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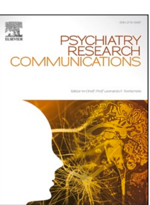

Influence of Threat/Control-Override symptoms on emotion recognition, emotional attribution, and aggression in schizophrenia

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A B S T R A C T

Background: Threat/control-override (TCO) delusional experiences have been linked to aggression in schizophrenia and may also shape threat-related social-cognitive processing. We compared facial emotion recognition and stimulus-based emotional attribution in patients with schizophrenia and healthy controls, and tested whether TCO symptoms were associated with task performance, aggression, and insight.

Methods: Thirty male inpatients meeting DSM-5 criteria for schizophrenia and fifteen healthy controls completed a computerized task assessing recognition of five facial expressions (happiness, anger, disgust, fear, neutral) and attribution of the identified emotion's likely cause (forced choice between a neutral vs emotion-congruent context picture). TCO symptoms were assessed with the Threat/Control-Override Questionnaire (TCOQ), aggression with the Buss-Perry Aggression Questionnaire (BPAQ), and insight with the Birchwood Insight Scale (BIS).

Results: Compared with controls, patients showed reduced accuracy in both emotion recognition and causal attribution, with the largest deficits for anger recognition and anger attribution. Within the patient sample, higher TCO symptom levels were associated with higher self-reported aggression, primarily anger and hostility, and with poorer insight driven by reduced perceived need for treatment. In exploratory subgroup analyses (low vs high TCO), both patient subgroups showed impaired anger recognition, while additional differences emerged for fear and neutral attribution in low TCO group.

Conclusions: TCO symptom severity was associated with heightened aggressive affect and reduced treatment-related insight and may selectively modulate threat-relevant social-cognitive processes. In this sample, higher TCO levels were linked to differences in fear-related processing without further exacerbating anger recognition deficits, suggesting a specific association with threat vigilance rather than generalized social-cognitive impairment.

1. Introduction

Schizophrenia is a heterogeneous psychiatric disorder characterized by diverse combinations of positive and negative symptoms that affect cognition, emotion and behavior. Although violent behavior is neither systematic nor specific to schizophrenia, patients who engage in aggression often present more severe positive symptoms, poorer psychosocial functioning, reduced insight, and lower treatment adherence, particularly in the presence of comorbid substance use or personality disorders (Vandamme, 2009; Bo et al., 2011). Aggression appears to arise from specific symptom patterns and contextual factors, highlighting the need for symptom-focused and mechanism-oriented models (see Fig. 1).

Joyal (2005) proposed three broad profiles of violence in schizophrenia: (1) patients with neurological impairment and undifferentiated schizophrenia, whose aggression is typically impulsive and of limited severity; (2) patients with comorbid antisocial personality disorder and substance abuse, in whom violence relates more strongly to personality pathology than to psychosis per se; and (3) patients with paranoid schizophrenia, whose persecutory delusions and hallucinations may motivate targeted violent acts. These profiles underscore the need to examine symptom-specific mechanisms.

Within this perspective, particular attention has been paid to the Threat/Control-Override (TCO) concept, introduced by Link and Stueve (1995). TCO refers to delusional experiences involving perceived imminent threat (e.g., being followed or poisoned) and beliefs that one's thoughts or actions are controlled by external forces. Early findings suggested that TCO symptoms may increase the likelihood of aggressive behavior (Swanson et al., 1996), yet subsequent studies yielded mixed results. For instance, Stompe et al. (2004) reported no difference in TCO prevalence between patients with schizophrenia with versus without a history of criminal offenses. Using a dimensional approach, Nederlof et al. (2011) found that TCO symptoms were globally associated with aggression, yet when examined separately, the Threat component—rather than control experiences—emerged as the more consistent predictor. This suggests that perceived threat may represent a more proximal contributor.

Recent large-scale forensic studies refine this view (Findeis et al.,

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2025; Grohmann et al., 2024). Only a minority of patients exhibit the full TCO profile, and high-affective-intensity delusions (e.g., anger/-hostility) appear more consistently linked to violence. Together, these findings suggest that TCO content alone may be insufficient to account for aggression and highlight the need to consider emotional and cognitive mechanisms involved in threat processing.

