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RESEARCH

Introducing e-Motions: a novel intraoperative test for social cognition mapping. Triple validation in normative, schizophrenia, and autism spectrum disorder populations

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Abstract

Background Social cognition is essential for daily functioning, as it influences quality of life, return to work, and interpersonal communication. While schizophrenia and autism spectrum disorder (ASD) have been the paradigmatic conditions in which social cognition is markedly impaired, emerging evidence suggests that up to 30% patients with brain tumors may experience persistent deficits in this domain. Despite its clinical relevance, social cognition remains insufficiently studied in neuro-oncology and lacks dedicated intraoperative assessment tools specifically tailored for its use during awake brain surgery.

Method This study introduces e-Motions, a new test designed ad hoc to address this gap. The e-Motions test comprises 34 four-second video stimuli depicting two hyper-realistic avatars (one male, one female) expressing complex emotions. These avatars were developed using an AI-based facial motion capture system applied to 60 professional actors. Validation was performed in three groups: (1) healthy adults ($n = 226$), (2) individuals with schizophrenia ($n = 33$), and (3) ASD ($n = 30$).

Results Internal consistency (KR-20), test–retest reliability (ICC), and correlations with established social cognition tools (Reading the Mind in the Eyes [RMET], Ekman-60 faces test [Ekman-60F], and the Movie for the Assessment of Social Cognition [MASC]) were evaluated. The e-Motions test demonstrated high global internal consistency (KR-20 = 0.86) and good test–retest reliability ($ICC_{2,1} = 0.73$). Scores showed positive moderate correlations with both lower-level mentalizing tests (RME: $\rho = 0.44$; Ekman-60F: $\rho = 0.48$) and higher-level mentalizing test (MASC: $\rho = 0.57$). Discriminative power was strong for distinguishing healthy participants from individuals with schizophrenia (AUC = 0.89) and ASD (AUC = 0.79).

Conclusions e-Motions test is the first AI-based test created ad hoc for awake brain mapping. Its good internal consistency and significant correlation with low-level and high-level mentalizing tests make this tool a novel, ecological and promising way to identify critical regions involved in social cognition during awake brain mapping. Future studies should be performed to demonstrate its validity preserving this complex higher-order cognitive construct during and after brain tumor surgery.

Keywords Social cognition · Awake mapping · Connectomics · Emotions · Artificial intelligence · Higher-order functions

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Abbreviations

AF	Arcuate fasciculus
APANATE	Canary islands autism spectrum association
ASCATEC	Canary association of creative therapies
ASD	Autism spectrum disorder
AUC	Area under the curve
BART	Brief affect recognition test
CI	Confidence interval
DES	Direct electrical stimulation
EK-60F	Ekman 60-faces test
FESPAU	Spanish confederation for autism
ICC	Intraclass correlation coefficient
IFOF	Inferior fronto-occipital fasciculus
MASC	Movie for the assessment of social cognition
OR	Operating room
QoL	Quality of Life
RME	Reading the mind in the eyes
ROC	Receiver operating characteristics curve
SEM	Standard error of the measurement
SLF	Superior longitudinal fasciculus
UF	Uncinate fasciculus

Introduction

Our higher-order functions allow us to perceive, interpret and act according to other people's emotions, thoughts and feelings, what we call social cognition in cognitive-affective neuroscience [25, 26]. Although autism spectrum disorder (ASD) and schizophrenia have been the paradigm of mental disorders where social cognition is affected [1, 66] this higher-order function can be significantly affected after brain tumor surgery [9]. These socio-cognitive impairments caused by either the tumor itself or its treatment, can lead to major deficits in quality of life (QoL), disrupting various aspects of interpersonal functioning [29, 60], such as recognizing and understanding the emotional and mental perspectives of others. Therefore, preserving social cognition in patients diagnosed with brain tumors seems to be crucial for return to work, socio-familial life, and overall (QoL)[21, 22, 26]. In the field of neurosurgical oncology, although some series have described up to 30% of patients presenting long-term deficits in social cognition after surgery[27, 47, 51], the mapping and monitoring of this higher-order functions remains understudied [10, 11, 29, 33, 49, 53, 56].

This gap in neurosurgery can be largely attributed to three factors: (1) the lack of understanding of the neural underpinnings of social cognition as a construct extending beyond face-based mentalizing[29, 30, 56]; (2) the residual influence of localizationism (one-to-one single mapping) [12, 34] still prevalent in clinical neurosurgical practice, where awake surgery has been focused on avoiding hemiplegia and aphasia [13, 48, 59]; and (3) the challenging conditions of the operating room, involving (i) the need for rigid head fixation, which complicates stimulus presentation[46], and (ii) the 4-s time constraint for direct electrical stimulation (DES) to avoid DES-induced seizures [64]—although a recent work has shown that alternating short stimulation periods (e.g., 4 s on) with equivalent off periods during longer tasks can safely extend evaluation time and allow the assessment of complex cognitive functions [2]—and iii) the inherent fatigue of awake procedures that appears after 1.5–2 h which limits the ability to extensively map social cognition and all its subprocesses[8]. Collectively, these factors have led to the current absence of dedicated, comprehensive and ecologic intraoperative tests for assessing social cognition. In fact, the existing instruments used are adaptations of those originally developed to evaluate social cognition in disorders such as schizophrenia or ASD [8]: Ekman-60 Faces test (Ekman-60F) [50], the Brief Affect Recognition Test (BART) [65], which involves facial emotion recognition tasks consisting of photographs representing the six basic emotions in a static way: anger, happiness, fear, surprise, disgust, and sadness [19, 28, 38], or the Reading the Mind in the Eyes test (RMET) [8] that, although static, evaluates complex emotions or mental states based on the eye's gaze. However, it has been postulated several limitations regarding these tests [29, 57, 58], such as the lack of ecological validity because of its use of black-and-white and low-resolution photographs [72] or the exclusive restriction to the eye region, which omits crucial emotional information for accurate mental-state inference [39,]. In this vein, dynamic facial expressions are more accurately recognized than static expressions [73, 74], but it has never been used in neurosurgery.

