Theory of mind deficits in patients with acquired brain injury: a quantitative review

Juan Francisco Martín-Rodríguez[1, 2]

José León-Carrión[2, 3]

[1] Biomedicine Institute of Seville (IBiS), Spain

[2] Center for Brain Injury Rehabilitation (C.RE.CER.), Seville, Spain

[3] Human Neuropsychology Lab, Department of Experimental Psychology University of Seville, Spain

Corresponding author:

Juan Francisco Martín-Rodríguez
C.RE.CER. C/Torneo, 23
Phone: +34 95 457 4137 Fax: +34 95 437 4558
e-mail: idi@neurocrecer.es
41002 Seville, Spain

Abstract

Impaired theory of mind (ToM) reasoning is considered an underlying cause of social cognition deficits in patients with acquired brain injury (ABI). However, the literature does not agree on the severity of ToM impairment in this clinical population, nor does it coincide on the proper tools for its assessment. In this paper, we use a meta-analytic approach to review 26 studies which compare the performance of ABI patients and healthy controls in four widely-used ToM tasks: first-order belief task, second order belief task, understanding indirect speech (IS) and social faux pas. Overall, patients show moderate to severe ToM impairment. The latter appears in faux pas (effect size = 0.70) and understanding IS tasks (ES = 0.87), while moderate impairment can be seen in second-order (ES = 0.60) and first-order belief tasks (ES = 0.52). The severity of ToM impairment was influenced by ratio of patients with frontal lobe lesion, ratio of patients with right hemisphere injury, type of belief task, and heterogeneity of the sample's etiology. Our results provide important quantitative evidence on the severity of ToM deficits in the ABI population, while identifying variables that influence these deficits. Implications for basic and clinical neuropsychology are discussed.

Keywords: social cognition, frontal lobe, right hemisphere, belief tasks, indirect speech, faux pas

1. INTRODUCTION

There is a growing interest in social cognition deficits following acquired brain injury (ABI). Research shows that patients who have suffered an ABI may exhibit lower empathy (Shamay-Tsoory, Tomer, Goldsher, Berger, & Aharon-Peretz, 2004), social isolation (Lezak, 1995), difficulty understanding sarcasm and irony (Shannon et al., 2005; Martin & McDonald, 2005), little social competence (Spatt, Zebenholzer, & Oder, 1997), poor talkativeness and social insight, and maladjusted emotional expressions (Santoro & Spiers, 1994). Any of these deficits may be due to impaired social information processing. In many cases, social cognition deficits after ABI may be more incapacitating than other cognitive deficits, placing a great burden on patients' relatives and caregivers (Koskinen, 1998). Furthermore, patients with social deficits have greater difficulty adapting to their return to community (Grattan & Ghahramanlou, 2002; Leon-Carrion, Taaffe, & Barroso y Martin, 2006), and to their rehabilitation process (Yates, 2003).

Some authors have postulated that impaired theory of mind (ToM) reasoning may underlie social cognition impairment in ABI (Stuss, Gallup, & Alexander, 2001; Stone, Baron-Cohen, & Knight 1998; Milders, Fuchs, & Crawford, 2003; Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003). According to Baron-Cohen (2000), ToM is the ability to infer or reflect on the content of one's own and other's mental states. This content could be associated with beliefs, intentions, emotional states, etc. Patients who have suffered an ABI tend to fail tasks that require reasoning on others' mental states. As a result, ToM has been considered a good predictor of social behavior deficits.

ToM appears to be a multidimensional function and thus, different tasks have been designed for its assessment. Most of these tasks stem from normal and clinical

Child Psychology, and have been adapted for assessing adults with ABI. Belief reasoning tasks, considered the key ToM test (Stone, 2006), are the most widely used to assess ABI. They require subjects to infer someone else's knowledge state (e.g. 'Peter thinks that object A is in location 1'), be it real (true belief) or not (false belief). These are known as first order ToM tasks (FOTOM; Dennett, 1978; Wimmer & Perner, 1983). In the ontogenesis of ToM, at age four, children are able to pass this task, whereas younger children cannot. A more complex belief reasoning task requires the subject to identify embedded mental states, known as second order ToM (SOTOM) task (e. g. 'Peter thinks that Mary thinks that object A is in location 1'). The complexity of this task is seen when children at age 6 pass the task by being able to understand that a character can have beliefs regarding others' beliefs, whereas younger children cannot (Perner & Wimmer, 1985).

ToM tasks of greater complexity, including those that demand more pragmatic ToM abilities, have also been used to assess neurological patients. For instance, Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall (2006), assessed ToM using a non-verbal task in which the patient was asked to infer a character's intention based on a previous character's actions. This kind of task requires well-consolidated first-order ToM abilities as well as more complex mental inferences, and includes richer social scenarios than the tasks previously described. Other tasks which assess more advanced use of ToM inference (McDonald & Flanagan, 2004) include understanding indirect speech (IS) and the detection of social faux pas. These tasks, mostly language-based, assess the ability to comprehend inferences that arise from language in social settings. Another distinctive feature of these tasks is the involvement of emotional information (Stone, Baron-Cohen & Knight, 1998; Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005a).

Understanding IS tasks (assess understanding irony, sarcasm, metaphors, or jokes) are used to assess ToM because in order to represent other's mental states to understand or effectively. An example of ToM involvement in IS is the SOTOM ability of understanding sarcasm (Winner and Leekman, 1991). However, other studies identified factors other than ToM as contributing to the correct understanding of IS, namely executive functions (Channon & Watts, 2003), or general inference (Martin & McDonald, 2005). Children aged 7-9 are able to understand IS while younger children have difficulty with its comprehension (Dews et al., 1996).

The detection of social *faux pas* (Stone, Baron-Cohen, & Knight, 1998) is another task widely used to assess pragmatic ToM in patients with ABI. In this task, the patient must recognize when someone says the wrong thing without realizing that they should not say it. This task includes questions that inquire into the emotional state of the character that commits the faux pas. Hence, the task assesses cognitive as well as emotional aspects of ToM. Children are able to pass this task between the ages of 9 and 11.

