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# **Social cognition in adult survivors of brain tumors: Studying the relationship between theory of mind and quality of life**

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## **Abstract (196 words)**

**Objective.** The present study is the first to examine theory of mind (ToM) sequelae in a sample of adult survivors of primary brain tumors, and to investigate the assumed relationship between ToM and health-related quality of life (HRQoL).

**Method.** Participants were 40 long-term adult survivors of primary brain tumors and 40 matched healthy controls. They completed ToM tests (Faux-Pas test and Advanced ToM task) and two questionnaires assessing HRQoL (36-Item Short Form Health Survey and EORTC QLQ-C30/QLQ-BN20). Their relatives also completed an observer-rated version of the SF-36 questionnaire.

**Results.** Survivors performed worse than controls only on the Advanced ToM task. Overall, patients and caregivers reported more problems than healthy controls and their relatives regarding both global HRQoL and its social/emotional aspects. No relationship was found between ToM and HRQoL scores.

**Conclusion.** Adult survivors of primary brain tumors may exhibit ToM deficits several years after treatment, and report more problems on social/emotional HRQoL components. Our findings highlight the need to consider these late effects in survivors' long-term follow-up, even if the clinical involvement of ToM deficits still needs to be elucidated. The assessment of ToM deficits and their potential impact on survivors' everyday life is thoroughly discussed.

**Keywords.** Social cognition – Theory of mind - Health-related quality of life – Primary brain tumor – Survivorship

## Introduction

The European Organization for Research and Treatment of Cancer (EORTC) defines a *cancer survivor* as a person who was diagnosed with cancer, completed primary treatment, and has no evidence of active disease (1). Regarding primary brain tumors (PBTs), these can be divided into several different tumor types that require diverse treatment modalities, including chemotherapy, radiotherapy, and neurosurgical resection (2). In the past few decades, advances in PBT treatment have led to substantial improvements in patients' mean life expectancy. Although these survival rates vary according to the histological tumor subtype (e.g., poorer for patients with glioblastomas than for those with lower-grade gliomas), the central issue for all survivors of PBTs is the quality of the survivorship experience (3). Regardless of tumor type, size and location, surviving a PBT is frequently associated with long-term adverse effects (i.e., *late effects*) corresponding to the physical, cognitive and psychosocial sequelae of both the tumor and its treatment (4).

Late effects can emerge several years after treatment has ended and are assumed to negatively impact health-related quality of life (HRQoL), no matter the tumor type (5, 6). Consequently, a shift in emphasis has occurred in PBT interventions, away from increasing the survival rate to the quality of the survivorship experience and the preservation of an acceptable level of HRQoL (7, 8). The next step for clinical care is to highlight the consequences of PBT and its treatment for HRQoL, in order to design more targeted interventions and thus hopefully improve HRQoL. One of the most serious challenges survivors face is cognitive dysfunction, which is assumed to have an adverse effect on their ability to function in everyday life (9). Until now, studies exploring cognitive abilities in neuro-oncology have focused on attention, memory, and executive functions (10, 11), with social cognition attracting much less interest (12).

*Social cognition* is an umbrella term covering a variety of cognitive processes that allow for successful and adaptive behavior in a social context (e.g., 13). It includes abilities such as emotion recognition, sharing emotions with others (empathy), regulating one's emotional responses to others, and understanding others' mental states (theory of mind; ToM). The latter can be divided into cognitive ToM (understanding other people's intentions/beliefs) and affective ToM (understanding others' feelings and emotions; 14). ToM is one of the most studied components of social cognition in neurological populations (e.g., 15) and is considered as a potentially critical ability for patients' adaptation to their social environment (e.g., 16).

As two recent reviews of the literature have shown, there are only a few studies investigating ToM in adult patients with PBTs (17, 18). In these studies, patients were assessed either preoperatively or postoperatively, or their performance on ToM tasks was compared before and after surgery (immediately after resection and a few months later). The authors found that ToM processes can be significantly affected before and immediately after surgery, with an influence of tumor histology and lesion location. Patients with high-grade tumors display more sociocognitive deficits than those with low-grade tumors, and lesions of the frontal lobe and its connections (i.e., inferior frontal gyrus, orbitofrontal cortex, frontostriatal tracts, inferior fronto-occipital fasciculus) are more likely to induce sociocognitive impairments.