Since the first series on social cognition mapping was reported in 2017 using the RMET [15, 55], only a few studies have continued to explore this field [23, 47–49, 62]. Nonetheless, they demonstrated a significant decrease in long-term deficits in the lower-level mentalizing [15, 52, 53], a pivotal sub-process of social cognition. However, although preserving low-level mentalizing may imply the preservation of emotional well-being and social–familial life, it remains unclear whether this alone would be sufficient to maintain social cognition in its entirety [29, 68]. Expanding neurosurgical mapping to incorporate the multiple, interrelated components of social cognition—such as low- and high-level of mentalizing, social perception, and emotion regulation—may offer a more holistic understanding of social cognition in patients undergoing brain surgery [30].

The aim of this study is to introduce and validate a novel intraoperative neuropsychological tool, specifically designed and adapted to the constraints of the OR for in vivo social cognition mapping. The e-Motions test seeks to provide a more ecological and realistic approach through 34 four-second video stimuli. Each stimulus features two hyper-realistic avatars displaying dynamic complex emotions generated via an advanced AI-based facial motion-capture system applied to professional actors. We present here a triple and non-invasive validation of this tool in: (i) Spanish-speaking normative populations, (ii) schizophrenia and (iii) ASD.

Methods

Participants and data collection procedure

Healthy participants ($n = 226$) were recruited between February 2024 and June 2024 from three different sources: (i) research mailing lists at Universidad de Loyola, (ii) Universidad de La Laguna, and (iii) social media sharing. Participants aged between 18 and 65 years who provided written informed consent were considered eligible for inclusion (Fig. 1). For the healthy group, the inclusion criteria were: (1) age 18–65 years, (2) absence of psychiatric history, (3) verbally fluent and Spanish as first language, and (4) at least 8 years of academic studies completed; and the exclusion criteria was having physical or auditory-visual limitations. For the schizophrenia group the inclusion criteria were: (1) age 18–65 years, (2) diagnosis of schizophrenia for > 5 years, (3)

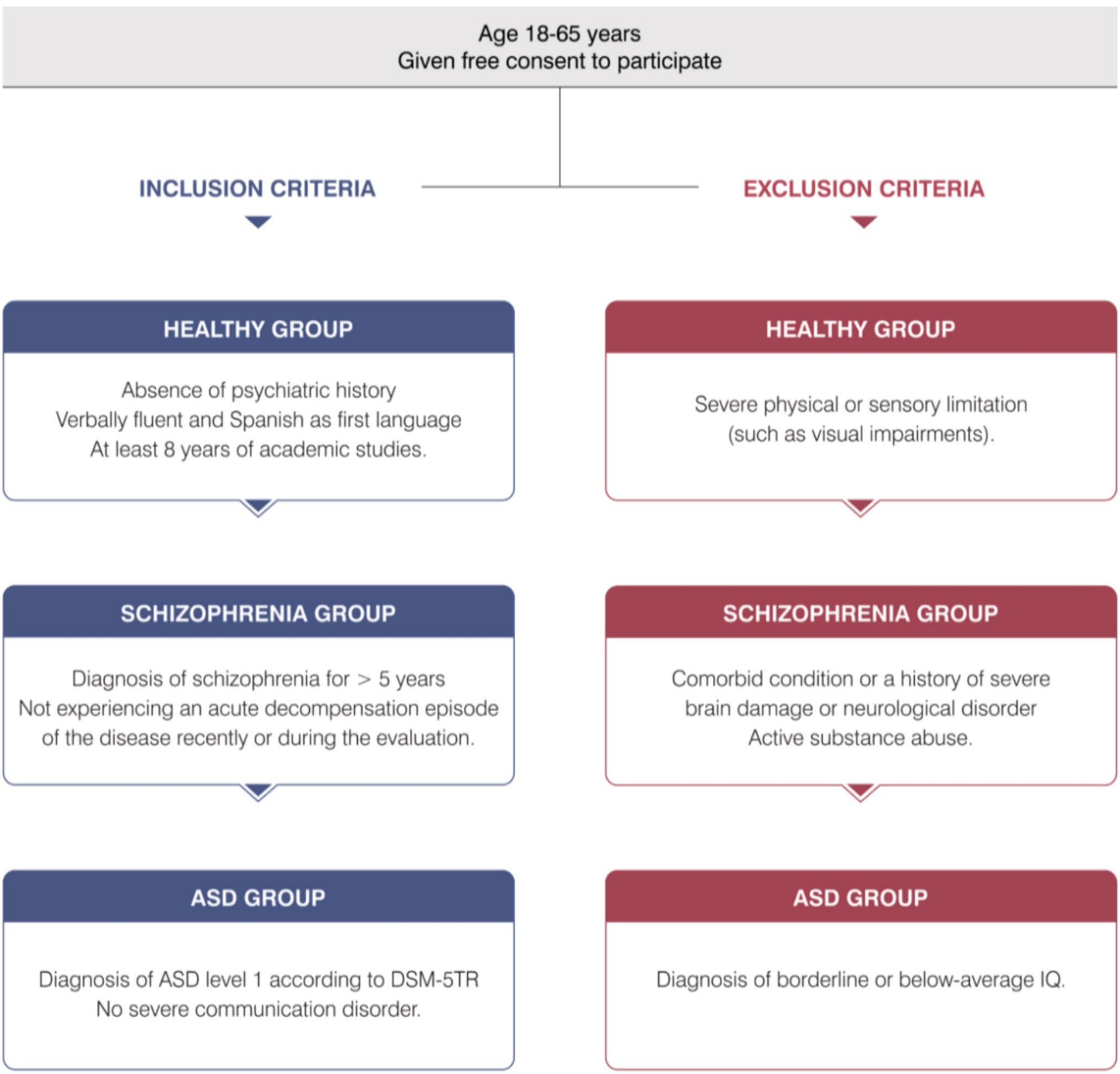

Fig. 1 Inclusion and exclusion criteria for each group

not experiencing an acute decompensation episode of the disease recently or during the evaluation, while the exclusion criteria included: (1) previous history of brain damage or co-existence of other neurological disorder and (2) active abuse of substances. For the ASD group the inclusion criteria were: (1) diagnosis of ASD level 1 according to DSM-5-TR; (2) No severe communication disorder; (3) No co-occurring intellectual disability, while the exclusion criteria was previous diagnosis of borderline or below-average IQ. Clinical groups were recruited from the Canary Association of Creative Therapies (ASCATEC) for schizophrenia ($n = 33$) and from APANATE association (members of the Spanish Confederation for Autism, FESPAU) for ASD level 1 ($n = 30$). The summary of descriptive data of included subjects is presented in Table 1.

