Impaired Comprehension of Nonliteral Language in Tourette Syndrome

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Objective: To investigate theory of mind and the understanding of nonliteral language in patients with Tourette syndrome (TS).

Background: In TS, striatal dysfunction could affect the functioning of the frontal cortex. Changes in frontal functioning could lead to impairments in theory of mind: the understanding of mental states, such as beliefs, emotions, and intentions. Poor understanding of a speaker's mental state may also impair interpretation of their nonliteral remarks.

Method: In this study, patients with TS and healthy controls completed tasks to assess their understanding of sarcasm, metaphor, indirect requests, and theory of mind. These tasks were the Pragmatic Story Comprehension Task, the Hinting task, and a faux pas task. Inhibitory ability was also assessed through the use of the Hayling task and a black and white Stroop test.

Results: Patients with TS exhibited significant impairment on the faux pas task and Pragmatic Story Comprehension Task despite limited evidence of inhibitory impairment.

Conclusion: TS may be associated with changes in theory of mind.

Key Words: Tourette syndrome, frontostriatal dysfunction, theory of mind, nonliteral language

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Tourette syndrome (TS) is a chronic neurodevelopmental disorder characterized by multiple motor tics and one or more phonic tics, which may be defined as semi voluntary, repetitive, stereotyped movements, and vocalizations.[1] Tics may be linked to striatal dysfunction.[2,3] Changes in striatal functioning could affect abilities reliant on the frontal cortex, such as social cognition, through dysfunction within frontostriatal circuitry.[4,5] TS can be associated with antisocial behavior[6,7] and patients can exhibit nonobscene socially inappropriate behaviors, including making offensive remarks.[8] Comorbid obsessive-compulsive disorder (OCD) or attention deficit hyperactivity disorder (ADHD) are also common.[6,7,9]

Studies[10,11] indicate that problematic social interaction can be associated with deficits in theory of mind (ToM): the understanding of mental states (eg, beliefs, emotions). For example, socially inappropriate remarks may result from a failure to consider the likely emotional response of the listener to such remarks. Previous research[12] showed that patients with TS exhibited ToM deficits on a faux pas task, which featured a story protagonist making potentially offensive remarks, but with no intent to offend. Understanding faux pas requires ToM in order to understand the protagonist's lack of intent to offend and the victim's negative emotional response. Dysfunction of medial orbitofrontal cortex (OFC) can lead to ToM difficulties and poor understanding of faux pas,[13] so the impairments exhibited by patients with TS could result from dysfunction within frontostriatal pathways involving this region.

Impairments in ToM have been linked to deficits in the understanding of nonliteral language such as sarcasm or metaphor.[14–19] Brain regions linked to ToM, such as the medial prefrontal cortex and inferior frontal gyrus, are active in neurologically intact participants during sarcasm comprehension.[20] Shamay-Tsoory et al[21] found evidence of poor comprehension of sarcasm in association with dysfunction of ventromedial prefrontal cortex (VMPFC), which includes regions involved in ToM (eg, medial OFC). These findings are likely to reflect that accurate interpretation of a nonliteral remark requires an appreciation of the speaker's mental state, because the intended meaning is not directly conveyed in the language used. The speaker of a sarcastic remark, for example, often means the opposite of what they say. As sarcasm often expresses disapproval, ToM may aid the comprehension of sarcasm through an understanding of the negative affective state of the speaker. The interpretation of metaphor may be aided by appreciation of the speaker's intent to use language in a symbolic manner, and finally, the meaning of an indirect request also requires the listener to infer the speaker's true desire or intention.

Channon and colleagues[22] tested 15 patients with "uncomplicated" TS (ie, patients with motor and phonic

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tics but no associated behavioral problems) on story tasks containing examples of sarcasm and lies. No impairments were reported, though it may be premature to conclude that patients with TS have no difficulties in processing nonliteral language in light of other evidence indicating changes in ToM in TS.[12] Poor comprehension of nonliteral language could have a significant impact on patients' social functioning, as nonliteral remarks occur frequently during everyday social interaction.