Several observations can be made from these literature reviews. The first is that the conclusions are drawn from a very limited number of publications with conflicting results, which can be explained by some methodological limitations. The authors mention that some studies assessed ToM impairment using self-report measures, while others used objective tasks. The most challenging aspects of sociocognitive skills (i.e. complex social reasoning skills) were not assessed. Secondly, there are only two publications with more than ten

patients assessing ToM exclusively in the post-treatment period (maxi: 12 months post-neurosurgery) (19, 20). This means that there is a complete lack of data on ToM in long-term adult survivors of PBT, which is problematic given that ToM deficits are thought to cause profound impairment in social life (21). Third, very few studies exploring social cognition in neuro-oncology have examined its clinical implications. In particular, ToM is assumed to crucially contribute to HRQoL, but no evidence of this has yet been found in patients with PBTs. Pertz et al (18) mention only one published paper on this topic in patients with primary central nervous system lymphoma (22), and there is only one study examining the relationship between ToM and psychosocial distress (not HRQoL) in preoperative brain tumor patients (23). In the case of long-term survivors of PBT, the aim is not so much to detect the presence of cognitive impairment, but to investigate its potentially detrimental impact on daily life and HRQoL. The next step is to identify the sociocognitive sequelae that may affect HRQoL, with the ultimate goal of improving survivors' HRQoL. Thus, the present study was motivated by research demonstrating a relationship between ToM and HRQoL in various clinical populations (e.g., epilepsy 24, schizophrenia 25). If ToM disorders negatively influence HRQoL, this finding may help guide the development of effective cognitive interventions targeting ToM, as social skills training has been shown to be effective in several clinical populations (e.g., 26).

The aim of the present study was therefore twofold. We wanted to (1) examine social cognition in a sample of stable, long-term adult survivors of PBT, focusing on ToM, and (2) investigate the assumed relationship between ToM and HRQoL, with a particular focus on the social and emotional aspects of quality of life. We predicted that, compared with matched healthy controls, adult survivors of PBT would exhibit ToM and HRQoL limitations. Based on the literature for other etiologies, we expected to find significant correlations between ToM scores and social/emotional aspects of HRQoL. By the same token, we also expected

patients who performed poorly on ToM tasks to have poorer social/emotional HRQoL than those with few or no ToM deficits. Finally, although this could not be considered a primary objective, given the sample size, we investigated the influence of tumor location, type, and grade on ToM. Following the preliminary conclusions of Pertz et al. (17), we predicted that frontal lobe lesions and high-grade gliomas would have a more negative impact on this ability.

## **Material and Methods**

This observational multicenter study received French regulatory ethical approval (Comité de Protection des Personnes Ouest II, no. 2015/27, ID-RCB no. 2015-A01192-47) and international review board authorization (no. NCT02693405), and was performed in line with the principles of the Declaration of Helsinki.

### **Participants**

We recruited 40 survivors of PBT in three university hospital neurosurgery departments, following a procedure described elsewhere (27). Patients had to have been treated (chemotherapy, radiation therapy, and/or surgery) for a PBT and to have completed their treatment at least 2 years before enrollment, with no recurrence of the disease. Eligibility regarding study criteria and lesion location was verified by experienced physicians (PM, VR, RS). Given that the study protocol required a certain level of understanding, patients with major cognitive impairments, as measured with the Mini-Mental State Examination (MMSE; score < 24), were excluded.

We also recruited 40 matched (age, gender, and education level) control participants via a research center affiliated with one of the university hospitals. Participants had to be aged between 20 and 59 years, with no history of psychiatric or neurological disease. French had to

be their native language. Plausible participants were identified within the center's volunteer database and contacted by a nurse if they matched the inclusion criteria. If they agreed to take part, they were enrolled in the study. Information about the patients' disease and participants' sociodemographic data are summarized in Table 1.

In the patient group, caregivers were either the patient's spouse (81.08%) or a close family member (18.92%) living with the patient. The observer reports for the control group were completed either by the participant's spouse (69.23%) or by a close family member (30.77%) living with the control.