Human ethics and consent to participate

This study was approved by the Drug Research Ethics Committee of the Canary Islands University Hospital Complex (Santa Cruz de Tenerife, Spain; protocol CHUNSC_2023_115) in accordance with the Declaration of Helsinki. All participants were volunteers who provided written informed consent prior to inclusion and all personal data were anonymized.

Selection of complex emotions

To determine which complex or social emotions would be included in the test, 60 professional actors from the theater company "Timaginas Teatro" were asked to list the most common emotions they experience in daily life. From that pool, the list was refined to 36 emotions to allow e-Motions test for a statistical comparison with the RMET, which also comprises 36 items. Before tracking each emotion performed by each actor, a panel of five social cognition experts (FRP, JMF, EVB, IMM, NCE) evaluated the feasibility of depicting each emotion within 4–5 s. Two emotions (offended and helpless) were excluded due to their complexity and overlap with other reported emotions Therefore, 34 emotions were selected and represented by two hyper-realistic avatars (one male and one female; Fig. 2). Two emotions—determined and interested—were included in both avatars, while the remaining 32 were randomly assigned to either the male or female avatar using the "randomizr" package in R software (version 4.1.0).

Table 1 Demographic background characteristics by group

Variable	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median
Group	Healthy ($n = 226$)				Schizophrenia ($n = 33$)				Autism Spectrum Disorder ($n = 30$)			
Sex	226				33				30			
… Men	103	45.6%			20	61%			24	80%		
… Women	123	54.4%			13	39%			6	20%		
Age, years	204	34.27	12.97	27.5	32	45.34	10.98	44.5	30	32.77	7.98	30
Education	224				33				30			
… Below secondary education	35	16%			22	67%			27	90%		
… Secondary education	50	22%			8	24%			3	10%		
… Incomplete university studies	23	10%			2	6%			0	0%		
… Bachelor's degree	50	25%			0	0%			0	0%		
… Postgraduate	58	26%			1	3%			0	0%		
… PhD	2	1%			0	0%			0	0%		
Employment	214				33				30			
… Unemployed	1	0.5%			0	0%			0	0%		
… Unemployed not seeking employment	45	21%			14	42%			0	0%		
… Unemployed seeking employment	22	10%			8	24%			26	87%		
… Employed full-time	113	53%			2	6%			4	13%		
… Employment part-time	29	14%			0	0%			0	0%		
… Disability	2	1%			8	24%			0	0%		
… Retired	2	1%			1	3%			0	0%		

SD standard deviation, *Pctil* percentile

Tracking emotions by advanced AI-based motion-capture

Sixty actors were asked to portray the 34 selected emotions over a 4-s interval. They were instructed to express each emotion as if in a real-life social context. The entire process took place in a professional recording studio under optimal lighting conditions. Emotion tracking was carried out using AccuFACE® plugin within iClone® v8.33 on an iOS system, which employs an NVIDIA RTX-based AI-powered facial tracker. AccuFACE software enables precise synchronization of facial movements and full-frame animation recording—key factors in ensuring both time accuracy (4 s) and emotional fidelity. A total of 2,040 animations were generated through this AI-based tracking process and then put into the two pre-created hyper-realistic avatars. All details regarding the step-by-step process from AI-tracking to the avatars, as well as the professional equipment used for image capture and recording, are provided in the supplementary material (Text 1).

Fig. 2 Presentation of hyper-realistic avatars of e-Motions test**.** Stimulus presentation diagram of e-Motions test for the three populations studied. The stimulus was displayed in PowerPoint®, showing a dynamic, complex emotion for 4 s. Upper: An example of the male avatar. Lower: An example of the female avatar. The asterisk indicates the hypothetical moment when DES would be applied during awake mapping in brain tumor patients

Expert evaluation

These animations were subsequently presented using both female and male avatars to the aforementioned group of experts. Each correctly identified expression was assigned 1 point. From the 2,040 tracked animations, the 34 most accurate complex expressions were selected based on the committee's evaluations. For each selected emotional stimulus, the committee introduced three distractors: one sharing the same emotional valence (positive or negative) as the target emotion, and two with different valences, ensuring a moderate level of difficulty. The decision to use two generic hyper-realistic avatars instead of real faces was guided by several considerations: (1) Preventing memorization or false associations. Given the ceiling effect [29, 45, 68], observed in some studies using the Ekman-60F and RMET, employing a single avatar face per gender centers the focus on dynamic emotional content rather than facial changes and reduces the risk of memorizing or associating specific faces with particular emotions. This is crucial for intraoperative use, as it would minimize the likelihood of false positives/negatives during mapping. (2) Balancing emotions. An equal number of expressions (17 each) are portrayed by the male and female avatars. (3) Minimizing perceptual biases. By avoiding real human faces, the risk of inadvertently resembling familiar individuals—and thus transferring affective associations to new faces [43]—is reduced. Finally, a comprehensive refinement of textures and a detailed examination of each facial element (e.g., wrinkles, muscle activity, subtle gestures) were jointly carried out by the expert committee and 3D graphic design specialists using iClone 8® and Character Creator from Reallusion®.

Data collection procedure

In this study, the e-Motions test, the Spanish RMET [17], the Spanish Ekman-60F test [45], and the Movie for the Assessment of Social Cognition (MASC) [20] were used to assess social cognition. All tests were administered by trained neuropsychologists (NCE, IMM, NNP). The sequence was: (1) Phase 1: MASC; (2) Phase 2: e-Motions, RMET, and Ekman-60F; and (3) Phase 3: test–retest of e-Motions, RMET, and Ekman-60F six weeks later. Participants received a glossary of emotional terms before each phase.

Instruments

e-Motion test. As mentioned above, the test consists of the presentation of hyper-realistic avatars (one male and one female) representing complex emotions for four seconds. The goal of this test is measuring the ability to identify emotions and feelings of others in an ecological way by means of showing every single detail of those emotions represented in the human face as in our everyday life. The participant is asked to choose the most accurate emotion with a time constraint of 4–5 s. The e-Motions test has a maximum score of 34, giving 1 point per correct item.