Understanding nonliteral language and ToM could be related to executive functions which rely on the integrity of the frontal cortex. Performance on ToM and executive tasks can be related in healthy participants[23] and patients with brain damage (Henry et al[24]). On the whole, patients with TS and no comorbidities are unlikely to exhibit significant executive deficits (for a review Ref. 25). However, these uncomplicated patients can exhibit mild difficulties on tasks with considerable attentional or inhibitory demands.[26–29] These subtle deficits could reflect dysfunction within frontostriatal circuitry involving the anterior cingulate. This region is important for response initiation, conflict, and inhibition.[30] A recent imaging study[31] provides further evidence for anterior cingulate changes in TS.

Inhibition is one executive function that may be particularly important for the comprehension of nonliteral language. Inhibitory dysfunction may impair the understanding of nonliteral language directly, through a failure to inhibit automatically activated literal meanings,[32,33] or indirectly, through deficits in ToM, because appreciation of another's mental state may involve the inhibition of one's own perspective of the world.[34] One inhibitory task that often yields evidence of impairment in uncomplicated TS is the Hayling task,[35] as shown by a number of studies.[22,28,36] Inhibitory dysfunction in TS may also have the potential to impair patients' understanding of nonliteral language.

This study investigated the comprehension of nonliteral language in TS using tasks featuring sarcastic and metaphorical remarks[37] and indirect requests.[38] These tasks were selected as they were easy to administer and had been used previously with other clinical groups. ToM was also investigated using a faux pas test,[39] which has already highlighted impairment in TS.[12] As inhibitory tasks appear to be the most sensitive executive tests in TS, participants completed 2 inhibitory measures: a black and white Stroop and the Hayling task.[35] We hypothesized that inhibitory dysfunction would occur alongside poor understanding of faux pas, and nonliteral language, in patients with TS.

MATERIALS AND METHODS

Participants

The study received approval from South Birmingham Ethics Committee. Eighteen participants (9 females), who met Diagnostic and Statistical Manual of Mental Disorders: Text Revision[1] criteria for TS, were recruited from the Tourette clinic, Queen Elizabeth Psychiatric Hospital, Birmingham, UK. They volunteered to take part after being informed about the study by their consultant. Patients with TS were of mean age 24.72 (SD 10.95, median 20, range: 17 to 54 y) and had an average of 12.83 (SD 1.04, median 13, range: 11 to 15 y) of education. All patients underwent a comprehensive clinical interview using a detailed semi-structured interview schedule: the National Hospital Interview Schedule for TS.[40] Patients were assessed on a number of occasions by a clinical neuropsychiatrist with relevant experience (H.R.). Mean duration of TS was 17.47 years (SD 13.82, median 12, range: 2 to 46 y). Six patients exhibited comorbid OCD, and one of these also had comorbid ADHD. Another patient exhibited TS and comorbid ADHD without OCD. No patients had received a diagnosis of autism, Asperger syndrome, or learning disability. Eight were taking medication for tics (4 risperidone, 3 haloperidol, and 1 pimozide). Ten healthy controls (3 females) of mean age 24.70 years (SD 7.60, median 23.50, range: 17 to 41 y) with mean 13.4 years (SD 1.78, median 13, range: 11 to 16 y) of education also took part.

Procedure

Patients were tested in a consultation room at the TS clinic at the University of Birmingham or at home. Participants gave informed consent after reading information leaflets. They were fully debriefed after testing, which took 30 to 40 minutes. Participants undertook 5 tasks in the following order: Hayling Task; faux pas task; black and white Stroop; and then alternating vignettes from the Hinting task, which featured indirect requests, and Pragmatic Story Comprehension Task (PSCT), which included sarcastic and metaphorical remarks. The tasks were administered by an experienced psychology researcher who was unblinded to the study hypotheses.

Vignette Tasks: ToM and Nonliteral Language Comprehension

Participants were asked to read each vignette and were then questioned by the experimenter. The appropriate vignette remained in view during questioning. The order of presentation of vignettes within each task was fixed.

Pragmatic Story Comprehension Task

This task contained 4 vignettes taken from a study investigating the influence of schizotypal personality on nonliteral language comprehension.[37] They describe social scenarios involving 2 characters, and end with a list of 4 possible remarks that may be spoken by one character in response to the other character's behavior. Participants were asked to decide which of these remarks would make sense, what the character would mean by them, and if there were any remarks that did not make sense. Three remarks made sense relating to the story context: one was literally appropriate, one was appropriate if interpreted as sarcasm, and another was an appropriate use of metaphor. The remaining statement did not make sense. For example: Mr Jones is a very generous man. He has donated $10,000 to the local

hospital. When he tells his friend Peter what he had done, Peter says: (1) "How generous!" (literal), (2) "What a miser!" (sarcastic), (3) "You have got big pockets!" (metaphorical), and (4) "You keep pulling the shutters down" (nonsense).