Impairments in social cognition may amplify threat appraisals and contribute to aggression. Social cognition encompasses processes such as facial emotion recognition and emotional attribution (i.e., identifying emotions and linking them to plausible causes), and more broadly the capacity to integrate contextual information to infer mental states (Motut et al., 2023; Wieser and Brosch, 2012). Individuals with schizophrenia frequently show interpretation biases, including a tendency to attribute threatening meaning to neutral expressions (Pinkham et al., 2011; Romero-Ferreiro et al., 2018). Importantly, while many studies have used decontextualized faces, context strongly modulates facial-emotion perception (Wieser and Brosch, 2012). Experimental evidence suggests that contextual information can either exacerbate or attenuate emotion misattribution in schizophrenia; for instance, neutral contextual cues may reduce the tendency to ascribe threat-related emotions to neutral faces (Romero-Ferreiro et al., 2018). Computational modeling suggests abnormal weighting of contextual cues may contribute to these biases (Mirza et al., 2021). Deficits are strongest for fear and anger while happiness recognition is relatively preserved ("happy face advantage"; Gao et al., 2021). Such deficits may be especially relevant to threat-related delusions because they increase ambiguity in social interactions and reduce the capacity to generate benign explanations for others' behavior.

Social-cognitive impairments may also intersect with insight, which is frequently reduced in schizophrenia and associated with poorer treatment adherence and outcomes; insight may modulate links between positive symptoms, social cognition, and aggression (Lysaker et al., 2013). Threat/control experiences may undermine illness-related explanations and reduce perceived need for treatment.

Taken together, aggression in schizophrenia likely emerges from interactions between threat-related delusions, social-cognitive difficulties, and reduced insight. However, these factors have rarely been examined jointly using both clinical and experimental measures.

The present study aimed to investigate facial emotion recognition and stimulus-based emotional attribution in patients with schizophrenia presenting positive symptoms, and to examine their relationships with TCO symptoms, insight, and aggression. We hypothesized that participants with schizophrenia would perform worse than healthy controls in emotion recognition and emotional attribution. More specifically, we expected that higher TCO symptoms—particularly threat-related experiences—would be associated with (1) higher aggression-related scores, (2) poorer performance and/or threat-specific patterns in emotion recognition and emotional attribution, and (3) reduced insight.

2. Method

2.1. Participants

Thirty male inpatients meeting DSM-5 criteria for schizophrenia were recruited from the acute units of the Secure Psychiatric Hospital Les Marronniers (Tournai) and Van Gogh Hospital (Marchienne-au-Pont). All were native French speakers aged 25–53 years (M = 39.71, SD = 7.51) and had a current or recent history of positive symptoms documented in the medical record and confirmed by the treating clinician. TCO symptoms were assessed with the TCOQ. Exclusion criteria were prominent negative symptoms interfering with testing, intellectual disability or major cognitive impairment, neurological history, and