Spanish version of the movie for the assessment of social cognition (MASC). [20] Originally developed by Dziobek et al. [17][24], is a reliable measure of high-level mentalizing ability. The MASC consists of a short film depicting interactions among four characters. Participants are then asked to infer the characters' thoughts, feelings, and intentions, as well as interpret nonverbal communication, irony, sarcasm, implicit social norms, "social mistakes", etc. The maximum score is 45, with one point for each correct item.

***Spanish version of the reading the mind in the eyes test (RMET).* [5, 17]** The revised version of RMET was developed by Baron-Cohen et al., in 2001 as an advanced Theory of Mind (ToM) [8] test created with the goal of detecting mild to moderate difficulties frequently observed in adults with ASD. Participants are asked to choose, from four alternatives, the word that best describes the eye's gaze depicted in the photograph. The instrument's maximum total score is 36, one point for each correct answer.

***Ekman 60-faces test (Ekman-60F).* [45, 50]** It is a tool for measuring emotional recognition ability based on 60 black and white photographs of faces showing a given emotion among six possible options (happiness, sadness, anger, disgust, fear and surprise), which are represented by four men and six women, each going through the six emotions. The maximum score is 60 points, one for each correct answer, with a maximum of 10 points per emotion category.

Statistical analysis

All the statistical analyses were conducted using R v.4.1.0 (R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria), assuming 95% confidence intervals (CI).

For the descriptive analysis of quantitative variables, the mean, standard deviation, median, 1 st and 3rd quartiles and range were reported. For categorical variables absolute frequencies and percentages were provided. Data distribution was evaluated by visual inspection of histograms and QQ plots. No questionnaire was normally distributed. The differences between sex, age, and education level in all tests were evaluated with a multivariable ordinal cumulative probability model with a logit link function (logistic distribution). This model was selected because it can deal with upper and lower bounded variables, and because it assumes no distribution shape for the dependent variable [31].

The analysis of internal consistency was conducted using the KR-20 statistics which is equivalent to the Cronbach's

Alpha when all items are dichotomous. Internal consistency evaluates whether the items within a questionnaire are all measuring the same underlying construct. The statistic was calculated for the first measurement of the e-Motions, RMET and Ekman-60F tests. Furthermore, the KR-20 value when each item was deleted was also reported.

Test–retest reliability was evaluated using an Intraclass Correlation Coefficient ($ICC_{2,1}$). The presence of a systematic error was also evaluated calculating the 95% CI of the mean difference between two measurements using a percentile bootstrap with 2,000 samples. The standard error of the measurement (SEM) was calculated as the squared root of the mean squared error of the analysis of variance used for calculating the $ICC_{2,1}$. The minimum detectable change with 95% confidence bounds ($MDC_{95\%}$) was calculated as follows: $MDC_{95\%} = SEM*\sqrt{2}*1.96$.

Finally, a Bland–Altman plot of agreement was constructed including a straight line for the systematic error, a regression line for evaluating the presence of heteroskedasticity, and the limits-of-agreement with 95% confidence. Bland–Altman plots show the individual differences between the test–retest assessments of the questionnaires on the Y-axis, against the mean of the two measurements on the X-axis. Additionally, 95% confidence limits are displayed, representing the range within which most individual measurement errors are expected to fall. The plots also include a horizontal line indicating the systematic bias, as well as a regression line used to evaluate whether there is a relationship between individual errors and mean values (i.e., to assess the assumption of homoscedasticity) [75].

Convergent validity was evaluated using bivariate spearman correlations between the e-Motions test and the MASC, RMET, and Ekman-60F tests in the whole sample (Spanish healthy subjects plus schizophrenia subjects). The 95% CI for spearman correlations were calculated using a percentile bootstrap procedure with 2,000 samples. Furthermore, a multivariable ordinal cumulative probability regression model with logit link function (logistic distribution) was implemented to evaluate the percentage of the variability of the e-Motions test (R_2) explained by the other three questionnaires.

Finally, for the evaluation of the discriminative ability of the e-Motions, MASC, RMET, and Ekman-60F tests to differentiate between subjects with and without schizophrenia, the area under the curve (AUC) from logistic regression models was calculated, and receiver operating characteristics (ROC) curve plots were constructed.

Results

The final sample was composed of 226 healthy subjects (54.4% women), 33 subjects with schizophrenia (39% women), and 30 subjects with autism spectrum disorder (20% women). Additionally, a total of 81 healthy subjects from other Spanish-speaking nationalities were included to analyze whether any changes in the internal consistency of the e-Motions test occurred. Summary descriptive statistics for Spanish healthy, schizophrenia and ASD subjects are presented in Table 2. Data for healthy subjects of other nationalities, full descriptive statistics of all groups, histograms, and the frequencies of correct responses for each individual item of the e-Motions test are presented in Supplementary Fig. 2.

Subgroup analysis Subgroup descriptive data for all tests by sex, age, and education level are presented in Table 3. The ordinal regression model for the e-Motions test showed no differences between males and females ($\chi^2(1) = 0.37$; $p = 0.54$), and a trend towards greater values in younger subjects ($\chi^2(1) = 13.99$; $p = <0.01$) and subjects with higher education level ($\chi^2(3) = 17.25$; $p < 0.01$). For the other three tests, no differences were observed between males and females, neither age, but a trend towards greater values in subjects with higher education level was observed (Table 3).