Each of these ToM tasks, from FOTOM and SOTOM to the more pragmatic IS and faux pas tasks, place increasing demands on ToM ability, making successive tasks more difficult. ToM development shows a fixed and universal sequence of reasoning abilities (Wimmer & Perner, 1983; Leslie, 1987; Avis & Harris, 1991). It would thus seem plausible to use them to assess the severity of ToM deficits in adult patients with ABI and detect deficits in patients who can only pass low-level ToM tasks. This hypothesis was first suggested by Stone, Baron-Cohen, & Knight (1998), followed by other authors (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Shaw et al., 2004). The fact that an individual can pass lower-level ToM tasks but fails higher-lever ones has been observed in schizophrenia and the autistic spectrum (Apperly, Samson & Humphreys, 2005).

Saxe (2006) proposes three different brain areas as the basis for ToM: prefrontal cortex (PFC), the posterior cingulate cortex, and the bilateral temporo-parietal junction (TPJ). Although these three areas are consistently activated in neuroimaging studies involving basic ToM tasks (Fletcher et al., 1995; Saxe & Kanwisher, 2003; Ruby & Decety, 2003), their specific contributions remain unresolved. Neuropsychological data supports the role of these areas as necessary for mentalizing. Patients with highly selective frontal lobe lesions (Rowe, Bullock, Polkey, & Morris, 2001), anterior capsulotom that interrupt neural pathways between frontal lobe and subcortical nuclei (Happé, Malhi, & Checkley, 2001), or selective temporo-parietal junction damage (Samson, Apperly, Chiavarino, & Humphreys, 2004) show ToM impairments. Saxe (2006) suggests that right TPJ is engaged in achieving a representation of others' mental states, while medial PFC aids with the simultaneous management of different mental representations. During this process, medial PFC may implement inhibitory processes when mental contents do not coincide. Similarly, other models suggest that more posterior cerebral regions are involved in the representation of self and others' mental states, while more anterior regions are primarily in charge of applying and controlling the process of "mentalizing" (Abu-Akel, 2003).

Another neuroanatomical issue--the roles of left and right hemispheres in ToM reasoning--has been addressed using neuropsychological methodology. While the right hemisphere (RH) has traditionally been linked to social cognition (Happé et al., 1999; Ruby & Decety, 2001), neuroimaging studies commonly show activation in the left hemisphere (LH) during this sort of task (e.g. Fletcher et al., 1995). Other studies have also found ToM deficits in patients with unilateral LH lesions (Channon and Crawford, 2000; patients vs. healthy controls comparison). However, LH patient performance did not differ from that of RH patients (e. g. Shamay-Tsoory, Tomer, & Aharon-Peretz, 2005b; faux pas comparison).

ToM research on patients with ABI has several advantages over functional neuroimaging studies. Brain lesion analysis offers a more accurate method for studying the role of brain areas necessary for ToM reasoning (Bird, Castelli, Malik, Frith, & Husain, 2004). However, patients should be specifically recruited to test research hypotheses, and lesions should be confined to well-defined brain locations. The use of heterogeneous ABI groups in ToM studies (e.g., different etiology, disparate severity), may dissipate the differences reported in the literature, inasmuch as this increases the variability of estimating cognitive performance in these patients. ToM studies which include persons with traumatic brain injury (TBI) may be biased given that these patients typically show more diffuse brain lesions (especially in cases with diffuse axonal injury) and greater severity of brain damage, as compared to other types of ABI.

This study aims to investigate the extent of ToM impairment reported in the literature on ABI. Using meta-analysis, we examined two issues. Firstly, do patients with ABI show impaired ToM abilities? Although ToM deficits have been reported throughout the existing literature, some studies show no differences, or even better performance, in ABI patients as compared to healthy controls (see Martin & McDonald, 2006 - first order ToM task; Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005a –second order ToM task). Secondly, if ToM abilities are indeed impaired, what is the severity of this impairment?

Our meta-analysis also investigated associated factors which could explain the differences in ToM performance between studies. These potential moderator variables were selected from published studies, and included factors that may affect effect sizes.

The variables are related to the samples' demographic features, the task and material used to assess ToM, and other variables related to the etiology and location of the brain damage. The purpose of using meta-analysis in this area of research was to overcome possible weaknesses of qualitative reviews, namely, listing controversial findings, relying on the result of a single study, or ignoring the effect of moderator variables on the reported findings (Rosenthal & DiMatteo, 2001).

2. METHODS

2.1. Literature Research and Study Selection

We searched the MEDLINE and PsychINFO databases using the keywords "theory of mind" [AND] "brain injury", "theory of mind" [AND] "brain damage", and "theory of mind" [AND] "head injury", from January 1995 to June 2008. Only studies conducted on adult ABI population were selected. Studies considered eligible were empirical studies written in English and published in peer-reviewed journals. Clinical samples were limited to ABI patients who had suffered brain injury in adulthood. Studies including patients with neurodegenerative diseases were not selected, given that accepted definitions for ABI generally exclude this type of brain injury (mainly because of differential disease development and the difficulty in establishing brain injury onset (Leon-Carrion, 2002). Finally, only studies that compared patients' ToM performance with healthy controls were considered.

Single and group case studies were excluded from the analysis. Studies had to include both means and standard deviations or sufficient statistical information (*t*, *F*, *X*, *Z*-scores or *p*-values) to calculate effect sizes. Only studies that used FOTOM, SOTOM, understanding IS and detecting faux pas tasks to evaluate ToM abilities were included in our meta-analysis. Other tasks, such as character intention (see Sarfarti et al., 1997; used on ABI population in Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall, 2006), were excluded because of their scarce appearance in the literature. These tasks require the subject to infer the final character's behavior based on the contextual information that precedes it. Although they require FOTOM abilities, the scenario usually provides a richer amount of information to infer the final character's behavior than classic FOTOM tasks (e. g. object transfer tasks). Based on this we decided not to include these tasks in FOTOM.