The 4 remarks formed 4 trial types that were counterbalanced in order across the stories. The vignettes comprised 2 pairs. Within these 2 pairs, 2 of the 4 possible remarks were the same; however, depending on the story, they could be interpreted appropriately as literal or sarcastic (ie, the appropriate literal and sarcastic remarks were reversed). The vignettes appeared in a fixed order. Presentation of these vignettes alternated with presentation of the 4 vignettes from the Hinting task.

The Hinting Task

This task consisted of 4 vignettes that described short social scenarios involving 2 characters, developed by Corcoran et al[38] for research into Schizophrenia. Each vignette ended with a remark made by one character, which should be correctly interpreted as an indirect request. For example: Melissa goes to the bathroom for a shower. Anne has just had a bath. Melissa notices the bath is dirty. She calls downstairs to Anne, "Couldn't you find the bleach, Anne?" Participants were asked what the character meant by the remark. Correct responses required an inferential and appropriate nonliteral interpretation identifying the speaker's hint.

Faux Pas Test

This task contained 8 vignettes developed by Baron Cohen et al[39] to test children with autism. Four test vignettes describe a character saying something inappropriate without realizing it is likely to offend another character, and 4 control vignettes describe exchanges involving no faux pas. For example, in one test vignette Jill has moved house and bought new curtains. Lisa says the curtains are horrible. The first question assessed recognition of faux pas: "Did someone say something they shouldn't have?" If participants said yes, they were asked, "Who was it and what did they say?" Reasoning was assessed using 2 further probes: "Why should not they have said that?," and "Why shouldn't they have said that?" Another question checked story recall, "What had Jill just bought?" Finally, a belief question was asked about test vignettes, "Did Lisa know that Jill had chosen the curtains?"

Tests of Inhibition

Hayling Sentence Completion Test Adapted

For both parts of this test, 2 practice and 10 fixed test sentences were read one by one to the participant. They were told to complete each sentence with a single word. Some of the sentences were taken from Burgess and Shallice's[35] study and some were developed previously[12] by the present authors. For part A, initiation, participants were told to complete the sentences with obvious words that "fit" the sentence. Part B, inhibition, required suppression of the word strongly primed by the cue sentence (suitable answers to part A). Participants were told the word should make contextual sense, but must not be the most obvious word. These instructions prevented participants using a simple strategy (eg, naming objects in the test room). Two raters scored participants' responses with reference to relevant sentence completion norms provided by Bloom and Fischler.[41] Incorrect responses for part A were words that did not make sense. Incorrect words for part B were words that made sense but were too obvious (ie, words that would be correct for part A) or words that made no contextual sense. Response latency was also recorded.

Black and White Stroop Test

Stimuli consisted of a page of 40 equally sized squares colored black or white and arranged in a pseudorandom order to form 8 rows of 5. For the baseline condition, participants were asked to say the color of each square, moving across each row from left to right. For the test condition, the same stimuli sheet was rotated 180 degrees, and participants were told to say black if they saw a white square and white for a black square. Both number of errors and the total time taken was recorded for each condition.

RESULTS

Patients with TS and controls did not differ in age, $t(26) = 0.006$, $P = 0.996$, or years of education, $t(26) = -1.070$, $P = 0.295$. One patient with TS did not complete the faux pas and Hayling tasks.

Analysis of skewness and kurtosis indicated that data were not normally distributed. Therefore, statistical analysis employed nonparametric Mann-Whitney U (MWU) tests for between group comparisons, and relationships were analyzed using Spearman's rho correlation coefficients.

Nonliteral Language Tasks

Controls performed at ceiling on the Hinting task, whereas the patient group made 3 errors (mean 0.17, SD 0.38, median 0, range: 0 to 1), a difference that was not significant, MWU = 75, $P = 0.180$. Patients exhibited little difficulty in the understanding of indirect requests.