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INSERT TABLE 1 ABOUT HERE

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### **Assessment of Social Cognition**

#### *Faux-Pas test*

We administered a modified French version of the Faux-Pas test developed by Baron-Cohen et al. (28). Four stories containing a faux pas were randomly combined with four stories without a faux pas, to avoid a *yes* response bias. A *faux pas* is defined as a situation in which one character unintentionally neglects social norms by saying something awkward. After each story, participants were asked a *detection question* ("Did anyone say something they should not have said?"). If the participant answered "yes" to this question, then the following five questions were asked: 1) *person identification question* ("Who said something they shouldn't have said?"); 2) *explanation question* ("Why should he/she not have said it?"); 3) *content question* ("Why do you think he/she said that?"); 4) *false belief question* ("Did he/she know/remember that?"); and 5) *empathy question* ("How do you think the listener felt?"). After each story, participants were also asked about its factual comprehension (*understanding question*). For each of the eight stories, participants scored 1 point if they



correctly answered this question (*understanding score*). For each story containing a faux pas, participants were awarded 1 point for each correctly answered detection question (*detection score*). A *cognitive ToM score* was obtained by summing the correct answers to the first four questions (each scored 1 point), and an *affective ToM score* by summing the correct answers to Question 5 (scored 1 point) (29).

#### *Advanced TOM task*

We administered a French modified version of the Strange Stories task (30), one of the tests most frequently used to investigate advanced ToM (31). Participants read 14 short vignettes and had to explain after each one why a character said something that was not literally true. This task is claimed to present a more naturalistic challenge to participants, by questioning them about everyday life social situations. The task consists of 11 ToM stories probing 11 types of ToM: Joke, Sarcasm, Metaphor, Double Bluff, Figure of Speech, Persuasion, Lie, Social Lie, Misunderstanding, Forget, and Appearance/Reality. There are also three control stories that do not involve mental states. For each ToM story, participants were asked an *understanding question* ("Was what he/she said true?") and a *ToM question* ("Why did he/she said that?"). Participants were awarded 1 point for each understanding question they answered correctly (*understanding score*). The justifications given in response to the ToM question were rated as either correct or incorrect, with 2 points for a full and explicit answer, and 1 point when the response was incomplete or partial (*ToM score*). The number of incorrect responses was also counted (*incorrect score*). For the three control stories, 2 points were awarded for a correct full answer, and 1 point when the response was partial (*control score*). As the justifications were submitted to subjective judgments, scoring had to be covalidated. Accordingly, a second rater who was naive to the hypothesis being tested independently coded the justifications given by each participant. Interrater agreement was high (Cohen's kappa = .92).

## **Assessment of HRQoL**

We used two questionnaires to accurately assess HRQoL (see also 32). One was generic (Medical Outcomes Study 36-Item Short-Form Health Survey, SF-36), the other specific to the assessment of HRQoL in cancer patients and patients with PBTs (EORTC QLQ-C30 with EORTC QLQ-BN20). Both questionnaires allow the social and emotional components of HRQoL to be assessed and are suitable for assessing patients with PBTs (e.g., 33).

### *SF-36*

We administered the French version of the self- and observer-rated SF-36 (34). This questionnaire measures eight dimensions of individuals' generic health status: physical and social functioning, role limitations (physical and emotional problems), bodily pain, general health, mental health, and vitality. It yields two composite scores: a physical component score (PCS) and a mental component score (MCS). It has proven to be valid and reliable in patients with brain tumors (35).

### *EORTC QLQ-C30/QLQ-BN20*

We administered the EORTC QLQ-C30 and its brain-specific module QLQ-BN20 (36, 37). This self-report questionnaire comprises five functional subscales (physical, role, emotional, cognitive, and social functioning), three symptom subscales (fatigue, nausea and vomiting, pain), six single items (dyspnea, insomnia, appetite loss, constipation, diarrhea, financial difficulties) and a global health status scale. The QLQ-BN20 module contains 20 questions assessing brain-specific symptoms, including communication deficits.

SF-36 and EORTC QLQ-C30/QLQ-BN20 scores range from 0 to 100, with higher scores indicating better functioning and health status (except for the QLQ-B20

communication deficit). Given the purpose of the present study, analyses focused on scores on the global HRQoL scale and the social and emotional functioning subscales (see also 38).

### **Statistical Analysis**

Owing to the low number of participants, unequal variances, and significant deviation of the dataset from normal distribution (Shapiro-Wilk test), we chose to run nonparametric tests. Mann-Whitney  $U$  tests and Kruskal-Wallis tests were used to compare quantitative measures between groups. Qualitative analyses were performed with the Chi-square test. Effect sizes are reported as Cohen's  $d$ . We used Spearman's rank correlation coefficient to test correlations between two ordinal variables. Parametric analyses led to similar conclusions regarding statistical significance. Significance tests were conducted using a two-tailed significance level of  $p \leq .05$ . Statistical analyses were performed using Statistica™ Version 13.3 software (TIBCO).

