture (Hünefeldt et al., 2021). Yet more recent meta-analytic work on the RMET did not reveal gender differences (Peñuelas-Calvo et al., 2019), presumably (as suggested by the authors) because 30% of the analyzed cohort were children. Higher accuracy in older Korean women was found only in the specific age range of 65–74 years (Lee et al., 2021). Merely observer's gender (as a social construct), in particular, social gender roles, rather than neurobiological sex, impacts the RMET (Vonk et al., 2016). By involving transgender women/men and non-binary assigned female/male at birth, a lower level of RMET performance is found in transgender men and non-binary assigned at birth females than in females in general population (Kung, 2020). In accord with this, testosterone administration to young women does not impair RMET performance (Carré et al., 2015), although it alters connectivity of the left IFG with the anterior cingulate cortex (ACC) and the supplementary motor area (SMA) during RMET performance, independent of 2D:4D ratio (the ratio between the length of the index and ring finger, a proxy for fetal testosterone; Bos et al., 2016). In females solely, higher social anxiety predicts better RMET performance (Berg et al., 2020).

Female advantage may be accounted for by common beliefs about overall greater curiosity and sensitivity to visual social signals, in particular, when visual social cues are subtle (Kirkland et al., 2013; Krüger et al., 2013; Dodell-Feder et al., 2020; Fig. 7b). In accord with this, gender impact on RMET performance is modulated by difficulty/ambiguity of the items (Guariglia et al., 2015). However, female superiority in non-verbal social cognition had been questioned by earlier work of our group indicating, for example, that body language reading in point-light displays can be modulated by emotion and gender of an actor. In other words, while females excel on recognition of angry actions as well as tend to be more accurate in inferring the lack of emotions, males over-perform on recognition of happy body motion of female actors (Sokolov et al., 2011; Krüger et al., 2013; see also Sokolov et al., 2020). Another (though complementary rather than alternative) explanation for female advantage on the RMET is that females are more proficient in language command and vocabulary, upon which the RMET heavily relies (Olderbak et al., 2015; Kittel et al., 2021). In accord with this, improved performance on the RMET after anodal transcranial direct current stimulation (tDCS) over the dmPFC is observed in females only, whereas stimulating the right TPJ has no effect in either sex (Martin et al., 2017). Both factors (higher sensitivity to social cues and better language command) may contribute to the female advantage on the RMET. Clarification of whether, and, if so, how these factors interact warrants further research. This work would be of value for further improvement of the RMET: to avoid gender biases (that is of importance for testing clinical populations with psychiatric, neurological, and neurodevelopmental conditions, most of which are sex/gender specific), the test should be normed by gender in the neurotypical population. Gender (and age)-specific standard scores obtained in the standardization sample of 966 neurotypical adults (the population-based Leipzig Research Center for Civilization Diseases, LIFE, study) of five age groups (20–29, 30–39, 40–49, 50–59, 60+ years) are recently reported for the German version of the RMET: irrespective of age, males exhibit a larger variance in RMET performance, whereas scoring range of women is less variable within an age group (Kynast et al., 2021). Of note, there are only very few reports available of normative scores of the RMET in different cultural/language versions, for instance, for the French version (Ehrlé et al., 2011).

Finally, in a large-sample study [395 adults with autism (178 males, 217 females) and 320 neurotypical adults (152 males, 168 females)], Baron-Cohen and colleagues (Baron-Cohen et al., 2015) found that individuals diagnosed with ASD exhibited no gender differences in RMET scores, although neurotypical females outperformed males. In our opinion, more subtle gender differences may be camouflaged by social cognition deficits in ASD, since the factor *disease* presumably has a much stronger influence on social cognition than the factor *gender*. At the same time, remitted female patients with schizophrenia, schizoaffective and bipolar disorder score better on the RMET and have higher empathy level than males (Dehelean et al., 2021).