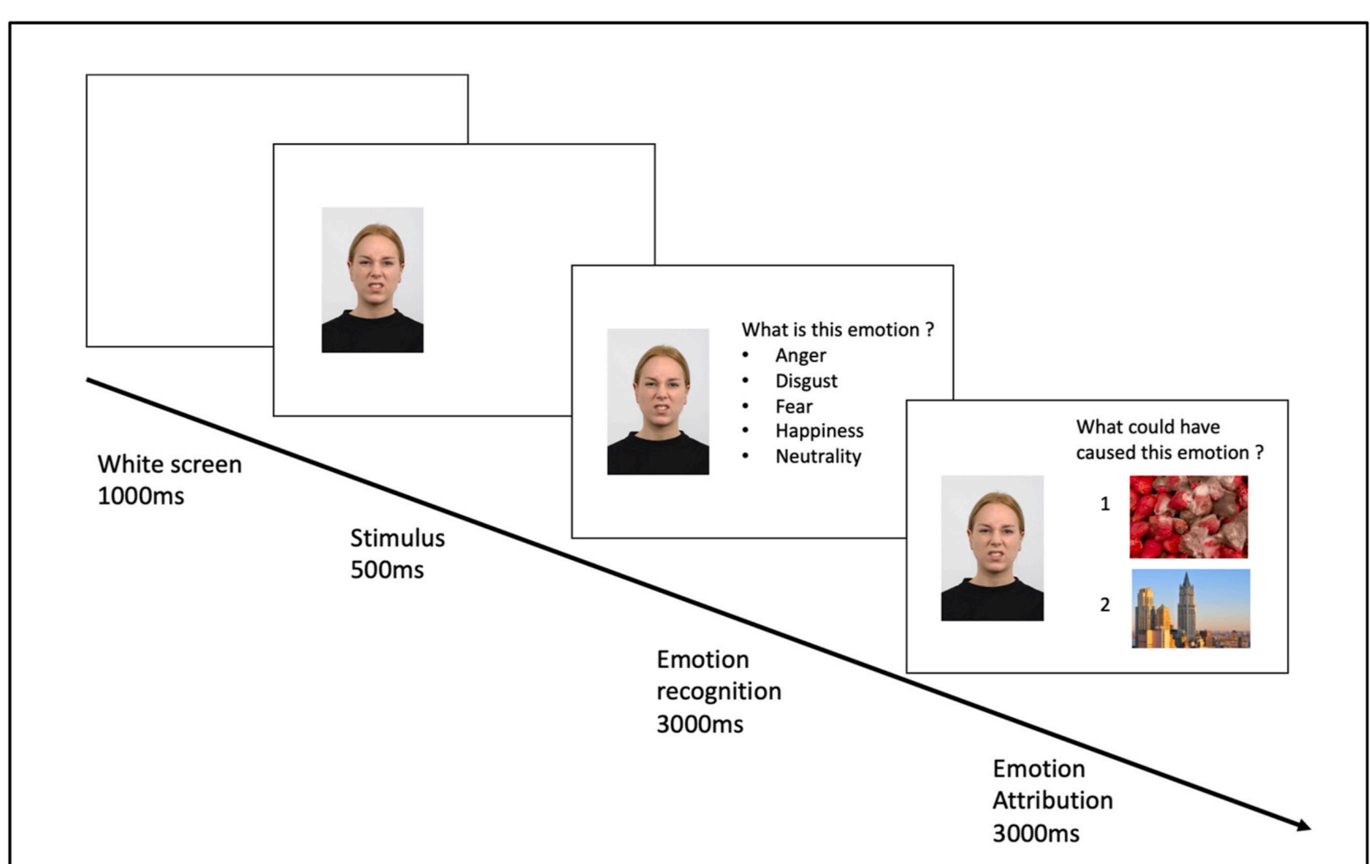

Fig. 1. Experimental task including facial expression recognition (forced choice among 5 propositions) and attribution of the identified emotion to a stimulus among a neutral and an emotional stimulus.

current dependence on alcohol, cannabis, or other drugs (except tobacco). All patients were hospitalized and receiving antipsychotic treatment. Participants did not report acute hallucinations during testing, consistent with clinical stabilization; residual positive symptoms remained. Educational attainment differed within the patient group (9 had completed upper secondary education; 21 had not).

Fifteen male healthy controls were recruited via social-network advertisements and were age-matched to the patient group (M = 34, SD = 8.19; t(43) = 1.43, n.s). Exclusion criteria were any current or past psychiatric or neurological disorder and current substance dependence. All controls completed upper secondary education; therefore, educational equivalence could not be established ($\chi^2 = 19.68$, $p < .001$).

2.2. Material and design

Facial emotion recognition and stimulus-based emotional attribution were assessed with a computerized Facial Expression Recognition and Attribution Task (FERAT) programmed in E-Prime 2.0. Facial stimuli were photographs of 10 adults (5 men) displaying happiness, fear, anger, disgust, or neutrality, selected from the Radboud Faces Database (RaFD; Langner et al., 2010). Faces were size-standardized (9 × 6 cm) and presented on the left side of the screen. Each trial began with a 1000-ms white screen, followed by a face displayed for 500 ms. Participants identified the expression by selecting one of five written labels (happiness, fear, anger, disgust, neutral) using a response-labeled keyboard; the display remained until a response or for 3000 ms.

Immediately afterward, two IAPS pictures (Langner et al., 2010) were presented one neutral and one emotional-for up to 3000 ms. Participants selected the picture that could plausibly have elicited the identified facial emotion, indexing contextual causal attribution. IAPS images were chosen based on valence and arousal (neutral vs. emotionally congruent, high-arousal stimuli). Emotional faces were followed by a neutral image (i.e. a building) and an emotion-congruent image: fear stimuli consisted of natural disasters, happiness stimuli consisted of gifts, disgust stimuli consisted of rotten food, and anger stimuli consisted of broken objects; neutral faces were followed by a neutral image and a negative-valence image. The task comprised two blocks of 25 trials separated by a 5-min break.