Internal consistency There was an acceptable value of internal consistency within the healthy group (KR-20 = 0.74; 95% CI, 0.69 to 0.79), which increased when considering the sample of subjects with schizophrenia (KR-20 = 0.86; 95% CI, 0.83 to 0.88). Furthermore, the internal consistency was not notably affected when subjects with other

Table 2 Descriptive statistics of tests within each group

Variable	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median
Group	Healthy ($n = 226$)				Schizophrenia ($n = 33$)				Autism Spectrum Disorder ($n = 30$)			
e-Motions	226	77.34	12.46	79.41	33	49.47	18.14	50	30	58.63	22.46	64.71
RMET	226	70.08	11.39	72.22	33	46.8	17.49	44.44	25	54.67	12.77	52.78
Ekman-60F	226	81.95	10.73	83.33	33	58.59	17.55	56.67	25	78.4	8.16	80
MASC	188	71.99	12.73	75.56	18	47.53	13.49	45.56	25	45.87	16.21	44.44

SD standard deviation, *Pctil.* percentile, *RMET* Reading the Mind in the Eyes Test, *Ekman-60F* Ekman-60 Faces test, *MASC* Movie for the Assessment of Social Cognition test

Table 3 Descriptive subgroup analyses of tests by sex, age, and education level of Spanish healthy subjects

Subgroup	e-Motions		MASC		RMET		Ekman-60F	
	N	Median (1st-3rd quartiles)	N	Median (1st-3rd quartiles)	N	Median (1st-3rd quartiles)	N	Median (1st-3rd quartiles)
Sex	$\chi^2(1)=0.37$; $p=0.54$		$\chi^2(1)=0.89$		$\chi^2(1)=0.12$; $p=0.73$		$\chi^2(1)=2.96$; $p=0.09$	
Men	100	79.41 (73.53–85.29)	81	75.56 (66.67–80.00)	100	72.22 (63.89–77.78)	100	83.33 (76.67–86.67)
Women	123	79.41 (73.53–85.29)	104	75.56 (68.89–80.56)	123	72.22 (65.28–77.78)	123	85 (80.00–90.00)
Age#	$\chi^2(1)=13.99$; $p<0.01$		$\chi^2(1)=2.37$; $p=0.12$		$\chi^2(1)=0.45$; $p=0.50$		$\chi^2(1)=1.23$; $p=0.27$	
< 24	43	82.35 (76.47–88.24)	40	75.56 (68.89–82.22)	43	72.22 (66.67–77.78)	43	85 (81.67–88.33)
[24, 27.5]	59	82.35 (79.41–88.24)	58	75.56 (71.11–82.22)	59	72.22 (66.67–79.17)	59	85 (80.00–89.17)
(27.5, 45]	53	79.41 (70.59–82.35)	46	73.33 (66.67–80.00)	53	72.22 (66.67–77.78)	53	83.33 (78.33–86.67)
> 45	49	79.41 (73.53–82.35)	37	71.11 (64.44–77.78)	49	85 (81.67–88.33)	49	86.67 (81.67–90.00)
Education	$\chi^2(3)=17.25$; $p<0.01$		$\chi^2(3)=10.49$; $p=0.01$		$\chi^2(3)=22.09$; $p<0.01$		$\chi^2(3)=7.06$; $p=0.07$	
Below secondary education	35	67.65 (50.00–79.41)	20	58.89 (50.56–68.89)	35	66.67 (54.17–69.44)	35	78.33 (68.33–83.33)
Secondary education	50	77.94 (73.53–82.35)	40	73.33 (66.67–77.78)	50	66.67 (61.81–72.22)	50	83.33 (75.83–86.67)
Incomplete and bachelor's degree	79	82.35 (76.47–85.29)	71	75.56 (66.67–80.00)	79	75.00 (66.67–77.78)	79	86.67 (81.67–89.17)
Postgraduate and PhD	60	82.35 (79.41–88.24)	55	75.56 (71.11–82.22)	60	75.00 (69.44–80.56)	60	85.00 (81.25–90.00)

#Age subgroups are based on quartiles. Abbreviations: *RMET* Reading the mind in the eyes test, *Ekman-60F* Ekman-60 Faces test, *MASC* Movie for the assessment of social cognition test

Spanish-speaking nationalities were included in the healthy group (KR-20 = 0.71; 95% CI, 0.67 to 0.76) (Table 3). The value of KR-20 when each item was deleted ranged from 0.73 to 0.75 within the Spanish healthy group, and from 0.85 to 0.86 when including subjects with schizophrenia and ASD (Supplementary Table 5). The internal consistency of RMET and Ekman-60F tests are presented in Table 4.

Test–retest reliability A total of 159 healthy subjects had data available to analyze the test–retest reliability. The e-Motions test showed good test–retest reliability ($ICC_{2,1}=0.73$; IC 95% 0.65 to 0.80). The SEM was 7.01% and the $MDC_{95\%}$ was 19.44%. Furthermore, there was no systematic error (mean difference, −0.68%; 95% CI, −2.22% to 1.00%). The results of RMET and Ekman-60F tests are presented in Table 5. The Bland–Altman plot for the e-Motions test is presented in Fig. 3. For the RMET and Ekman-60F tests see Supplementary Material (Figs. 3 and 4).

Convergent validity There were moderate correlations between the e-Motions test and the MASC (rho = 0.57), RMET (rho = 0.44), and Ekman-60F tests (rho = 0.48). Furthermore, the multivariable ordinal regression model showed an R_2 value of 0.46 ($LRX^2(3)=144.41$; $p<0.001$) when predicting e-Motions test results based on the other three questionnaires. Full data of bivariate spearman correlations is presented in Table 6, and scatterplots in Fig. 4.

Discriminative ability The e-Motions test showed good ability to discriminate between healthy subjects and subjects with schizophrenia (AUC = 0.89; 95% CI, 0.82 to 0.96) and ASD (AUC = 0.79; 95% CI, 0.69 to 0.88), showing values slightly superior to the RMET and Ekman-60F but inferior to MASC. The ROC curves for each test are presented in Fig. 5.