## **Results**

### **Characteristics of the groups**

Patients and controls did not differ on either gender, age, or education level (all  $ps > 0.46$ ). No significant difference was found between the two groups on MMSE scores ( $U = 550.5, p = .36$ ).

### **TOM Analyses**

There were no differences between patients and controls on the Faux-Pas test (all  $ps > .15$ ), whereas significant differences were found on the Advanced ToM task. Patients performed more poorly than controls on the ToM variables (ToM score:  $U = 588.5, p = .04$ ; incorrect score:  $U = 569, p = .02$ ). There were no differences between groups on the understanding ( $U =$

527.5,  $p = .47$ ) and control ( $U = 710$ ,  $p = .26$ ) scores. Table 2 provides an overview of participants' performances on the ToM tasks.

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INSERT TABLE 2 ABOUT HERE

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To investigate the impact of tumor location, type, and grade on ToM, we conducted further analyses between patient subgroups: frontal ( $n = 24$ ) versus nonfrontal ( $n = 16$ ), and high-grade gliomas ( $n = 15$ ) versus low-grade gliomas ( $n = 18$ ) versus non-glioma patients ( $n = 7$ ). No differences were found between patient subgroups on any of the variables we considered (all  $ps > .08$ ).

The heterogeneity of patients' performances on the ToM tasks led us to divide them into subgroups. Patients were considered *impaired* on ToM if they had a pathological score on a key ToM variable (detection and ToM scores) in at least one of the tasks. As there are no normative data for ToM tasks, and as patients and controls were matched on sociodemographic criteria, we used Crawford and Garthwaite's procedure (39) to compare a single case with a control population to determine whether or not a patient's ToM score was pathological (see also 40). When we applied this classification method, we found that 14 patients (35%) had a ToM impairment: 5 patients (12.5%) were impaired on the Faux-Pas test, 12 (30%) on the Advanced TOM task, and 3 on both tasks (7.5%). Table 3 provides information about the patients who were classified as having ToM deficits and confirms the heterogeneity of etiology, grade, and tumor location.

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INSERT TABLE 3 ABOUT HERE

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## HRQOL analyses

The results of the HRQoL questionnaires are summarized in Table 4. Concerning the SF-36, some observer-reports were missing, especially in the control group (several participants' proxies failed to return their questionnaires by mail). The study's investigator called the patients' caregivers, but not the proxies for the control group. Consequently, nine informant reports were not mailed back for the control group (77.5% response rate), and three were not mailed back for the PBT patient group (92.5% response rate). Informant report comparisons for the SF-36 were therefore conducted for 37 patients with PBT and 31 control participants. Compared with patients, controls had significantly higher self- and observer-rated MCS and PCS. They also had significantly higher scores on the self-rated social functioning subscale and observer-rated social functioning and role limitations (emotional problems) subscales.

As for the QLQ-C30/QLQ-BN-20, patients and controls scored similarly on the role and emotional subscales, but differed significantly on the physical and cognitive subscales. Differences on the social functioning subscale, communication deficits, and the global health status scale tended toward significance.

Additional analyses were conducted between patient subgroups to test the effects of tumor location, type, and grade on HRQoL. No differences were found between patients with frontal and posterior brain lesions (all  $ps > .12$ ). The only statistically significant difference was between patients with gliomas and nonglioma patients, as the former scored higher on the QLQ-C30 physical subscale: high-grade glioma versus nonglioma:  $U = 19.5, p = .02$ ; low-grade glioma versus nonglioma:  $U = 29, p = .039$ .

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INSERT TABLE 4 ABOUT HERE

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## Associations Between ToM and HRQoL

We calculated Spearman's rank correlation coefficients between patients' ToM scores and their scores on HRQoL measures, focusing on the social and emotional subscales. There were no associations between these variables, so we did not perform a multiple regression analysis.

To meet our second objective, we ran comparisons between patients classified as impaired and unimpaired on ToM tasks, according to the criteria stated above. There were no differences between patient subgroups on any HRQoL variables (Mann-Whitney  $U$  tests, all  $ps > .09$ , data not shown). Numerous correlations were found between the social and emotional subscales of the HRQoL questionnaires (see Table 5).

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INSERT TABLE 5 ABOUT HERE

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## Discussion

The present study is the first to have investigated the late effects of PBT on ToM and the latter's potential detrimental impact on HRQoL. We focused on ToM because this ability is assumed to be critical for social interactions (e.g., 17, 18), and on the social/emotional components of HRQoL.