2.3. Clinical assessment

TCO symptoms. The Threat Control-Override Questionnaire (TCOQ; Nederlof et al., 2011) includes 14 items rated on 1-4, yielding a total score and Threat and Control-Override subscale scores.

Aggression. The Buss-Perry Aggression Questionnaire (BPAQ; Buss and Perry, 1992) contains 29 items rated on a 5-point scale and provides Physical, Verbal, Anger, Hostility, and total aggression scores.

Insight. The Birchwood Insight Scale (Birchwood et al., 1994) includes eight items across Symptom Awareness, Illness Awareness, and Need for Treatment, rated 0–2. Higher scores indicate better insight, with 9 indicating good insight.

2.4. Procedure

Ethical approval was obtained from the faculty ethics committee and from both hospital ethics committees. Clinicians identified eligible patients based on inclusion/exclusion criteria and provided study information emphasizing voluntariness and the right to withdraw. After written informed consent, participants completed the FERAT and the three self-report questionnaires individually in a quiet room. Testing duration was approximately 30–45 min.

2.5. Statistical analyses

Analyses were performed using SPSS 21. Descriptive statistics were computed for demographic and clinical variables. Pearson correlations assessed associations between TCO symptoms, aggression, and insight. Stepwise regressions examined Threat and Control-Override symptoms as predictors of aggression and insight.

Because the TCOQ lacks a validated clinical cut-off, we used an exploratory median split (median = 23): 14–23 = TCO−; 24–49 = TCO+. Groups were compared using independent-samples t-tests. The subgroups did not differ in age (t(28) = 0.50, n.s.) or sociocultural level ($\chi^2(1) = 0.690$, n.s.).

FERAT outcomes were mean accuracy for emotion recognition and attribution. Given the exploratory aims, analyses focused on accuracy. Repeated-measures ANOVAs included Emotion (5 levels) as a within-subject factor and Group as a between-subject factor, with Bonferroni-corrected post-hoc tests. Alpha was set at $p < .05$.

3. Results

3.1. Clinical assessment

Descriptive statistics for patient subgroups are reported in Table 1, and correlations among clinical measures are presented in Table 2.

Threat and Control-Override scores were strongly correlated. Across the three TCO indices, higher TCO scores were associated with higher total aggression; BPAQ subscales were also intercorrelated. Notably, Physical Aggression was specifically correlated with Threat symptoms.

Group comparisons indicated that the TCO + subgroup showed higher total aggression (t(28) = 2.46, p = .02), anger (t(28) = 3.217, p = .003) and hostility (t(28) = 3.211, p = .003) than the TCO− subgroup, but no difference for verbal (t(28) = .673, n.s) or physical aggression (t (28) = .941, n.s).

The TCO + subgroup also had lower insight (t(28) = 2.36, p = .025), driven by reduced Need for Treatment (t(28) = -3.256, p = .003), with no difference in Symptom Awareness (t(28) = .604, n.s.) or Illness Awareness (t(28) = .777, n.s).

Threat symptoms significantly predicted total aggression (F(1,28) = 14.30, p < .001), hostility (F(1,28) = 21.14, p < .001) and physical aggression (F(1,28) = 6.29, p = .018). Control-Override symptoms predicted anger (F(1,28) = 11.61, p = .002). No significant predictors emerged for verbal aggression or insight.

These results indicate that Threat symptoms explain a substantial portion of affective and cognitive aggression variance, while Control-Override contributes more specifically to anger.

Table 1
Means and standard deviations for all patients with schizophrenia and for the two composite subgroups based on median TCOQ score.