Discussion

The e-Motions test demonstrated good internal consistency in healthy subjects which increased when including schizophrenia and ASD patients, being significantly higher than the consistency of RMET, which has so far been the most widely test used in social cognition mapping [49] being

Table 4 Internal consistency analyses for the e-Motions, reading the mind in the eyes, and Ekman-60 faces tests

Test	KR-20	Range of KR-20 when item deleted
e-Motions		
Healthy (Spain)	0.74 (95% CI, 0.69 to 0.79)	0.73 to 0.75
Healthy and Schizophrenia and ASD	0.86 (95% CI, 0.83 to 0.88)	0.85 to 0.86
Healthy (with other nationalities)	0.71 (95% CI, 0.67 to 0.76)	0.70 to 0.72
RMET		
Healthy (Spanish)	0.61 (95% CI, 0.53 to 0.68)	0.59 to 0.63
Healthy and Schizophrenia and ASD	0.76 (95% CI, 0.72 to 0.80)	0.74 to 0.77
Healthy (with other nationalities)	0.58 (95% CI, 0.58 to 0.65)	0.56 to 0.60
Ekman-60F		
Healthy (Spanish)	0.84 (95% CI, 0.81 to 0.87)	0.83 to 0.84
Healthy and Schizophrenia and ASD	0.89 (95% CI, 0.87 to 0.91)	0.88 to 0.89
Healthy (with other nationalities)	0.85 (95% CI, 0.89 to 0.93)	0.84 to 0.85

RME Reading the mind in the eyes test, *Ekman-60F* Ekman-60 faces test, *CI* confidence interval, *ASD* autism spectrum disorder

Table 5 Test–retest reliability for the e-Motions, Reading the Mind in the Eyes, and Ekman-60 Faces tests

Test	$ICC_{2,1}$ (95% CI)	Systematic error	SEM	MDC95%
e-Motions	0.73 (0.65 to 0.80)	−0.68%	7.01%	19.44%
RMET	0.10 (−0.05 to 0.24)	−0.30%	8.92%	24.71%
Ekman-60F	0.05 (−0.09 to 0.20)	−1.13%	7.39%	20.49%

ICC intraclass correlation coefficient, *SEM* standard error of the measurement, *MDC95%* minimum detectable change with 95% confidence bounds, *RME* Reading the mind in the eyes test, *Ekman-60F* Ekman-60 faces test, *CI* confidence interval

reported similar internal consistency values in previous validation studies, although showing some heterogeneous results [4, 6, 40]. Furthermore, the numerical differences reported with RMET between healthy and clinical groups have been small, showing a considerable overlap of test score distribution between both groups [40]. Some authors have emphasized that, although the RMET is widely used, its validity remains difficult to ascertain in the absence of a gold standard for comparison [29, 40, 57].

In other vein, in line with studies suggesting certain universal aspects of facial expressions [18, 44, 71], e-Motions test retained good internal consistency even after including 81 healthy subjects from other Spanish-speaking

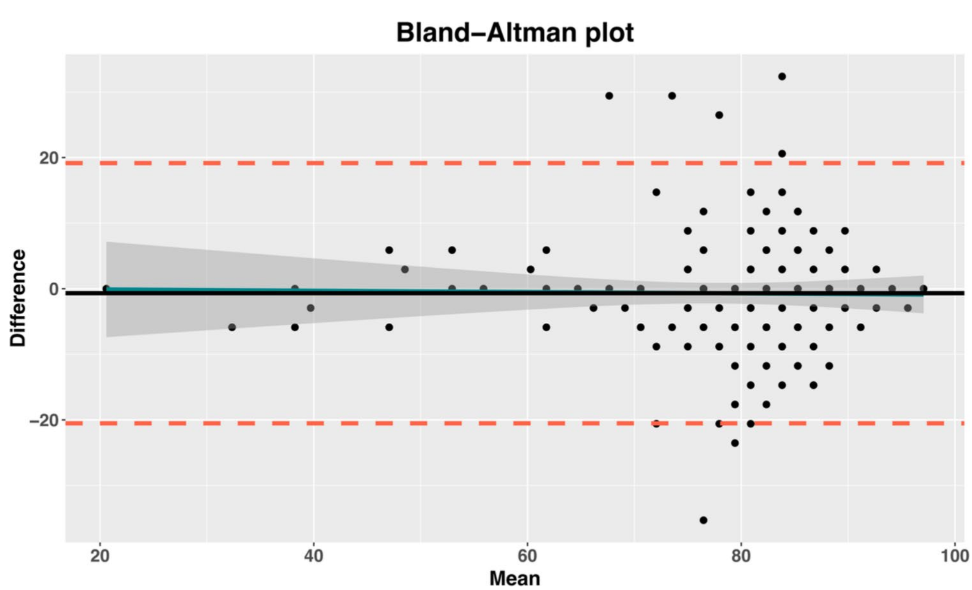

Fig. 3 Bland–Altman plot for the e-Motions test**.** Bland–Altman plot for the e-Motions test (Spanish healthy subjects). Black horizontal line refers to the systematic error (i.e., mean difference), and dashed horizontal red lines refer to the limits of agreement. The blue line and grey filled area refer to the regression line between mean value and observed differences with 95% confidence interval (i.e., homoskedasticity assumption)

Table 6 Bivariate spearman correlations

Test	e-Motions	RMET	Ekman-60F	MASC
e-Motions	-	p < 0.001	p < 0.001	p < 0.001
RMET	0.44 (95% CI, 0.33 to 0.54)	-	p < 0.001	p < 0.001
Ekman-60F	0.48 (95% CI, 0.37 to 0.57)	0.46 (95% CI, 0.34 to 0.56)	-	p < 0.001
MASC	0.57 (95% CI, 0.47 to 0.66)	0.31 (95% CI, 0.19 to 0.43)	0.44 (95% CI, 0.33 to 0.53)	-

Confidence intervals are calculated using a percentile bootstrap method with 2,000 samples. *RMET* Reading the mind in the eyes test, *Ekman-60F* Ekman-60 faces test, *MASC* Movie for the assessment of social cognition test

countries—being essential given that Spanish is among the most widely spoken languages globally. Additionally, e-Motions also demonstrated good test–retest reliability measured via ICC, SEM and the minimal detectable change at 95% confidence. Although the Ekman-60F and RMET showed lower ICC values, their SEM values were similar to that of the e-Motions test. This suggests that the three tests exhibited a similar test–retest reliability despite the differences observed in their ICC values [63], since ICC is influenced by between-subject variability.