## 6. Age impact on the RMET

Non-verbal visual social cognition is believed to remain intact in elderly (Moran, 2013; Natelson Love et al., 2015; Reiter et al., 2017). In accord with this, a meta-analysis comparing 237 young (mean age about 22 years) with 271 older adults (defined as aged > 65 years; mean age about 71 years) from 7 studies indicated only slight to moderate declination of reading the mind in the eyes abilities, with a mean weighted effect size $r = -0.43$, $p < 0.001$ (Henry et al., 2013). Between 24 and 79 years, performance on the RMET is rather stable across the decades 20–70 (with a slight decrease of this ability with aging) and independent of executive functions (Cabinio et al., 2015). An age-related decrease in volume occurs in a number of brain areas (including the precentral gyrus bilaterally, left IFG, left STG, and bilateral posterior insula, but mostly

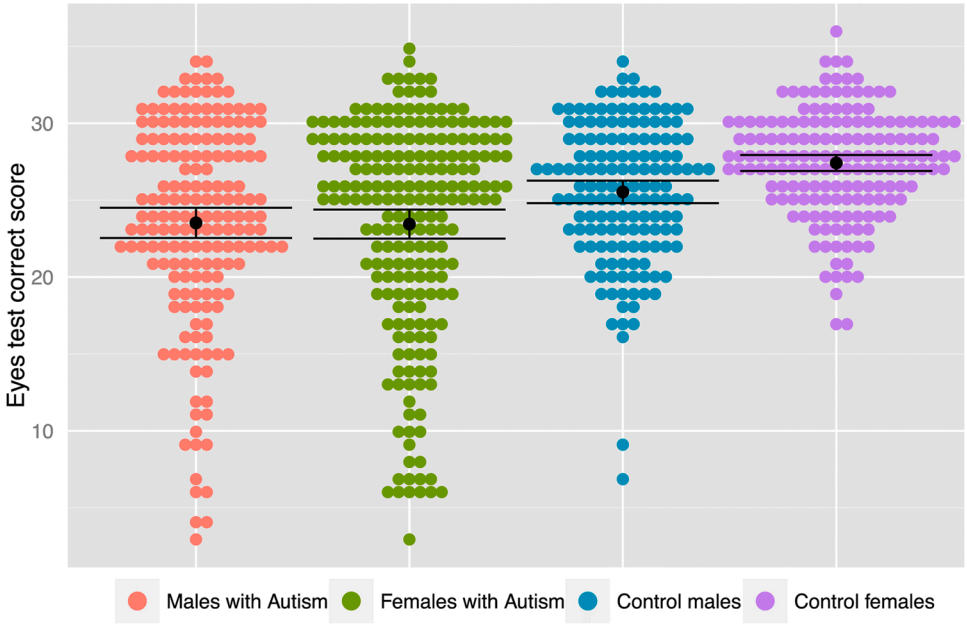


**Fig. 6.** RMET scoring in ASD and neurotypical females and males. Total correct score on the RMET for each individual is plotted as a dot, marked by color according to group, illustrating the distribution of performance by group (maximum 36). Mean score for each group is shown by a black dot, and the error bars indicate the 95% confidence interval of the mean score. From Baron-Cohen et al., 2015. The "Reading the Mind in the Eyes Test": complete absence of typical sex difference in ~400 men and women with autism. *PLoS One*, *Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/4.0/).*

over the frontal cortices) along with progressive white matter disconnection of the left fronto-temporal brain regions (Cabinio et al., 2015). In healthy aging, lower RMET scores are related to smaller hippocampal volume (Michaelian et al., 2019). Age-related decline appears to be profoundly modulated by individual differences: with increasing age, the RMET scoring variance increases in both men and women (Kynast et al., 2020, 2021). In individuals older than 66 years, RMET scores are higher with younger age, higher education, higher cognitive screening scores, literacy, social norms scores, and lower clinical dementia rating (Lee et al., 2020; Dodell-Feder et al., 2020). Older patients with common mental disorders show deficits on the RMET (Peters and Schulz, 2021). As the RMET and faces covered by masks due to COVID-19 regulations provide rather comparable visual input, it is worthwhile to mention that the social cognition of older people (and individuals with dementia) is considered to suffer most from covering faces by masks (Schroeter et al., 2021; Pavlova and Sokolov, 2022). Yet, no correlation is found between age and RMET performance in individuals diagnosed with ASD (Senju et al., 2002; Brent et al., 2004).