In their meta-analysis on ToM in schizophrenia, Sprong, Schothorst, Vos, Hox, & Engeland (2007) included character intention tasks as an independent task category, consisting of seven effect sizes. However, we could only find two studies (Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall, 2006; Channon et al., 2007), which used this kind of task. The 'eyes task', where the subject has to infer mental states from looking at a picture of eyes, was not included given the low number of studies that used it (we identified only two: Milders, Fuchs, & Crawford, 2003; Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall, 2006). Finally, metaphor comprehension tasks, which may be included in the understanding IS task category, were not analyzed because this type of task has been shown to have little relation to intact ToM abilities or other IS tasks, and comprehension depends on the subject being familiar with the metaphor (Channon & Watts, 2003; Langdon & Coltheart, 2004).

The filters for our reserach identified twenty-six studies. Thirteen studies used FOTOM tasks to assess ToM, thirteen used SOTOM, twelve used IS, and seven used faux pas. Within each task, non-overlapping participant samples were included. To determine this, we compared sample sizes, demographics and clinical factors (site of lesion, type of injury) as well as effect sizes. If a case needed clarification, we tried to contact the corresponding author directly. One study was excluded (Milders, Ietswaart, Crawford, & Currie, 2008), because data concerning certain participants had been reported by the same authors in a previous paper (Milders, Ietswaart, Crawford, & Currie, 2006). Sample characteristics (*n* of patient sample, demographics, year of publication and lesion site groups) were similar in two studies by Shamay-Tsoory and colleagues (Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005a; and Shamay-Tsoory, Tomer & Aharon-Peretz, 2005b). We selected Shamay-Tsoory et al. (2005b) because of its higher sample size. Table 1 displays the studies included in the current meta-analysis, as well as the number of ABI patients and healthy controls in each study.

Insert Table 1

2.2. Calculation of effect sizes (ES)

In each ToM task, the number of correct responses was used as an indicator of ToM performance for both patient and healthy control group. In FOTOM and SOTOM tasks, correct responses included correctly inferring the main character's mental state (FOTOM), or a character's mental state regarding another character's mental state, and holding these characters' belief as false or not. These mental states include belief, desires, or intentions. In understanding IS tasks, correct non-literal message comprehension was used as an indicator of ToM performance. In faux pas tasks, the correct identification of who said/did something awkward (detection of faux pas), why it was a faux pas (epistemic attribution), and the emotional state of the characters after committing a faux pas (affective attribution) were recorded. In accordance with Baron-Cohen, O'Riordan, Stone, Jones, and Plaisted (1999), a single faux pas performance, combining the correct responses to these three questions, indicated sound ToM abilities. Faux pas measures did not include control conditions that assessed task memory-load or non-mental inferences. Other indicators, such as number of errors or time to complete the task, were excluded due to their limited use in the literature.

Cohen's *d* (Cohen, 1988) was used to standardize the mean difference in ToM performance between ABI patients and demographically-matched healthy controls. In this calculation, a positive value indicated worse performance in the patient group. The ES measure is based on the difference between means, divided by the pooled standard deviation of both groups:

$$d = (mean_{\text{healthy controls}} - mean_{\text{ABI patients}})/SD_{POOLED}$$

Where $SD_{POOLED} = \sqrt{\frac{(n_{controls}-1)\,SD^2_{controls} + (n_{ABI}-1)\,SD^2_{ABI}}{n_{controls}+n_{ABI}-2}}$

For studies which provided *Z*-scores, *d* was calculated using the formula $d = \frac{2Z}{\sqrt{N}}$, where *N* is the sample size of ABI and control groups combined. For studies that provided *t* values, Cohen's *d* was calculated using the following formula: $d = \frac{2t}{\sqrt{df_{error}}}$ (Rosenthal, 1994). Hedges' *d* correction was applied to Cohen's *d* with the aim of obtaining an unbiased estimator (Hedges & Olkin, 1985). Each Cohen's *d* was then weighted according to the study inverse variance following Hedges' recommendations (Hedges, 1981).

2.3. Moderator variable coding

In accordance with our research goals, a number of moderator variables were coded and further analyzed, with the aim to significantly explain part of the heterogeneity between the results of the studies. These variables were classified as demographic, task-related or clinical.

The *demographic* coding included age, gender distribution, and differences in education level between patients and controls. Gender representation was coded as a difference in male distribution between samples. These demographic variables were coded as zero if data in one or both groups was missing/unavailable. However, the study reported no statistical differences between patients and controls.

Task-related coding began with FOTOM and SOTOM, which may require the subject to infer true or false beliefs and place different demands on ToM abilities. Hence, we divided the effect sizes for FOTOM and SOTOM into true belief task group (FOTBT and SOTBT) and false belief task (FOFBT and SOFBT), depending on whether the task demanded inference of a real mental state or not. A second task-related coding was based on whether the task is administered verbally or non-verbally. Verbal ToM tasks consisted of stories and passages describing a scenario, while non-verbal tasks included pictures and cartoons without verbal information to help understand them.

Finally, three *clinical* moderator variables were coded. 1) Studies where patients shared the same etiology were included in the "homogeneous etiology group" (e. g. Milders et al. [2006], where all patients had suffered a traumatic brain injury; or Happé, Brownell, & Winner [1999], that included only patients with stroke). The remaining studies were assigned to the "heterogeneous etiology group". 2) The proportion of patients with frontal lobe lesion was calculated for each study. Lesions could either be confined to frontal lobes (documented via traditional neurodiagnostic techniques--MRI or CT) or be frontal lobe but with other smaller lesions located elsewhere in the brain. The coding of this variable was based on clinical descriptions from different authors. When available, patient classification as 'frontal' or 'non-frontal lesion' was based on direct interpretation of MRI/CT figures. Frontal lesions extending to the basal ganglia were excluded. 3) The proportion of patients with lesion exclusively in the right hemisphere was coded based on the same sources used in frontal lobe coding.