In contrast, patients demonstrated significant impairment on the PSCT (Table 1), MWU = 18, $P < 0.001$. Patients (n = 18) made 45 errors overall (mean 2.5, SD 1.89, median 2.5, range: 0 to 6), whereas controls (n = 10) made just 1 (mean 0.1, SD 0.32, median 0, range: 0 to 1). When comparing the number of errors made in response to the 4 remark types, pair-wise comparisons indicated that patients exhibited significant deficits in the detection of appropriate use of sarcasm, MWU = 25, $P = 0.001$, and metaphor, MWU = 52, $P = 0.032$, but no deficits in detecting appropriate literal remarks, MWU = 65, $P = 0.072$, or inappropriate nonsense statements, MWU = 70, $P = 0.115$.

TABLE 1. Errors Made by Patients With Tourette Syndrome (n = 18) on Different Trial Types During the Pragmatic Story Comprehension Task

Trial Type	Sarcasm Detection	Metaphor Detection	Literal Detection	Nonsense Detection
Total errors	20	14	6	5
No. of patients who made errors	13	9	5	4
% incorrect responses	27.78	19.44	8.33	6.94

ToM: Faux Pas Task

The control group made only 1 error in detecting faux pas (mean 0.1, SD 0, median 0, range: 0 to 1). Patients' total of 19 errors (mean 1.06, SD 1.06, median 1, range: 0 to 4) was significantly greater, MWU = 31, $p = 0.003$. When test and control scenarios were considered separately (Table 2), patients made mean 0.59 errors (SD 1.00, median 0, range: 0 to 4) and performed significantly more poorly than controls on test vignettes, MWU = 50, $P = 0.021$, who performed at ceiling. Patients also made more errors (mean 0.53, SD 0.62, median 0, range: 0 to 2) on control vignettes than control participants (mean 0.1, SD 0.32, median 0, range: 0 to 1 errors), and this difference reached borderline significance, MWU = 53, $P = 0.051$.

Controls performed at ceiling and patients (mean 0.13, SD 0.32, median 0, range: 0 to 1 errors) almost performed at ceiling for story recall checks. No difference in performance was evident, MWU = 80, $P = 0.283$. Patients (mean 0.28, SD 0.57, median 0, range: 0 to 2 errors) did not perform more poorly than controls (mean 0.6, SD 0.699, median 0, range: 0 to 2 errors) on belief check questions, MWU = 65.5, $P = 0.152$.

Tests of Inhibition

The control group performed at ceiling on the Hayling task, whereas patients made a total of 6 errors (mean 0.35, SD 0.61, median 0, range: 0 to 2), a difference that was not significant, MWU = 60, $P = 0.063$. On average, patients (mean 1.67 s, SD 0.92, median 1.30, range: 0.61 to 3.91) exhibited a greater increase in response latency for each inhibition trial in relation to baseline when compared with controls (mean 1.13 s, SD 0.5, median 1.07, range: 0.53 to 2.10). However, this difference was not significant MWU = 55, $P = 0.132$.

Patients with TS made 36 errors (mean 2, SD 2.59, median 1, range: 1 to 8) on the black and white Stroop interference condition in comparison to controls who made 6 (mean 0.6, SD 0.84, median 0, range: 0 to 2). This difference was not significant MWU = 65, $P = 0.198$. Patients showed a greater increase in response latency (mean 7.12 s, SD 3.28, median 6.44, range: 1.2 to 16.03) from baseline to the interference condition in comparison to controls (mean 5.13 s, SD 1.05, median 5.36, range: 3.2 to 6.7), and this difference was significant, MWU = 45, $P = 0.031$.

TABLE 2. Errors Made by Patients With Tourette Syndrome (TS) and Controls on the Faux Pas Task

	Patients With TS (n = 18)		Controls (n = 10)	
Error Type	% Incorrect	Errors/Total Possible	% Incorrect	Errors/Total Possible
Recognition errors				
All	13.19	19/144	1.25	1/80
Test vignettes	13.88	10/72	0	0/40
Control vignettes	12.50	9/72	2.5	1/40
Belief errors	6.94	5/72	15	6/40
Fact recall errors	1.39	2/144	0	0/80

Comorbidity Analysis

It is possible that deficits in task performance exhibited by patients with TS reflect the influence of comorbid disorders. Six of the patients tested in this study exhibited comorbid OCD, one of these also exhibited ADHD and a further patient exhibited ADHD, but not OCD. Therefore, further analysis (Table 3) compared the performance of the patients without comorbidities (n = 11) to that of controls (n = 10).