	Patients with schizophrenia (N = 30)	TCO- (N = 15)	TCO+ (N = 15)
TCOQ			
Total Score	26,4 (11,4)	16,8 (3,6)	35,9 (7,8)
Menace	12,9 (5,9)	8,2 (3,1)	17,5 (4,3)
Control-override	13,5 (6,3)	8,6 (0,9)	18,4 (5,5)
Aggression Questionnaire			
Score total	85,93 (20,9)	77,3 (22,3)	94,6 (15,7)
Physical Aggression	25,6 (6,9)	24,5 (7,2)	26,9 (6,2)
Verbal Aggression	16,9 (4,2)	16,4 (4,5)	17,5 (4,1)
Anger	20,33 (7,2)	16,6 (6,5)	24,0 (5,9)
Hostility	23,7 (7,7)	19,7 (7,4)	27,7 (5,7)
Insight			
Total	9,10 (3,7)	10,6 (3,6)	7,6 (3,3)
Re-label symptoms	2,5 (1,2)	2,6 (1,3)	2,3 (1,1)
Disease Awareness	1,5 (1,1)	1,7 (1,0)	1,3 (1,3)
Recognition of a need for treatment	2,5 (1,1)	3,1 (1,0)	1,9 (0,9)

Table 2
Correlations between TCOQ, BPAQ, and insight (N = 30).

Inventories	TCO			BPAQ					Insight
	Total	*Threat*	*CO*	*Total*	PA	VA	Anger	Hostility	
TCO total	1	,923**	,931**	,535**	0,324	0,158	,573**	,642**	−0,209
Threat		1	,719**	,582**	,428*	0,232	,521**	,656**	−0,224
Control/override (CO)			1	,415*	0,18	0,066	,541**	,537**	−0,165
BPAQ				1	,794**	,759**	,860**	,806**	−0,229
Physical Aggression (PA)					1	,564**	,516**	,475**	−0,224
Verbal Aggression (VA)						1	,677**	0,36	−0,169
Anger							1	,677**	−0,121
Hostility								1	−0,164
Insight									1

3.2. *Experimental task*

FERAT performance is reported in Table 3.

Regarding EFE recognition, the Emotion × Group ANOVA showed a main Group effect ($F(2,42) = 12.233$, $p < .001$): both schizophrenia subgroups performed worse than controls, with no difference between TCO− and TCO+ ($p = .446$). A main effect of Emotion ($F(4,168) = 20.749$, $p < .001$) was qualified by an Emotion × Group interaction ($F(8,168) = 2.842$, $p = .010$).

Follow-up analyses showed minimal emotion-related variability in controls ($F(4,56) = 3.165$, $p = .058$) but significant differences in both patient groups (TCO−: $F(4,56) = 9.344$, $p < .001$; TCO+: $F(4,56) = 9.778$, $p < .001$). Across patients, anger was the most impaired emotion. Per-emotion comparisons confirmed a significant group effect for anger (patients < controls, $ps < .001$). TCO− and TCO + did not differ ($p = .708$).

For fear, TCO− performed worse than controls ($p = .02$), whereas TCO + did not significantly differ from controls or TCO− ($p = .239$).

Thus, recognition deficits were robust across emotions, with the clearest impairments for anger and fear.

Attribution accuracy also showed a main Group effect ($F(2,42) = 5.915$, $p = .005$): controls outperformed TCO− ($p = .002$) and TCO+ ($p = .022$), with no difference between patient subgroups ($p = .337$). A main Emotion effect ($F(4,172) = 40.921$, $p < .001$) showed better performance for happiness and disgust and lower performance for fear and neutrality.

This was qualified by an Emotion × Group interaction ($F(4,172) = 2.56$, $p = .026$).

Controls showed relatively lower attribution for neutrality and fear, whereas patients additionally struggled with anger. Per-emotion tests indicated that controls were more accurate than both patient groups for anger attribution (vs. TCO− $p = .005$; vs. TCO + $p = .016$). Controls also outperformed TCO− for fear ($p = .002$) and neutrality ($p = .015$), with no difference from TCO+. Overall, attribution impairments in schizophrenia were most pronounced for anger, neutrality, and fear.

4. Discussion

The aim of this study was to examine whether Threat/Control-Override (TCO) symptoms are associated with aggression-related dimensions, insight, and social-cognitive performance in schizophrenia.

Consistent with our first hypothesis, higher TCO symptomatology was associated with elevated aggression-related scores. Patients in the TCO + group showed higher total aggression, anger, and hostility than those with moderate TCO symptoms, with no group differences for verbal or physical aggression. Threat symptoms significantly predicted total aggression, hostility, and physical aggression, whereas Control-Override symptoms specifically predicted anger.