The two authors of this paper coded each study independently. The coding of certain characteristics was complex, especially quantitative moderator variables (namely, 'ratio of patients with frontal lobe lesions' and 'ratio of patients with right hemisphere lesions'). In order to assess the appropriateness of this complex coding, we carried out a coding reliability study, analyzing a random study sample (20% of total studies). Inter-rater reliability was analyzed using Pearson's correlation coefficient for quantitative variables and Cohen's kappa coefficient for qualitative variables. The agreement level attained for all coded variables--around 90% on average--was highly satisfactory. Inconsistencies between the coders were resolved by consensus. Finally, we contacted corresponding authors directly if data was needed to complete moderator variable coding.

2.4. Meta-analytic methods

All analyses were performed using software from *Comprehensive Meta-Analysis Version 2* (Borenstein, Hedges, Higgins & Rothstein, 2005) and SPSS meta-analysis macros (available at http://mason.gmu.edu/~dwilsonb/ma.html), developed by Wilson (2005). The random-effects model was used on all analyses. Four independent meta-analyses were performed, one for each ToM task (FOTOM, SOTOM, understanding IS and faux pas).

One study assessed ToM abilities using two variants of FOTOM task (FOTBT and FOFBT); four studies used two variants of the SOTOM tasks (SOTBT and SOFBT) (Winner, Brownell, Happé, Blum, & Pincus, 1998; Martin and McDonald, 2005; Igliori and Damasceno, 2006; Martin and McDonald, 2006). In order to guarantee the independence assumption among ESs, a unique estimate was calculated. The arithmetic mean between ESs was calculated (Marascuillo, Busk, & Serlin, 1988), given that the correlation structure of these effects could not be obtained in most studies.

For the four meta-analyses, each ES was weighted based on the inverse variance method, where weight is computed as the inverse of the squared standard error (Lipsey &Wilson, 2001). In order to estimate the variability of *d*, a 95% confidence interval (CI) was calculated around each ES. This interval was also used to test whether ESs were significantly different from zero. A heterogeneity test (Hedges & Olkin, 1985) was included for each meta-analysis using the following formula:

$$Q = \sum w_i(\Theta_i - \hat{\Theta}_i)^2$$

Where $(\Theta_i - \hat{\Theta}_i)^2$ is the squared distance from each study to the combined effect weighted by the inverse variance method. Sources of heterogeneity were investigated by performing sub-group analysis and weighted linear regression analysis (Higgins and Green, 2008). We arbitrarily set a minimum of three eligible studies for sub-group analysis comparison.

Lastly, we conducted a study on publication bias, given that our meta-analysis did not include unpublished studies. A fail-safe number was computed using Rosenthal's approach (1979): this method calculates the number of unreported and/or unretrieved studies averaging null results which are necessary to bring the result of the meta-analysis to non-significance. This calculation is known as tolerance level. Tolerance levels > 5*k* +10, where *k* is the number of studies included in each meta-analysis were considered resistant to publication bias.

3. RESULTS

3.1. Main results

A relatively high number of patients were included in the analyses, from *n* = 173 in faux pas task to *n* = 354 in SOTOM. Healthy controls ranged from *n* = 142 in faux pas to *n* = 326 in SOTOM. Table 2 shows the demographics for both ABI patients and healthy controls in the four ToM tasks.

Figure 1 forest plots display mean weighted ESs for each ToM task. All ESs were significantly different from zero based on 95% CI (all *P*s < 0.01). The ESs indicate moderate to large deficits in ToM abilities. The lowest ESs corresponded to FOTOM (unbiased *d* = 0.52), followed by SOTOM (unbiased *d* = 0.60) and faux pas (unbiased *d* = 0.70). The highest ESs pertained to understanding IS (unbiased *d* = 0.87). According to CI for mean effect sizes, all comparisons overlapped between tasks. Percentage of overlapping between CIs ranged from 18% (FOTOM vs. Understanding IS), to 75% (FOTOM vs. SOTOM).

Shamay-Tsoory et al's research contributed 2 ESs to FOTOM, 3 to SOTOM, 2 to IS and 2 to faux pas, hence our concern that a bias from this research could affect our results. A random effect model was repeated without these studies, resulting in a combined ES (95% CI) of 0.59 (0.18-0.99) in FOTOM, 0.74 (0.45-1.03) in SOTOM, 0.91 (0.69-1.14) in IS, and 0.69 (0.34-1.03) in faux pas. According to 95% CI overlapping, this data does not support the existence of an author bias.

For FOTOM, 186 studies averaging null results would be necessary to bring *P* to non significance (*P*< 0.05); 235 would be needed for SOTOM, 241 for IS and 112 for faux pas. According to Rosenthal (1979), these fail-safe numbers would be resistant to sampling bias.

3.2. Moderator variable analyses

Homogeneity among ESs was found in both faux pas (*Q*= 6.12; *P*= 0.41), and understanding IS (*Q*= 11.31; *P*= 0.33). Significant tests of heterogeneity were observed in both FOTOM (*Q*= 39.33; *P*< 0.001), and SOTOM (*Q*= 31.18; *P*< 0.01). To account for this heterogeneity, moderator variable analysis was performed.

3.2.1. Demographic moderator variables

Weighted regression analysis did not show any relationship between ESs. No differences were observed between patients and control group in age, gender representation and education level (all *P*s> 0.05). Table 3 shows the impact of these variables on ESs.

3.2.2. Task-related moderator variables

Six ESs were included in the FOFBT analysis; seven comprised each FOTBT, SOTBT, and SOFBT analyses. For FOTBT, the weighted effect size (95% CI) was 0.35 (0.143-0.556; $P<0.01$). According to Cohen (1988), this effect size is small. FOFBT, in turn, showed an effect size of 0.72 (0.423-1.02; $P<0.0001$). SOTBT showed a weighted effect size of 0.55 (0.35-0.75; $P<0.0001$), whereas SOFBT showed 0.66 (0.48-0.88; $P<0.0001$).