Despite the crucial role of social cognition in QoL, in a recent systematic review [49] only 8 articles of the 31 articles analyzed reported intraoperative mapping of social cognition. From this rigorous review we can draw some conclusions: (1) social cognition as a whole was not assessed pre-, intra-, or postoperatively, having been based on lower-level mentalizing [15, 52, 55]—a potentially limited approach, given that the lower, prereflective, and automatic aspect of mentalizing[33] contrasts with higher-level, reflective and inferential mentalizing [41, 61], and may therefore be insufficient [29, 68] given the complexity of social cognition subprocesses—such as face perception, motor resonance, cognitive and emotional empathy or emotion regulation [30]; (2) There was no meticulous long-term follow-up to determine the presence of potential long-lasting deficits in those subprocesses of social cognition [29, 52]; (3) There's no universally accepted gold standard for assessing social cognition in patients with brain tumors, making it challenging to interpret results and compare across studies [29]; (4) Existing intraoperative tools such as the RMET and Ekman-60F suffer from several practical and theoretical shortcomings when applied to neurosurgical mapping. Both rely on static, black-and-white and low resolution photographs [8]—RMET restricted to images of the eye region alone [8] which omits crucial emotional cues, constraining the information available for accurate mental-state inference [39,], and it has been validated primarily against low-level emotion-perception tasks rather than higher-order inferential measures [57, 69]. On the other hand, Ekman-60F presents posed stills of basic emotions [38] that lacks dynamic and complex cues that are critical for real-world emotion recognition [3]. Therefore, these tests have shown its ability to preserve the low-level mentalizing abilities when applied under DES in brain tumor patients [9, 15, 52, 55], but they seem ill-suited to capture the full spectrum of social-cognitive processes that neurosurgeons must monitor and preserve intraoperatively given that up to 30% of patients exhibit long-lasting deficits in social cognition [29, 47, 67].

In contrast, the e-Motions test, by presenting 34 four-second video clips of hyper-realistic, full-face avatars dynamically expressing complex emotions, was designed to overcome these limitations: (1) dynamic, high-resolution stimuli ensure ecological validity; (2) by covering the entire face rather than just the eyes, e-Motions captures the integrated contributions of brows, eyes, mouth, and cheeks to emotional inference; (3) we anchored the test in a comprehensive model of social cognition, validating it with both low-level (RMET, Ekman-60F) and high-level (MASC) mentalizing tasks to demonstrate a higher sensitivity across the social-cognitive spectrum, since the convergent validity of e-Motions with MASC surpasses what RMET and Ekman-60F themselves have shown when correlated with that high-level inference task; (4) the 4-s clip duration aligns with DES time constraints—thus offering a potentially feasible tool for mapping social cognition during awake surgery.

It is important to emphasize that the main objective of this study was to rigorously validate this tool in schizophrenia and ASD prior to its implementation into the OR. Regarding the potential intraoperative application of e-Motions, we propose a three-step awake cognitive mapping from a dynamic connectomic-centric perspective [47, 48] based on recent frameworks that has sought to align neurosurgery with principles of complex dynamic systems theory [7, 16, 35, 70]: 1) Cortical step. DES would be applied while performing a social cognition task (e.g., the e-Motions test) to identify and preserve critical regions within those networks subserving social cognition—such as the mentalizing network [14, 37, 55] (precuneus, posterior cingulate cortex, the medial prefrontal cortex including the anterior cingulate gyrus…)[15]. An incorrect

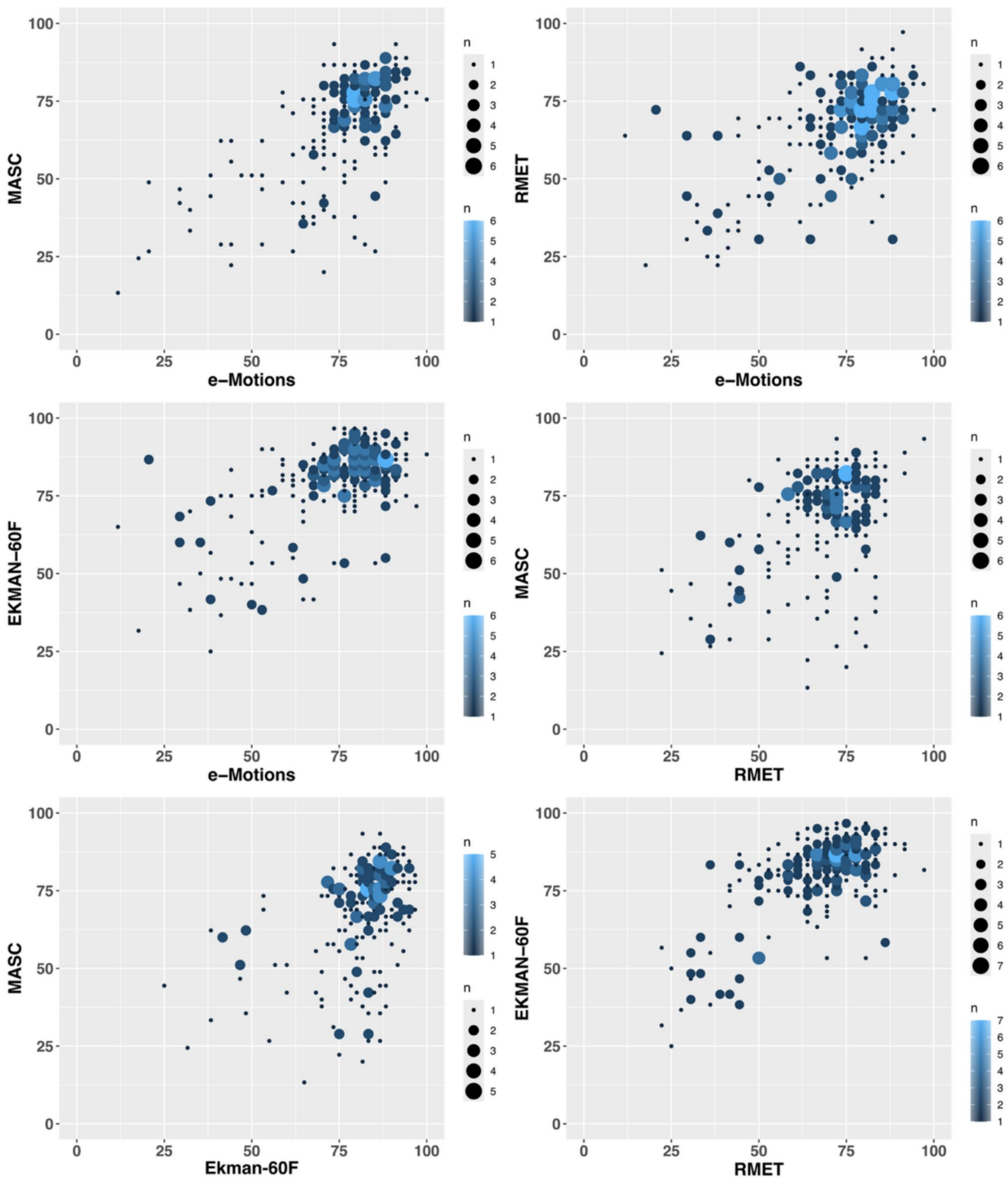

Fig. 4 Scatterplots for the relationships between all pairs of tests. Dot color and size refer to the number of subjects with those values. Abbreviations: MASC, Movie for the Assessment of Social Cognition test; RMET, Reading the Mind in the Eyes test; Ekman-60F, Ekman 60-faces test