Most recent experimental research suggests the lack of declination or even an increase in RMET scores in healthy aging (Yıldırım et al., 2020b; Dodell-Feder et al., 2020). It is reported that in 40,248 English-speaking internet users (age range, 10–70 years), performance on several cognitive tests exhibits sharp improvement through adolescence, reaching peaks in late adolescence/early adulthood (i.e., between 16 and 22 years), after which performance either declines, as with the digit symbol matching test (tapping processing speed and visual working memory), or remains stable, as with facial emotion recognition tasks (Dodell-Feder et al., 2020; Fig. 7). In contrast, segmented regression analysis indicates that RMET scoring increases with age (after adolescence, slope b = 0.006; 95% confidence interval 0.005–0.008), an effect observed with crystallized cognitive abilities increasing over the lifespan. Notably, the magnitude of education-level differences on RMET scoring is larger than on other tests. Ethnicity (Hispanic/non-Hispanic ancestry) and race (European White/non-European non-White) affect RMET scoring solely, but not other social and non-social cognition tasks.

## 7. Cultural impact on the RMET

Despite the fact that the RMET is available in many languages and widely used in many English-speaking countries of different cultural background (such as South Africa, Australia, the United States or Canada), there are only very few cross-cultural studies. They primarily focus on North American versus East Asian cultural differences. In general, accuracy of the RMET is higher when emotions and mental states are expressed and recognized by the same ethnic group, though a cultural in-group effect is modulated by the amount of exposure to the cultural out-group. For instance, difficulties on the classic RMET (with images selected from the UK newspapers) are more pronounced in those Singaporean individuals who had less contact with Caucasians (Martin et al., 2021). Palestinians score lower on the RMET than German and Italian individuals who are much more exposed to Caucasian facial affect (Hünefeldt et al., 2021). Functional MRI in Caucasian Americans and native Japanese adults reveals greater bilateral pSTS recruitment during same- versus other-culture RMET performance in both cultural groups (Adams et al., 2010). Black race and African home language respondents show lower RMET scores and different item level perspectives on certain mental states (van Staden and Callaghan, 2021). At the same time, the RMET translated into Korean (using images of Caucasian eyes) and Korean RMET version (36 photographs of Korean eyes) administered to neurotypical Korean individuals (195/101 females) are comparable in terms of psychometric properties such as internal consistency measured by Cronbach's alpha, and test-retest reliability (Koo et al., 2021).

## 8. Résumé

In a nutshell, the growing need for experimental assessment of social cognition skills in the neurotypical and clinical populations leads to the drastically increasing use of the RMET, a tool initially developed more than two decades ago by Simon Baron-Cohen and colleagues for testing ToM in autistic individuals (Baron-Cohen et al., 1997, 2001a). By bringing together the most recent clinical data, evidence from brain imaging (white matter connectivity, functional brain imaging, and lesion studies), as well as reports on predictive values of key social cognitive capabilities (such as empathy, body language reading and face reading) for RMET performance, we illuminate several crucial issues: what does the RMET really assess; RMET differentiation power; the neural networks underpinning RMET; and the impact of gender, age, and culture on the RMET. Converging experimental evidence indicates the following:

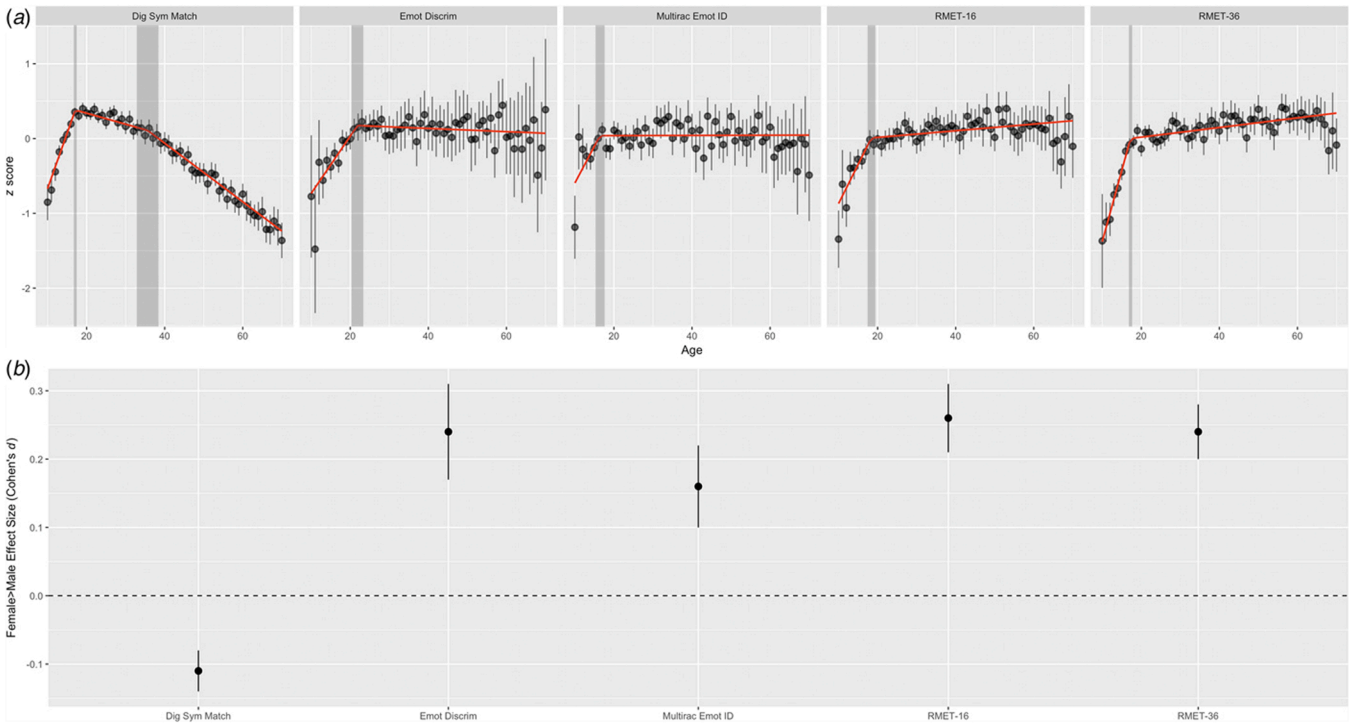


**Fig. 7.** Performance on the RMET and other tests. (a) Performance as a function of age. From left to right: Digit Symbol Matching (tapping processing speed and visual working memory), Emotion Discrimination (basic emotions with Ekman faces), Multiracial Emotion Identification Task, RMET-16 (modification with 16 items instead of 36), and standard RMET-36. The red line depicts the segmented regression slopes. The vertical grey bar depicts peaks (breakpoints) and their 95% confidence interval, CI. Data points represent mean score as a function of age with error bars denoting 95% CI. (b) Gender effect sizes with 95% CI across measures. Positive values represent a female>male performance advantage (on social cognition tasks); negative values represent a male>female performance advantage (on the Digit Symbol Matching test). From Dodell-Feder et al., 2020. Social cognition or social class and culture? On the interpretation of differences in social cognitive performance. *Psychological Medicine. Copyright © 2019 by Cambridge University Press, reprinted with permission of the Publisher.*