ToM tasks were divided into two groups, depending on whether they used verbal or non-verbal assessment material. In FOTOM, seven studies used verbal and six used non-verbal material. Group comparison did not show statistically significant differences ($P= 0.14$) between verbal and non-verbal material (verbal, $d = 0.65$, 95% CI = 0.38-0.93; non-verbal, $d = 0.53$, 95% CI = 0.20-0.86). In SOTOM, nine studies used verbal material, one study used non-verbal material, and four used a mix of verbal and non-verbal material. An analysis of task sub-type was not performed for SOTOM given that the number of ESs reported for non-verbal tasks ($k = 2$) may not be representative of the real differences between ABI and control populations. All IS and faux pas studies used verbal material, therefore a further analysis of task sub-type was not possible.

3.2.3. Clinical moderator variables

Homogeneity of the etiology of brain damage

Two groups were created and effect sizes were assigned depending on the homogeneity of patient etiology sample. For FOTOM, seven studies were assigned to the "homogeneous etiology group". The remaining studies were assigned to the "heterogeneous etiology group" (k = 6). In this task, the heterogeneous group showed larger effect size than the homogeneous group (heterogeneous group's d = 0.686; homogeneous group's d = 0.391). This difference was statistically significant (P< 0.0005). Similarly, the heterogeneous group performed significantly worse than the homogenous group in the SOTOM task (P for this comparison = 0.003; heterogeneous group's k = 7, d = 0.755; homogeneous group's k = 7, d = 0.452). In IS (heterogeneous' k = 6; homogeneous' k = 5) and faux pas (heterogeneous' k = 4; homogeneous' k = 3) tasks, differences in effect sizes between heterogeneous and homogeneous etiology were not significant (Ps > 0.33).

The proportion of patients with TBI was calculated for each study and entered into a weighted regression analysis. This was done to test whether this proportion was associated with differences in ToM performance among samples reported throughout the literature. The mean proportion of TBI was 0.48 in FOTOM studies, 0.48 in SOTOM, 0.58 in understanding IS, and 0.25 in faux pas. No association between this variable and ES was detected with the exception of faux pas, which showed a positive association that tended towards signification (P< 0.1) (Table 3).

Ratio of patients with frontal lobe lesions

Lesion location data was not available for one study included in the SOTOM analysis (Turkstra, Dixon, & Baker, 2004). In FOTOM, weighted regression analysis showed that the proportion of frontal lobe patients (mean proportion = 0.61) did not fully explain the effect size heterogeneity (P = 0.33). Similarly, the proportion of frontal lobe patients (mean proportion = 0.60) could not explain the variability in SOTOM (P = 0.49).

In accordance with our research objectives, two other analyses were performed including IS and faux pas effect sizes. The proportion of frontal lobe patients from one faux pas study was obtained upon request from the corresponding authors (Milders, Fuchs, & Crawford 2003). The mean for *proportion of frontal lobe patients* was 0.51 for IS and 0.41 for faux pas. No association was found between this variable and ES in IS. Table 3 shows that this variable predicted faux pas ESs (P = 0.02), indicating that effect size increases as number of patients with frontal lobe lesions increases.

Ratio of patients with right hemisphere lesions

Data on hemispheric lesion location was not available for one SOTOM study (Turkstra, Dixon, & Baker, 2004), and one faux pas study (Milders, Fuchs, & Crawford 2003). Proportion of right hemisphere patients were 0.56 for FOTOM, 0.49 for SOTOM, 0.55 for IS, and 0.36 for faux pas. ESs for FOTOM and SOTOM were not associated with this variable. Nevertheless, regression analyses showed that this variable was associated with ES in both IS (P< 0.01) and faux pas (P= 0.04) (Table 3).

4. DISCUSSION

The results of this meta-analysis showed moderate to severe impairment in ToM reasoning among patients with ABI. The highest effect size was observed in understanding IS, followed by faux pas, SOTOM, and finally FOTOM; yet there was extensive overlapping among confidence intervals associated with these effect sizes. Statistical analysis did not support the existence of author bias on ESs. A large fail-safe number was obtained for each task. Our research did not support the existence of publication bias in the meta-analyses.

Homogeneity tests showed heterogeneity in effect sizes for FOTOM and SOTOM. However, mean ESs for understanding IS and faux pas could be considered good estimates of typical standard differences in the ABI population. Moderator variable analyses showed that demographic variables (differences in age, gender and education level between samples) did not significantly affect effect sizes. This lack of influence has also been observed in schizophrenia (Sprong, Schothorst Vos, Hox, & Engeland, 2007). These authors interpret their results as a robustness of ToM impairment. However, the demographic variables we studied do not cover the many variables related to outcome following ABI. While our selection of variables was based on availability in the literature, other factors (e. g. premorbid IQs, time since brain injury) may also be significant moderator variables for ToM impairment. Nevertheless, we could not analyze other variables due to the limited information provided in the literature.

In our task-related moderator variable analysis, the use of false belief task to assess ToM increased FOTOM and SOTOM ESs considerably (at least at descriptive level), especially in first order ToM tasks. However, the ESs between tasks did not differ significantly based on the overlapping between their 95% CIs. The analysis of the use of verbal and non-verbal ToM tasks was limited to FOTOM, given that the other tasks included a minimal number of non-verbal tasks. The FOTOM analysis showed no differences between mean ESs for both verbal and non-verbal tasks.

Other moderator variables included heterogeneity of ABI etiology, which affected effect sizes in FOTOM and SOTOM. Studies on patients with varying etiologies reported significantly higher differences than those using homogenous etiological samples. Nevertheless, no differences were found between etiology groups in understanding IS and faux pas. In addition, weighted regression analysis showed no effect on the proportion of TBI patients in the samples, except for faux pas, which showed a significant trend. Studies with more patients with frontal lobe lesions reported higher ESs in faux pas tasks. Finally, the proportion of right hemisphere patient variables were positively associated with ESs in IS and faux pas.