Buss and Perry (1992) conceptualize aggression as a multidimensional construct comprising a cognitive component (hostility), an affective component (anger), and two behavioral components (physical and verbal aggression). Hostility captures distrustful or resentful interpretations of others' intentions and, unlike anger, is not necessarily accompanied by marked physiological arousal or expressive activation. Anger, by contrast, includes cognitive, physiological, expressive, and motor components that can facilitate action. Within this framework, our findings suggest that TCO severity is primarily linked to the cognitive and affective dimensions of aggression rather than to its overt behavioral expression. This profile resembles the "anger-in" pattern described by Spielberger et al. (1995), characterized by heightened internal anger without systematic outward expression, although our cross-sectional design precludes conclusions about stable emotion-regulation styles.

Contemporary models of violence in psychosis emphasize that delusional ideation alone is rarely sufficient to produce aggressive behavior; risk typically increases when threat-related beliefs co-occur with affective arousal, impulsivity, substance misuse, or poor insight (Bo et al., 2011). In line with previous work (Freeman and Garety, 2014; Nederlof et al., 2011), threat-related TCO experiences may amplify hostile attribution biases and anger arousal, thereby increasing interpersonal tension even when overt aggression is constrained—particularly in structured inpatient settings where medication and supervision limit behavioral expression. The dimensional association between Threat symptoms and physical aggression, despite the

Table 3
Results of patients and control subjects on the experimental task.

Task	General Mean	Healthy (N = 15)	Patients with schizophrenia (N = 30)	TCO− (N = 15)	TCO+ (N = 15)	ANOVA	*p*-value
Recognition							
Anger	74.4 (23.4)	92.7 (7.0)	65.3 (22.8)	64.0 (23.7)	66.7 (22.6)	**11,021**	**< .001**
Disgust	86.0 (16.8)	93.3 (12.3)	82.3 (17.8)	82.7 (16.6)	82.0 (19.4)	2.262	.117
Happiness	98.2 (2.9)	100.0 (0.0)	97.3 (3.5)	98.6 (3.5)	98.7 (3.5)	1.077	.350
Neutrality	91.8 (14.6)	98.0 (5.6)	88.7 (17.2)	88.6 (23.3)	88.7 (8.0)	1.170	.320
Fear	82.9 (18.5)	90.7 (12.8)	79.0 (19.7)	75.3 (21.2)	82.7 (16.8)	**4.158**	**.023**
Attribution							
Anger	87.6 (14.2)	96.7 (4.9)	83.0 (15.4)	81.3 (12.8)	84.7 (18.1)	**5.017**	**.011**
Disgust	96.8 (7.0)	98.7 (5.2)	96.0 (7.7)	96.7 (6.2)	95.3 (9.2)	0.853	.434
Happiness	97.3 (4.0)	99.3 (2.6)	96.3 (4.5)	96.0 (4.1)	96.7 (4.9)	1680	.199
Neutrality	78.0 (16.6)	85.3 (7.4)	75.7 (18.7)	72.7 (22.2)	78.7 (14.1)	**3.254**	**.49**
Fear	84.6 (8.4)	88.7 (3.5)	82.7 (9.1)	81.3 (10.3)	84.0 (7.4)	**5.654**	**.007**

absence of subgroup differences, may reflect such contextual constraints or limits of self-report measures capturing internal states rather than enacted behavior. Even without behavioral manifestations, elevated hostility and anger carry meaningful clinical consequences, including interpersonal conflict and strain on the therapeutic alliance.

Second, we confirmed our hypothesis that elevated TCO symptoms are associated with poorer insight, particularly reduced awareness of the need for treatment (e.g., medication, meetings with a clinician, hospitalization). Patients in the TCO−/moderate TCO group scored above 3 (relatively good insight), whereas the TCO + group scored below 2 (poor insight). The two groups did not differ in awareness of illness (both above 2), while symptom attribution was low in both groups (below 2), suggesting limited recognition of the psychological nature of symptoms. These findings align with models of insight in schizophrenia emphasizing the role of metacognitive and self-reflective capacities (Lysaker et al., 2013). Clinically, threat/control experiences may therefore be especially linked to reduced acceptance of treatment, whereas difficulties construing experiences as symptoms may be more pervasive in schizophrenia. However, regression analyses conducted at a dimensional level did not identify Threat or Control symptoms as significant predictors of global insight. This discrepancy likely reflects methodological differences between the categorical subgroup comparison and the dimensional regression approach. It is also possible that the association between TCO symptoms and insight is specific to certain dimensions—such as perceived need for treatment—rather than to overall insight scores. These findings require cautious interpretation and replication in larger samples.