When patients with TS only were compared with controls, the differences in performance found for the patient group as a whole remained significant. Patients with uncomplicated TS made significantly more errors than controls on the PSCT and the faux pas task. These patients also took significantly longer than controls to respond to inhibitory items during the black and white Stroop test. The lack of differences between patients and controls for times on the Hayling test and errors on the Hinting task, black and white Stroop, and Hayling test remained.

Correlations

Correlations were conducted to identify relationships in patients' performance between the tasks administered (Table 4). Calculations did not include errors made on the Hayling task or Hinting task as there were so few.

A significant relationship was apparent between errors on PSCT and black and white Stroop times. Patients who made more errors on the PSCT exhibited a greater increase in the time taken to respond to items during the inhibitory condition in comparison to baseline. A significant correlation was also found for faux pas recognition errors and the extra time taken to respond to inhibitory items in comparison to baseline on the Hayling task. Patients who made more errors on the faux pas task showed a greater effect of inhibitory demands on time taken during the Hayling task.

If adjustments for multiple comparisons were applied to these results, only the differences between patients and controls on the PSCT (for all patients, and patients with TS who had no comorbidities) would remain significant. However, such corrections may be

TABLE 3. Total and Mean Errors Made by Patients With ''Uncomplicated'' Tourette Syndrome (TS) and Controls on the Theory of Mind, Nonliteral Language, and Inhibitory Measures

	Patients With Uncomplicated TS (n = 11)		Controls (n = 10)		Statistics	
Measure	**Total**	**Mean**	**Total**	**Mean**	**MWU**	***P***
Hinting task errors	2	0.18	0	0	45	0.167
Pragmatic Story Comprehension Task errors	26	2.36	1	0.1	12	0.001**
Faux pas task errors	10	0.91	1	0.1	14	0.002**
Hayling test						
Errors	3	0.3	0	0	40	0.147
Time differences	—	1.62	—	1.13	39	0.406
Black and white Stroop test						
Errors	14	1.27	6	0.6	43	0.358
Time differences	—	6.83	—	5.13	19	0.011*

*Significant at 0.05 level.
**Significant at 0.01 level.
MWU indicates Mann-Whitney *U* test.

considered too stringent, as small sample size and the use of nonparametric tests would have increased the likelihood of making a type II error.

DISCUSSION

Performance on the PSCT indicated a highly statistically significant deficit in the comprehension of nonliteral language in patients with TS. Patients often decided that appropriate metaphorical remarks did not make sense, but their greatest impairment was in the detection of contextually appropriate use of sarcasm. Patients with TS could identify appropriate literal remarks or nonsense statements. Therefore, these findings seem to indicate specific impairments in understanding nonliteral remarks rather than general difficulties with language.

Patients' difficulties in comprehending sarcasm and metaphor were despite accurate comprehension of indirect requests, as revealed by intact performance on the Hinting test. The PSCT may have been a more sensitive test than the Hinting test, as the latter simply required interpretation of nonliteral utterances. During the PSCT, patients had to first recognize and select nonliteral remarks that would make contextual sense before justifying their selection. There was, therefore, greater margin for error on this task because patients were free to decide that the remarks did not make sense.

Changes in ToM may also be exhibited by patients with TS as indicated by impaired performance on the faux pas task. Errors included both failures to detect faux pas and occasions where patients suggested that an inappropriate remark had been made in control vignettes containing no faux pas. This finding replicates previous research involving patients with TS[12] and patients with frontal variant frontotemporal dementia.[42] Failure to detect faux pas may indicate reduced sensitivity to socially inappropriate behavior, resulting from a failure to draw inferences about a character's mental state (eg, the victim's emotional response to the inappropriate remark). Errors on control vignettes, however, suggest that patients are mindful of the fact that inappropriate social behavior can occur, although their judgment of what is socially appropriate differs to that of controls'. Other changes in reasoning about social exchanges may have contributed to patients' unconventional interpreta-

TABLE 4. Correlations for the Performance of Patients With Tourette Syndrome on the Theory of Mind, Nonliteral Language, and Inhibitory Measures

Measure	**Pragmatic Story Comprehension Task Errors**	**Faux pas Recognition Errors**	**Hayling Task Time Difference**	**Black and White Stroop Errors**	**Black and White Stroop Time Difference**
Pragmatic Story Comprehension Task errors	X	0.131	0.299	0.270	0.399
		0.508	0.122	0.174	0.039*
Faux pas recognition errors		X	0.490	−0.176	0.197
			0.008**	0.380	0.324
Hayling task time difference			X	−0.216	0.274
				0.279	0.167
Black and white Stroop errors				X	0.347
					0.076

Upper value = Spearman *r* correlation coefficient and lower value = *P* value.
*Significant at 0.05 level.
**Significant at 0.01 level.

tions of characters behavior in control scenarios. For example, patients may have a tendency to assume that behaviors that result in negative consequences are always made with negative intent.