According to the existing literature, patients with ABI show significantly impaired ToM abilities when assessed using these four tasks. This meta-analysis allowed us to test the severity of ToM impairment using the hierarchy of ToM tasks hypothesis. This hypothesis derives from reports that certain disorders show impairment in skills developed later in life, such as IS understanding or social faux pas, whereas skills developed earlier remained unaltered or showed little impairment (Stone, Baron-Cohen, & Knight, 1998; Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999; Brüne, 2003). Based on ES magnitude, our results do not support this hypothesis: ABI patients showed moderate FOTOM and SOTOM impairment, while understanding faux pas, hypothesized to be the most impaired skill (as they are the latest to develop), showed less impairment than understanding IS . One explanation for these results could come from the selection of ToM tasks. The fact that FOTOM and SOTOM, which include very diverse tasks, showed heterogeneity among ESs questions the representative nature of our task categorization. One possible explanation for this heterogeneity could be that the use of true and false belief reasoning moderated the ESs. Patients showed more ToM deficits when performing false belief tasks, where they must attribute a false belief to someone else.

Neuroimaging studies have shown that true and false belief reasoning involve different brain regions (Sommer, Döhnel, Sodian, Meinhardt, Thoermer, & Hajak, 2007). The fact that patients with ABI find false belief tasks more difficult could have several explanations. Bloom and German (2000) argue that true belief tasks could be completed by basing the reasoning on the actual state of affairs. Therefore, these tasks may not be valid for assessing ToM since they can be solved through logical, inferential reasoning. Indeed, patients failed false belief tasks more frequently, where they must infer a protagonist's mental state, which does not match the state of affairs. However, passing false belief tasks may require abilities other than ToM (Bloom & German, 2000), such as executive inhibition of irrelevant or prepotent responses.

We also explored whether the use of verbal and non-verbal tasks could help explain this heterogeneity. Patients performed the same on verbal and non-verbal tasks in all four ToM . It would be reasonable to think that patients would find verbal tasks more difficult than non-verbal tasks, given the high prevalence of language impairment, at least in TBI (Tennant, McDermott, & Neary, 1995) and stroke (Tatemichi et al., 1994). However, neuropsychological studies have reported that when verbal demands are controlled, patients show significant TOM impairments in non-verbal tasks (Stone, Baron-Cohen, & Knight, 1998; Samson, Apperly, Chiavarino, & Humphreys, 2004; Apperly, Samson, Chiavarino, & Humphreys, 2004). These findings suggest that ToM impairment may not be affected by language deficits, as observed in other conditions such as schizophrenia (Sprong, Schothorst, Vos, Hox, & Van Engeland, 2007).

Based on our analysis, patients showed moderate impairment in faux pas, and severe impairment in understanding IS tasks. These tasks demand reasoning on mental states in complex social situations, which may require higher or more sophisticated ToM abilities. In order to pass both tasks, the subject must be able to represent different mental states, an ability shared with SOTOM tasks (Winner & Leekman, 1991; Winner, Brownell, Happé, Blum, & Pincus, 1998; Stone, Baron-Cohen & Knight, 1998, Gregory et al., 2002, Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005a). The extensive overlapping between mean ES confidence intervals in our study supports this relationship. However, according to McDonald and Flanagan (2004), subjects performing these high-level ToM tasks must infer the mental content of verbal and non-verbal behavior that arises in specific social interactions between characters. Subject reasoning must infer beliefs, intentions and emotions within a certain social context to understand the task. This has led authors to categorize these tasks as 'applied use of ToM inferencing' (McDonald & Flanagan, 2004) or 'ToM pragmatics tasks' (Baron-Cohen, 2000; Channon et al., 2007).

However, it may be that impairment in more advanced ToM abilities is a consequence of alterations in other skills apart from 'pure' ToM reasoning. For instance, Martin & McDonald (2005) failed to find any association between basic ToM tasks and irony. These authors reported a sound relationship between general inference and irony comprehension, while other studies (Channon and Watts, 2003) identified different factors contributing to understanding IS (e.g. executive functions) or affective processing (Shamay-Tsoory, Tomer, & Aharon-Peretz, 2005). Likewise, faux pas detection has been associated with both executive functions and affective processing (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Bird, Castelly, Malik, Frith, & Hussain, 2004).

According to Stone, Baron-Cohen & Knight (1998), Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz (2005a), and Shamay-Tsoory, Tomer, & Aharon-Peretz (2005b), in order to detect the faux pas, the subject must be able to integrate both cognitive and affective information, where empathy seems to play a fundamental role (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003). Although certain studies point to interdependence between executive functions and empathy in more advanced ToM tasks, the proximity between brain areas responsible for these functions should be also considered (namely dorsolateral prefrontal, ventromedial prefrontal and orbitofrontal cortices), given that lesions in these areas may coexist, especially in TBI. It would therefore seem logical that future studies use these new ToM tasks to investigate the conditions which control the use of executive and affective information in ToM reasoning, while including patients with very specific brain lesions. New approaches can already be seen in the most recent literature (e. g. Shamay-Tsoory, & Tibi-Elhanany, 2006; Shamay-Tsoory, & Aharon-Peretz, 2007b).

Although our data does not support the existence of a hierarchy in adult patients with ABI, other methods should be considered to test this hypothesis. One possibility would be to assess ToM in a homogenous patient sample using the four tasks presented here. According to our hypothesis, patients would perform worse in faux pas, and then in IS, SOTOM and finally, FOTOM. Another study could include adult patients who suffered brain damage in the early stages of their lives, and observe whether damage during childhood and adolescence is related to adult performance in ToM tasks.

ToM is a multidimensional construct. The few differences found among these tasks may suggest that they do not assess the same construct, at least not in the human adult. The similarities found among effect sizes have also been observed in a recent meta-analysis on schizophrenia (Sprong, Schothorst, Vos, Hox, & Van Engeland, 2007). However, the lack of correlation analyses on ToM task performance restrained the current study from testing this hypothesis. Another explanation might be that the method used to group studies was not correct. The heterogeneity in FOTOM and SOTOM may dissipate actual differences in ToM between ABI and control populations. This is also apparent in the wide confidence intervals these tasks showed and the subsequent overlapping of IS and faux pas data. The fact that both FOTOM and SOTOM showed significant effect size heterogeneity, where faux pas and understanding IS tasks did not, may also be due to the task format used to assess first and second order ToM reasoning. Faux pas and understanding IS tasks show a more consistent task format, usually with written passages.