Regarding our third hypothesis, participants with schizophrenia showed the expected deficits relative to healthy controls in both facial expression recognition and causal attribution, but overall performance did not differ as a function of TCO symptom severity. At the recognition level, patients showed significant deficits for anger and fear, consistent with prior literature (Gao et al., 2021; Goghari and Sponheim, 2013). Fear recognition appeared less impaired among patients with higher TCO symptoms, whereas TCO symptomatology did not influence the anger recognition deficit. Attribution performance was also reduced in schizophrenia. Although controls made more errors for neutral and fearful expressions, their overall accuracy remained high. In contrast, patients showed a marked decline in accuracy for these expressions, together with an additional deficit in anger attribution and a pronounced impairment in recognizing fear. These results are important as facial expressions in daily life are rarely processed in isolation but associated with contextual cues that substantially modulate their interpretation (Wieser and Brosch, 2012).

Overall, these findings suggest a partially dissociable profile in which TCO severity is not associated with global social-cognitive performance, but may relate to specific threat-relevant signals. The relative preservation of fear recognition in the high-TCO group could reflect heightened vigilance for threat-related cues. However, concurrent difficulties in attributing fear and anger highlight that recognizing an emotion and explaining its cause rely on partially distinct processes. Given that context is crucial to emotion interpretation (Wieser and Brosch, 2012; Romero-Ferreiro et al., 2018), it is possible that TCO-related threat experiences become particularly salient under ambiguous or weakly contextualized conditions, where benign interpretations are less readily accessible.

Given the small sample size, the apparent advantage for fear recognition in high TCO should be considered preliminary and requires replication. More broadly, the absence of strong dimensional effects suggests that TCO symptoms may not globally impair social cognition but instead interact with context-dependent appraisal processes, potentially amplifying perceived threat under ambiguity.

Several limitations should be noted given the exploratory nature of this work. First, the small sample size reflects the study's exploratory and our primary aim to test whether assessing TCO symptoms may be informative for understanding patients' clinical experience and to generate hypotheses for future studies. Second, some patients were difficult to assess due to aggressive tendencies, and recruitment relied on clinicians' judgment. This limited the feasibility of broader standardized assessment. Third, we did not administer the aggression measure to controls because it elicited negative emotional responses in early interviews; accordingly, aggression comparisons were restricted to the patient subgroups rather than patients versus controls. Finally, because FERAT was designed as an exploratory task, its convergent validity with standardized emotion-recognition and ToM measures has not yet been established, and the findings should be interpreted with caution. Moreover, we focused exclusively on accuracy indices and did not analyze reaction times. Including reaction-time measures in future studies will help assess processing efficiency and potential speed–accuracy trade-offs.

This study also has strengths. It integrates three domains that are often examined separately—TCO symptomatology, threat-related social-cognitive processing (recognition plus contextual attribution), and aggression/insight indicators. To our knowledge, few tasks combine controlled emotion recognition with contextual attribution within a single paradigm. FERAT therefore offers a novel experimental framework that could be evaluated psychometrically and adapted for other clinical groups.

Overall, patients showed marked difficulty identifying causes of anger and attributing neutral or fearful expressions. TCO severity was linked to heightened anger/hostility and reduced perceived need for treatment. Taken together, these findings point to elevated affective–cognitive aggression components, reduced treatment-related insight, and distinctive threat-related processing. Replication in larger, well-characterized samples—including standardized symptom ratings, substance-use assessment, validated social-cognitive measures, and efficiency metrics, is needed to confirm these associations and clarify their clinical utility.

CRediT authorship contribution statement

Mandy Rossignol: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Aurelia Rendon de la Cruz:** Data curation, Formal analysis, Methodology, Software, Writing – review & editing. **Laurent Lefebvre:** Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

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Declaration of competing interest

The authors have no relevant interests to disclose.

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