Patients with TS exhibited a mild deficit on the black and white Stroop test, according to time taken to respond to inhibitory items in comparison to baseline. Although no other significant inhibitory deficits were evident, aspects of patients' performance on the black and white Stroop and Hayling task (ie, inhibition condition related increases in response times) were related to impairments on the faux pas task and PSCT. Difficulties with inhibition could have contributed to poor performance on the PSCT through poor inhibition of the literal meaning of nonliteral remarks. It is also possible that inhibitory deficits led to impairment on both the PSCT and faux pas task because both tasks involve ToM, and failure to inhibit one's own perspective may impair the understanding of another's mental state.[34] It is unlikely, however, that the mild inhibitory deficits observed in this study can completely explain patients' striking difficulties on the faux pas task and PSCT.

One possible explanation for patients' deficits on the PSCT and faux pas task could be the involvement of conflicting cognitive and affective mental states. Difficulties dealing with conflicting cognitive (eg, beliefs) and affective (eg, emotions) mental states could contribute to poor comprehension of nonliteral language. For example, a speaker may feel a certain way, but intend to make a sarcastic remark with a literal meaning that directly conflicts with their feeling. The faux pas task involves consideration of both the victim's emotional reaction (affective mental state) and the protagonist's conflicting belief and lack of intent to offend (cognitive mental states). Shamay-Tsoory et al[43] reported deficits on a faux pas task in patients with Asperger syndrome, which they suggest reflect poor integration of cognitive and affective mental states in association with dysfunction of right VMPFC.[11]

Changes in ToM in TS could contribute to patients' poor comprehension of nonliteral language. However, one weakness of this argument is that no correlation was apparent between patients' performance on the PSCT and faux pas task. Relationships between performance on ToM and nonliteral language measures may be stronger if the nonliteral language task administered is richer in ToM cues. For example, auditory cues such as vocal tone may aid understanding of the affective mental state of the speaker. Other limitations associated with this study include that patients' tic severity was not measured at the time of testing, and data about patients' social functioning was not collected. Future research should seek to assess tic severity, the presence of nonobscene socially inappropriate symptoms,[8] and everyday social functioning alongside ToM performance in patients with TS.

It may be speculated that the observed difficulties exhibited by patients in this study result from frontostriatal dysfunction. More specifically, patients' difficulties with inhibition, faux pas, and nonliteral language could reflect dysfunction of the anterior cingulate corticothalamo corticostriatal circuit (as described by Alexander et al[4]). This circuit, which includes the ventral striatum and anterior cingulate cortex, could also involve connections to regions to VMPFC (ie, medial OFC). The anterior cingulate is involved in inhibition,[30] whereas dysfunction of medial OFC can impair the understanding of faux pas[13] and dysfunction of VMPFC could lead to poor understanding of sarcasm.[11] A recent imaging study[31] reported structural abnormalities of the anterior cingulate in TS, in support of the proposal that patients exhibit dysfunction within this circuit. However, the inferior frontal gyrus may also be involved in the processing of nonliteral language;[20,44] thus, nonliteral language deficits in TS could also implicate changes within the lateral orbitofrontal circuit (as described by Alexander et al[4]).

In summary, patients with TS exhibited deficits in understanding nonliteral language and faux pas. These deficits were apparent despite evidence of only mild inhibitory dysfunction. Furthermore, when patients with TS and comorbid OCD were removed from analysis, the above impairments were still evident, indicating that deficits in ToM and the comprehension of nonliteral language appeared to result from TS rather than comorbid OCD. Such difficulties could indicate changes to ToM in TS as a result of frontostriatal dysfunction. Future research should seek to determine whether patients with TS exhibit changes in specific aspects of ToM as a result of dysfunction in particular frontostriatal pathways.

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