The source of ToM impairment in the ABI population is discussed extensively in the literature. Some studies propose that ToM abilities rely on dedicated functional and neuroanatomical mechanisms. Certain evidence points to the modular nature of ToM abilities, which may be impaired, while other functions remain intact (Baron-Cohen, Lesley, & Frith, 1985; Happé, 1994), or preserved, while other functions are affected (Karmiloff-Smith, Klima, Bellugi, Grant, & Baron-Cohen, 1995). Moreover, reasoning on mental states is considered independent from reasoning on physical experiences or general intelligence abilities (Baron-Cohen, Ring, Moriarty, Shmitz, Costa, & Ell, 1994). Cross-cultural studies have found that ToM abilities are present in many different cultures (Avis & Harris, 1991), while in every culture a fixed developmental pattern can be predicted (Wimmer & Perner, 1983; Leslie, 1987). However, the modular nature of ToM is still open to debate, and its total independence from other psychological functions, such as executive functions, is not fully established (Perner & Lang, 1999).

Patients sustaining an ABI may fail ToM tasks given that they usually show impairment in other, more general (non-mental) cognitive functions, such as inference, language, emotional processing or executive functions. However, findings related to this topic are controversial. For instance, Stone, Baron-Cohen, & Knight (1998), and Happé, Brownell, & Winner (1999) found dissociated performance in tasks that required mental and non-mental inferences. Yet this result could not be replicated in Bibby & McDonald (2005), and Martin & McDonald (2006). According to Apperly, Samson, & Humphreys (2005), this lack of consensus could be due to the fact that non-mental inferences used as control tasks are not adequate. Recently, these authors used a modified “false-photograph task”, considered to be a well-matched control for false belief ToM tasks (Saxe & Kanwisher, 2005). They used this technique on a sample of 11 patients with

ABI and found no dissociation between false belief and false-photograph tests (Apperly, Samson, Chiavarino, Bickerton, & Humphreys, 2007).

Neuropsychological studies have also tried to dissociate ToM reasoning from more general cognitive functions. ToM tasks usually require the participation of working memory. For instance, in classic object transfer tasks, subjects must remember where the object was located before transferring the object to another place. Studies on the ABI population show that when working memory demands are controlled, patients still perform worse than controls (Winner, Brownell, Happé, Blum, & Pincus, 1998; Happé, Browell, & Winner, 1999; Rowe, Bullock, Polkey, & Morris, 2001; Milders, Fuchs, & Crawford, 2003; Stone, Baron-Cohen, Calder, Keane, & Young, 2003; Channon, Pellijeff, & Rule, 2005).

Independence between ToM and grammar has also been found in language (Varley & Siegal, 2000; Apperly, Samson, Carroll, Hussain, & Humphreys, 2006). However, no consensus has been reached on the dissociation between ToM abilities and executive functions. Some studies reported this dissociation (e. g. Bach, Happé, Fleminger, & Davis, 2000; Blair & Cipolitti, 2000; Fine, Lumsden, & Blair, 2001; Bird, Castelli, Malik, Frith, & Husain, 2004), suggesting independent processes, while others failed to replicate these results (Channon & Crawford, 2000; Snowden et al., 2003). Again, it is difficult to match the level of difficulty of ToM tasks with more general executive function tasks. In this respect, Samson, Apperly, Chiavarino, & Humphreys (2004) and Apperly, Samson, Chiavarino, & Humphreys (2004), responsible for modifying the classic object transfer task so as to minimize language and executive function demands, show ToM domain specificity in an ABI patient sample.

Studies that used samples with heterogeneous ABI etiology showed larger FOTOM and SOTOM effect sizes than those using homogenous samples. This variable did not have an effect on IS or faux pas. In the literature, mixing ABI populations has been a common approach for testing neuropsychological hypotheses on ToM (k = 14). The use of heterogeneous ABI groups, which vary in etiology or severity of injury, may add variability to ToM performance estimates. ABI is an “umbrella term” that covers a wide range of causes, all of which occur after birth: traumatic brain injury, stroke, tumor, infection, hypoxia, etc. However, the pathophysiology of brain damage not only differs among these conditions, but also within each condition, and thus, the brain could be damaged in different ways. For instance, damage associated with head trauma could be localized in grey matter or constitute part of a diffuse axonal injury, which in turn is associated with greater severity (although a number of studies exclude this category in the patient sample, e. g. Shamay-Tsoory & Tibi-Elhanany [2006]).

We tested whether the proportion of patients with TBI was associated with severity of ToM impairment. This variable was marginally associated with faux pas. Patients with TBI often show impairment in multiple cognitive functions (Leon-Carrion, Martin-Rodriguez, Damas-Lopez, Barroso y Martin, & Dominguez-Morales, 2009), necessary for passing faux pas tasks. Another confounding factor is the high vulnerability of frontal lobe damage after TBI, especially when caused by road traffic accidents (Levin et al., 1987). In this current review, we observed that performance in faux pas was also associated with frontal lobe damage, explaining 86% of the total variance (while the TBI ratio explained 63%). Hence, the strength of the relationship between the proportion of TBI and severity of faux pas impairment could be due, partly, to the aforementioned relationship between frontal lobe damage and faux pas.

However, the lack of effect on the other tasks does not invalidate the hypothesis that patients with TBI do not show severe impairments in ToM. A better approach for testing this hypothesis would be to compare mean effect sizes between etiologies.

Unfortunately, isolated clinical condition analysis was not possible, and more studies with homogenous etiology (controlling severity of damage) are needed in order to explore possible relationships between acquired ToM deficits and brain damage etiologies. The use of these specific clinical groups will generalize results and aid research on the relationship between ToM impairment and condition severity.