Patients' ToM deficit was not homogeneous, and only concerned the Advanced ToM task. It could be argued that this task was more demanding in terms of language understanding than the Faux Pas test. However, patients and controls performed similarly on the understanding and control questions in the Advanced ToM task. There is also theoretical and behavioral research suggesting that ToM should not be considered as a single construct

and that different ToM tasks do not necessarily assess the same process (e.g., 41, 42). Very few publications have been devoted to this issue, but a recent study reported minimal correlations between various ToM tasks across the lifespan in healthy populations (43). Regarding the tasks we used in our study, one advantage of the Advanced ToM task is that it is supposed to be closely related to everyday social situations (e.g., 44). In various cognitive assessments such as those probing executive functions, these more ecological tasks have been shown to highlight subtle deficits in neurological (e.g., 45) and psychiatric populations (e.g., 46). We can therefore assume that even if the recognition of a faux pas requires subtle social reasoning, the more ecological nature of the Advanced ToM task may explain the difference between groups. Overall, our findings demonstrate that ToM deficits can be present several years after finishing treatment in survivors of PBT, and underscore the importance of using sufficiently sensitive tests to highlight them. Although the Faux Pas task is sensitive enough to detect a deficit preoperatively (23), this does not seem to be the case several years after the end of treatment. Our data confirm the need to use sufficiently sensitive tests involving complex social reasoning skills, as pointed out by Pertz et al (18). Furthermore, as a comprehensive neuropsychological assessment is time-consuming, it is necessary to identify the tasks that are most sensitive to sociocognitive deficits. In this sense, our results are a contribution as they are likely to guide neurocognitive assessment in long-term follow-up of PBT survivors.

It is encouraging that ToM is not altered in all survivors of PBT: we observed a deficit in 35% of patients- a lower percentage than that reported in the few published studies among preoperative patients with PBT (23). Although preliminary, these are the first data to provide a detailed analysis of ToM deficits in a population of long-term stable adult survivors of PBT. Our results confirm those of previous studies investigating ToM pre-or posttreatment in

patients with brain tumors, namely that not all patients show a deficit in ToM. This may help to explain the contradictory results reported in the recent literature reviews (17, 18).

In addition, we did not find any effects of tumor location, type, and grade on ToM, contrary to our expectations and the results of previous studies (e.g., 47). Albeit surprising, these results are in line with neuroimaging studies demonstrating the involvement of a complex neural network in ToM, encompassing not only the frontal lobe but also posterior brain regions such as the temporoparietal junction and posterior superior temporal sulcus (e.g., 48). Our results also confirm the results of clinical studies reporting ToM impairments in the case of posterior lobe lesions (e.g., 49). In addition, it has been suggested that neuroplasticity could account for the decrease in social cognition deficits in patients with PBT several months after surgery (17). This could explain why some patients did not exhibit ToM impairments in our study.

Regarding HRQoL, the questionnaires yielded relatively homogeneous results and demonstrated that, as perceived by patients and caregivers, HRQoL may be impacted even when several years have elapsed since treatment end, with no effects of tumor location, type, or grade in our sample. This observation confirms, but also complements the literature, given that there are scant data concerning adult long-term survivors of PBT (5, 6, 50, 51). Social and emotional aspects of HRQoL remain significantly impacted in these patients (for the SF-36; scores on the QLQ-C30/QLQ-BN20 tended toward significance), with significant correlations for these variables between the two questionnaires. As quality of survivorship has become an additional focus in PBT care goals (3), our findings should encourage clinicians to consider socio-emotional HRQoL limitations when designing appropriate survivorship care plans.

The second research question concerned the putative impact of ToM impairment on HRQoL, especially its social/emotional components. No relationship was found between ToM



and HRQoL scores. Furthermore, patients with ToM deficits did not have lower global or social/emotional HRQoL scores. This finding was not expected, given previous results (e.g., 24, 25), although it has recently been reported in various other clinical populations (52-54). There are several possible explanations for this lack of a relationship. The first is that HRQoL questionnaires are not specifically designed to assess social deficits in everyday life, although they do include social/emotional items and are frequently used to obtain information about social functioning (38). Our primary aim was to study the harmful impact of ToM deficits on HRQoL, and not specifically on social functioning, which explains our choice of methodology. Thus, studying the expected relationship between social cognition deficits and social skills in patients with PBT represents an interesting avenue for future research, as has been done in psychiatric (e.g., 55) and neurological populations (e.g., 56).