(i) **Link to social skills.** In the neurotypical population, RMET performance is tightly linked with other non-verbal social skills and abilities such as empathy, emotional intelligence (EI), alexithymia (the inability to identify emotions in the self), face and body language reading. In addition, oxytocin, a neuropeptide facilitating social cognition, promotes RMET performance;

(ii) **Reliance on language skills and memory.** The RMET reflects inferring facial affect, but also heavily relies on proficient language command and vocabulary comprehension, as well as on working and episodic memory, verbal IQ and social decision making;

(iii) **Circuits beyond the social brain.** In harmony with this, RMET performance is supported by large-scale ensembles of neural networks far beyond the right-hemisphere dominated nodes of the social brain (e.g., the right STS, insula, and amygdala). Engagement of brain regions supporting language comprehension and semantic working memory (such as the IFG with primarily left-hemispheric involvement) and social decision making (the dmPFC) as well as communication between them is also acknowledged;

(iv) **Restricted differentiation power.** Although the RMET rather well separates individuals with neuropsychiatric, neurological, and neurodevelopmental disorders characterized by alterations in social cognition as well as individuals with elevated pathological traits (such as autistic or psychopathic traits) from neurotypical population, cross-sectional studies indicate that the RMET is often limited in its capacity for differentiation between neuropsychiatric conditions as well as between stages and severity of a single condition. One possible account might be that in the majority of neuropsychiatric conditions, deficits in social cognition (in particular, facial affect recognition) possess similar cross-diagnostic origins and, therefore, may be considered non-specific for a single disorder.

(v) **Gender and sex variability.** A growing body of evidence points to females' superiority on the RMET with a small to moderate but rather robust effect. Recent evidence suggests that merely observer's gender (as a social construct), in particular, feminine gender roles, rather than neurobiological sex, impacts reading in the eyes.

(vi) **Age impact.** In accord with common beliefs and experimental findings that visual social cognition remains intact in healthy aging, the lack of substantial declination or even an increase in RMET scoring is reported in healthy aging. RMET scores are higher with higher education, higher cognitive screening scores, literacy, social norms scores, and intact mental well-being. Importantly, individual variability is rather high even in healthy aging.

(vii) **Cultural impact.** Despite the fact that the RMET is available in many languages and used in many same-language (e.g., English-speaking) countries with diverse cultural backgrounds (such as Australia, South Africa, the United States, and Canada), there are only very few cross-cultural studies. The outcome is rather contradictory. In general, accuracy of reading in the eyes is higher (and engagement of such key nodes of the social brain as the STS is greater) when emotions and mental states are expressed and recognized by the same ethnic group. In accord with this, difficulties on the standard RMET (with images of Caucasian faces/eyes selected from the UK newspapers about two decades ago) are reported in individuals with other cultural background, especially, in those who possess less experience in interacting with Caucasians.

Further research is required for better understanding and optimization of the RMET as a valuable tool for snapshot examination of social cognition in the neurotypical population and clinical practice. In light of comparable visual information available in the RMET images and in faces covered by masks due to the current COVID-19 pandemic regulations, the present comprehensive analysis may be of substantial value not only for keeping intact adaptive and efficient daily-life social interaction, but also for professional domains closely related to social communication such as education and health care. Further studies are required to inform what may well appear as cohort effects in/across participants prior to and after the period during which mask-wearing in public and during social interactions is a common occurrence. In turn, studies on reading faces covered by medical masks (for review, see Pavlova and Sokolov, 2022) may inform experts how to further develop easy-to-administer, swift but reliable tests tapping visual social cognition. In light of comparable visual input from the RMET images and faces covered by masks due to COVID-19 regulations, the present analysis is of value for keeping efficient social interaction during the current pandemic, in particular, in professional settings related to social communication.

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## Data Availability

No data was used for the research described in the article.

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*Competing interests*

No competing interests are declared.

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