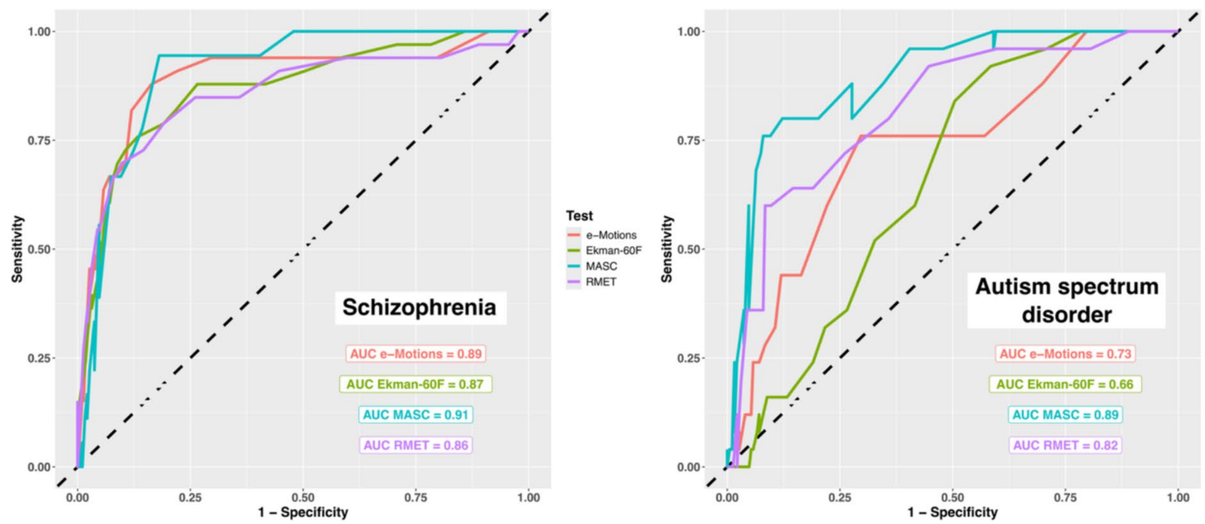

Fig. 5 Receiver operating characteristic curve plots. Abbreviations: *AUC* area under the curve, *MASC* Movie for the Assessment of Social Cognition test, *RMET* Reading the Mind in the Eyes test, *Ekman-60F* Ekman 60-faces test

response, failure to respond, or latency exceeding 4–5 s is marked as a positive "error". To improve objectivity, this should be elicited three times in non-consecutive trials. The preoperative baseline scores should be used to exclude any items the patient fails consistently[15]. 2) Resection step [47]. A multitasking is introduced by alternating among several cognitive tests in a non-serial order to monitor cognitive load [14] (e.g., alternating between e-Motions test and PPT test while the patient performs continuous contralateral arm flexion–extension). This allows the surgeon to stop the resection or to adjust the surgical plan if social-cognition failures emerge based on real time information about across-network dynamics[47, 48, 54]. 3) Connectome-stop points step [32, 36, 47]. Deep white-matter tracts known to subserve social cognition—such as the right inferior fronto–occipital fasciculus (IFOF), the uncinate fasciculus (UF), cingulum bundle, and the superior longitudinal fasciculus–arcuate fasciculus (SLF-AF complex) [42, 53] —should be identified and preserved to avoid long-term deficits in social cognition because of irreversible large-scale disconnections [36, 77].

The present study has several limitations that merit consideration. First, a comprehensive neuropsychological assessment encompassing all cognitive domains was not performed, making it unclear to what extent other higher-order functions—such as attention or executive functioning—may have influenced the results. In the second place, certain clinical data for the schizophrenia and ASD groups were not collected—for example, information regarding medication use, among others—therefore, the potential confounding effects of these variables were not explored. Third, the order in which the tests were administered may have influenced the results. Although the tests were different, a training effect may still have occurred and affected the outcomes. Fourth, the study primarily included young and middle-aged adults. In this vein, social cognition tends to decline with aging and the results of the present study should therefore be interpreted with caution in that population[78, 79]. Fifth, e-Motions test, like other single-construct social-cognition measures (e.g., RMET), may limit intraoperative analysis of distinct subprocesses—semantic processing, higher-order inference, and facial recognition. Finally, it is important to remark that the present study lacks clinical validation of the e-Motions test in both intraoperative settings and postoperative assessments in patients with brain tumors.

Conclusions

The e-Motions test is the first AI-based assessment tool validated for the intraoperative evaluation of social cognition, specifically developed for awake brain mapping and previously validated in paradigmatic mental disorders characterized by impaired social cognition, such as schizophrenia and ASD. Its robust internal consistency and significant correlations with the RMET, Ekman-60F test, and MASC demonstrate that the e-Motions test effectively measures key aspects of social cognition, including both low- and high-level mentalizing processing. Although its psychometric properties render this tool an innovative method for identifying critical regions involved in social cognition during awake mapping, future clinical validation of e-Motions test intraoperatively and postoperatively, seems to be necessary to draw a more certain conclusion concerning its ecological validity.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Consent for publication The study was considered a non-risk and non-invasive experiment in accordance with the ethical standards laid down in the Declaration of Helsinki (1964) and its later amendments. All subjects gave their written informed consent prior to their inclusion in the study and the identity of them was protected and was omitted personal information.

Consent to publication Not applicable because all personal information was anonymized and no images were presented that could identify the patient.

Conflicts of interest The authors declare no competing interests.

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