Another possible explanation lies in the tasks we used to assess ToM. They might seem appropriate, given that they provide a comprehensive assessment of ToM as classically described in the literature, with no evidence of a ceiling effect in participants. Nevertheless, beyond the fact that they probably do not assess the same ToM processes, their validity is questionable when it comes to assessing the ability to infer others' mental states in social interactions (i.e., the very definition of ToM). Some researchers have suggested that the majority of ToM tasks fail to involve participants in a social interaction, in that they assess so-called *offline social cognition* or *third-person perspective* (i.e., ToM from an observer's point of view; e.g., 57). The call for a shift toward a *second-person perspective* approach to ToM assessment, based on social engagement from an interactor's point of view, originates from theoretical (e.g., 58), neuroimaging (e.g., 59), and empirical studies (e.g., 60) that have demonstrated differences between interactionist tasks and those in which participants remain external observers. Thus, although we suggested earlier that the Advanced ToM task can be regarded as more ecological than the Faux Pas task, it must be acknowledged that this task

does not directly include participants in social interactions. Newer ToM tasks that actively engage participants in real-life interactions with a partner (e.g., 61) may therefore correlate more closely with social/emotional HRQoL variables than the traditional tests we used in the present study. Consideration of a more ecologically valid assessment of sociocognitive ability may help to predict psychosocial and HRQoL outcomes more reliably.

Finally, it should be noted that the HRQoL data, although significantly different, are quite similar between the groups (SF-36 means). This is another plausible explanation for the lack of correlation between ToM and HRQoL in this study (see also 52).

### **Limitations**

One limitation of this study is that our sample was relatively small and heterogeneous regarding cancer type and treatment protocols. It should, however, be noted that this heterogeneity was not specific to our study and does not seem problematic for two reasons. The first is that some studies have shown that the effects of chemotherapy versus radiotherapy on cognitive functioning and HRQoL do not differ among survivors of PBT, and the addition of chemotherapy to radiotherapy has no influence on these variables (e.g., 62). Second, a recent meta-analysis (6) suggested that several years after treatment end, regardless of tumor type, HRQoL is still significantly poorer among survivors of PBT. In particular, no difference has been found between patients with meningiomas versus high-grade gliomas (glioblastomas). Thus the main objective of the present study was to explore ToM and HRQoL sequelae in adult survivors of PBT and the relationships between them, regardless of etiology. Larger studies are needed to explore more precisely the impact of tumor location, type, and grade on ToM ability, as a more detailed analysis was beyond the scope of this study. It is worth noting that our preliminary results did not point to any difference between patient subgroups for ToM and HRQoL variables (except for the EORTC QLQ-C30 physical subscale).

Another limitation is that we could have provided a more comprehensive assessment of cognitive skills, as several relationships have been demonstrated between ToM and, for example, executive functioning, episodic memory, and language ability (e.g., 63-65). For the latter, it should be noted that the ToM tests we administered included questions related to language comprehension, on which patients performed similarly to controls. In addition, patients did not differ from controls on MMSE scores, reflecting efficient global cognitive functioning.

## **Conclusion**

By demonstrating ToM and social/emotional HRQoL sequelae in survivors of PBT, this preliminary study supports the importance of ongoing monitoring of these factors in long-term follow-up. Although our results did not reveal any relationships between ToM and HRQoL, clinicians should pay close attention to these difficulties, in order to ensure optimum postcancer care, especially as some authors have found that ToM impairments are associated with poor social functioning and behavioral changes in various etiologies, such as traumatic brain injury or stroke (e.g., 66, 67). It should also be emphasized that ToM deficits are liable to increase caregiver burden and distress (e.g., 68) and negatively impact caregivers' HRQoL (69). This is an additional reason to consider these disorders in PBT survivors. This observation also applies to other neurological populations, as social cognitive impairment remains a neglected consequence of acquired brain injury (70). Future research should be directed towards further investigation of sociocognitive impairments in long-term follow-up of people with acquired brain injury, and could investigate the extent to which they have a detrimental impact on social life or community reintegration, using a more ecological assessment of social cognition.

## **Declarations of Interest and Statement**

### **Disclosure of interest**

The authors have no conflict of interest to declare.

### **Ethics approval**

The present study was performed in accordance with the principles of the Declaration of Helsinki. It received French regulatory ethical approval (Comité de Protection des Personnes Ouest II, no. 2015/27, ID-RCB no. 2015-A01192-47) and international review board authorization (no. NCT02693405). Angers University Hospital backed the study.

### **Availability of data and material (data transparency)**

The datasets generated and/or analyzed in the current study are available from the corresponding author on reasonable request, after signing a confidentiality statement and a data-sharing agreement.

### **Code availability**

Not applicable.

### **Consent to participate**

Informed consent was obtained from all the participants included in the study.

### **Consent for publication**

Participants signed an informed consent form regarding the publication of their data. Participants acknowledged that they cannot be identified via this article, and their data were fully anonymized.

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**Table 1.** Participants' sociodemographic characteristics and patients' disease information.

Characteristics	<b>Patients</b>	<b>Controls</b>
	<i>n</i> = 40	<i>n</i> = 40
	Mean	Mean
<b>Age</b> (in years)	41.20 (11.06)	40.88 (11.06)
<b>Gender</b>		
Men	28 (70)	25 (63)
Women	12 (30)	15 (37)
<b>Handedness</b>		
Left-handed	5 (12.5)	2 (5)
Right-handed	34 (85)	36 (90)
Ambidextrous	1 (2.5)	2 (5)
<b>Education</b> (in years)*	11.83 (3.29)	12.38 (2.87)
<b>Time since treatment end</b> (in years)	3.67 (2.31)	--
<b>Tumor type</b>		
Oligodendroglioma	11 (27.5)	--
Oligoastrocytoma	5 (12.5)	--
Subependymoma	1 (2.5)	--
Astrocytoma	6 (15)	--
Glioblastoma	3 (7.5)	--
Radiologically diagnosed glioma	5 (12.5)	--
Ganglioglioma	2 (5)	--
Other tumors**	7 (17.5)	--
<b>Grade</b>		
Low-grade glioma	18 (45)	--
High-grade glioma	15 (37.5)	--
Nonglioma tumor**	7 (17.5)	--
<b>Frontal lobe lesion</b>		
Yes	24 (60)	
No	16 (40)	
<b>Treatment</b>		
Tumor resection	15 (37.5%)	
Chemotherapy and radiotherapy	1 (2.5%)	
Chemotherapy and tumor resection	5 (12.5%)	
Radiotherapy and tumor resection	5 (12.5%)	
Chemotherapy and radiotherapy and tumor resection	14 (37.5%)	
<b>Epileptic seizures</b>		
No	37 (92.5)	
Yes	3 (7.5)	

*Note.* \* Number of years after first grade (elementary school). \*\* Craniopharyngioma, meningioma, medulloblastoma, neurocytoma, or germinoma. Values in brackets are standard deviations or percentages (number of patients).

**Table 2.** Scores on ToM tasks and comparison between patients and controls.

Measure	<b>Patients</b>	<b>Controls</b>	<i>p</i>	<i>d</i>
	Mean ( <i>SD</i> )	Mean ( <i>SD</i> )		
<b>Faux-Pas test</b>				
Detection (max. 4)	3.22 (1.05)	3.15 (0.9)	0.47	0.16
Cognitive ToM (max. 16)	9 (3.8)	9.1 (3.1)	0.93	0.01
Affective ToM (max. 4)	2.27 (1.1)	2.47 (1.03)	0.57	-0.12
Understanding (max. 8)	7.62 (0.7)	7.85 (0.4)	0.15	-0.32
<b>Advanced ToM task</b>				
Understanding (max. 11)	8.9 (1.6)	8.7 (1.4)	0.47	0.16
ToM (max. 22)	13.8 (4.1)	15.5 (2.4)	<b>0.04</b>	-0.47
Incorrect (max. 11)	3.4 (2.3)	2.3 (1.3)	<b>0.02</b>	0.52
Control (max. 6)	5.4 (0.8)	5.6 (0.6)	0.26	-0.24

*Note.* Between-group comparisons were performed with Mann-Whitney *U* tests. ToM = theory of mind; *SD* = standard deviation. *p* < .05 is shown in bold.

**Table 3.** Characteristics of patients impaired on ToM tasks.

Patient	Tumor type	Grade	Lesion location
1	Craniopharyngioma	WHO I	Suprasellar
3	Oligoastrocytoma	WHO II	Left frontal lobe
4	Meningioma	WHO I	Cranial base, cavernous sinus and clivus
5	Oligodendroglioma	WHO III	Right frontal lobe
6	Meningioma	WHO I	Right jugum sphenoidale
9	Oligodendroglioma	WHO I	Left frontal and temporal lobe
11	Astrocytoma	WHO III	Left frontal lobe
14	Glioblastoma	WHO IV	Right parietal lobe
15	Oligodendroglioma	WHO II	Right frontal lobe
16	Oligodendroglioma	WHO II	Right frontal lobe
21	Astrocytoma	WHO II	Left frontal lobe
26	Glioblastoma	WHO IV	Right temporal lobe
28	Oligodendroglioma	WHO III	Left frontal lobe
34	Astrocytoma	WHO I	Right lateral ventricle

*Note.* Tumor grading according to World Health Organization (WHO).

**Table 4.** Comparison between patients and controls on SF-36 and EORTC QLQ-C30/QLQ-BN20 scores (composite and social/emotional scores).

Measure	Patients	Controls	<i>p</i>	<i>d</i>
	Mean ( <i>SD</i> )	Mean ( <i>SD</i> )		
<b>SF-36 Self-report</b>	<i>n</i> = 40	<i>n</i> = 40		
PCS	28.92 (1.1)	29.49 (0.9)	<b>0.026</b>	-0.51
MCS	23.09 (1.4)	23.8 (1.37)	<b>0.023</b>	-0.52
Social functioning	71.5 (21.6)	81.2 (21.2)	<b>0.025</b>	-0.51
Role-emotional	80.8 (32.8)	83.3 (34.6)	0.54	-0.13
<b>SF-36 Observer-report*</b>	<i>n</i> = 37	<i>n</i> = 31		
PCS	28.95 (1.2)	29.5 (0.9)	<b>0.025</b>	-0.52
MCS	23.12 (1.1)	24.2 (1.1)	<b>&lt; .001</b>	-0.86
Social functioning	78.04 (18.6)	89.9 (13.4)	<b>&lt; .01</b>	-0.7
Role-emotional	83.7 (27.9)	96.7 (10)	<b>0.016</b>	-0.55
<b>QLQ-C30</b>	<i>n</i> = 40	<i>n</i> = 40		
Global health status	76.04 (17.2)	82.3 (15.1)	0.053	-0.45
Cognitive functioning	79.6 (19.4)	89.6 (17.6)	<b>&lt; .01</b>	-0.65
Physical functioning	92.8 (11.1)	98.5 (3.2)	<b>&lt; .01</b>	-0.69
Social functioning	83.75 (24.9)	91.25 (23.3)	0.08	-0.4
Emotional functioning	74.8 (21.7)	82.5 (17.8)	0.09	-0.38
<b>QLQ-BN20</b>	<i>n</i> = 40	<i>n</i> = 40		
Communication deficit	19.7 (16.4)	13.9 (16.1)	0.07	0.4

*Note.* Between-group comparisons were performed with Mann-Whitney *U* tests. ToM = theory of mind; PCS = physical component score; MCS = mental component score; *SD* = standard deviation. \* Fewer participants, owing to missing data from proxies. *p* < .05 is shown in bold.



**Table 5.** Correlations between ToM/HRQoL scores and HRQOL variables associated with social/emotional functioning in patient group.

	Faux Pas test			Advanced ToM task		QLQ-C30/QLQ-BN20		
	Detection	Cognitive ToM	Affective ToM	ToM	Incorrect	EF	SF	CD
<b>SF-36 Self</b>								
Social functioning	-0.004	0.03	-0.04	-0.09	0.01	0.57***	0.3	-0.5***
Role-emotional	0.001	0.11	0.25	0.06	-0.09	0.2	0.35*	-0.08
<b>SF-36 Observer</b>								
Social functioning	0.13	0.11	-0.08	-0.07	0.02	0.26	0.47**	-0.32
Role-emotional	-0.31	-0.2	-0.32	0.15	-0.15	0.2	0.05	0.06
<b>QLQ-C30</b>								
EF	0.12	0.01	0.03	-0.03	-0.04	-	-	-
SF	0.14	0.24	0.12	0.12	-0.21	-	-	-
<b>QLQ-BN20</b>								
CD	-0.12	-0.18	-0.13	0.1	-0.05	-	-	-

*Note.* Spearman rank-order correlations were used to study relationships between variables.

EF = emotional functioning; SF = social functioning; CD = communication deficits. \*  $p < .05$ .

\*\*  $p < .01$ . \*\*\*  $p < .001$ .