Our meta-regression analysis also showed that other variables, namely the proportion of patients with frontal lobe lesions, had a moderating impact on faux pas tasks' effect sizes. Studies with a higher proportion of patients with frontal lobe lesions reported greater differences between patients and healthy controls.

While faux pas has often been associated with different frontal lobe regions, namely bilateral orbito-frontal cortex (Stone, Baron-Cohen, & Knight, 1998) and ventromedial prefrontal cortex (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005a), no relationship has been reported with dorsolateral prefrontal cortex when working memory demands are minimized (Stone, Baron-Cohen, & Knight, 1998; Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003). Other studies to support this relationship include recent experimental neurology research and neuropsychological studies on dementia. Costa, Torriero, Oliveri, & Caltagirone (2008) found that rTMS affects faux pas task performance when applied bilaterally to prefrontal lobe and temporo-parietal junction. In a sample of patients with a frontal variant of fronto-temporal dementia, Torralva et al. (2007) found impairment in faux pas task that was unrelated to performance in an executive function test. ToM deficits, as measured by the faux pas task, may underlie impairment to appropriate use of language in social contexts, as seen in patients with acquired damage to the frontal cortex (Saver and Damasio, 1991).

This analysis also shows significant correlation between the proportion of patients with right-hemisphere damage and size effects for understanding IS and faux pas. ESs increase as the number of right hemisphere patients increases.

It is not uncommon to find a sound relationship between right hemisphere and ToM abilities in the literature on ABI (Winner, Brownell, Happé, Blum, & Pincus, 1998; Siegal, Carrington, & Radel, 1996). Patients with lesions in the right hemisphere commonly show deficits in comprehending non-literal utterances, namely metaphors or irony (Kaplan, Brownell, Jacobs, & Gardner, 1990). They also show impaired perception and expression of emotion, as well as social behavior deficits (Griffin, Fiedman, Ween, Winner, Happé, & Brownell, 2006). Certain similarities have been reported between autism and deficits in pragmatics secondary to the right hemisphere. Individuals with autism preserve other linguistic elements, such us phonology or morphology, but show a marked deficit in pragmatics (Ozonoff & Miller, 1996; Waiter, et al., 2005). However, recent neuroimaging studies challenge this relationship, citing the important role of the left side of the brain along and communication between both hemispheres (Mason, Williams, Kana, Minshew, & Just, 2008; Tesink et al., 2009).

Both faux pas and IS tasks test pragmatics, so it would be reasonable to think that they share brain regions as well. However, faux pas also requires higher affective processing. The right hemisphere plays a crucial role in the perception of emotion and in emotional adaptation to context (Borod, 1992). These processes are also necessary in empathic responses (Decety & Jackson, 2004). Although empathic ability seems to be distributed across the brain rather than localized, patients with right prefrontal lesions show greater impairment in the empathic response as compared to patients with left frontal or posterior lesions (Shamay-Tsoory, Tomer, Berger, and Aharon-Peretz, 2003). Since both the ratio of frontal lobe and right hemisphere patients are associated, it would be of interest to test whether patients with right-sided frontal lobe damage, as opposed to left-sided prefrontal damage, show A higher degree of impairment in faux pas detection.

Other areas which do not form part of the right side of the brain are also needed for ToM reasoning. Recent neuropsychological and neuroimaging studies on healthy adults revealed that left-sided brain areas participated in ToM reasoning (Kobayashi, Glover and Temple, 2007; Apperly, Samson, Chiavarino, & Humphreys, 2004). Current research on ABI populations focuses on understanding how these regions are involved in ToM reasoning. Similarly, the proportion of patients with bilateral damage may correlate positively with performance on faux pas (Stone, Baron-Cohen and Knight, 1998). Although some studies do compare right and left hemisphere patients in various ToM tasks (e.g., Siegal, Carrington, & Radel, 1996; Surian & Siegal, 2001; Winner, Brownell, Happé, Blum, & Pincus, 1998), more studies are needed to shed light on the ToM reasoning required in faux pas tasks.

Study limitations

The first limitation arises from the type of task selection performed in our research. Our meta-analysis reviewed ABI patients' performance in four widely-used tasks. These tasks were chosen based on two criteria. Firstly, in order to test the hypothesis of hierarchy among ToM tasks, we selected tasks based on the development sequence of ToM abilities. The second criterion was to include at least a minimum number of studies within each task category so as to be able to conduct our data analysis with sufficient statistical power. In our literature search, we found that a small number of studies used other ToM tasks, such as those that test gaze direction, inference of mental states from pictures of eyes, or intention-inferencing based on a character's actions.

Although these tasks were not included in our review, the information they provide is of great value for assessing more specific ToM impairments using non-verbal material.

This review did not include single-case studies involving patients with ABI. However, we should not ignore the significance of this research. Most published single-case studies add important findings to debatable questions, such as the involvement of specific brain areas in ToM reasoning or the modular nature of ToM.

Some of the moderator variables, which may influence standard differences, could not explain between-study variability satisfactorily. This could be due to the statistical analysis chosen to study their effect. We opted to analyze the effect of a number of moderator variables in a quantitative fashion, using weighted regression analysis. However, more specific moderator effects could have been extracted from a subgroup analysis in some cases (for instance, comparing ESs between frontal lobe vs. non-frontal lobe lesions). However, this analysis was not possible because subgroup ESs could not be calculated in many studies. Other potential moderator variables not included in this review are the existence of language impairment or performance on executive function tests.

Regarding lesion-site analysis, we related widely damaged areas to performance in ToM tasks, which limits the usefulness of clinical moderator analysis. For instance, we related frontal lobe lesions to faux pas performance. However, frontal cortex has a relative size of almost 40% (Passingham, 2002). The same argument could be applied to the effect of patients with right hemisphere lesions on understanding IS or faux pas performance. Another issue limiting our lesion site analysis is the difficulty to localize brain damage in TBI, especially in cases where diffuse axonal injury is present. We tried not to include these cases, but studies seldom reported this condition. In spite of this limitation, we found lesion-site results valuable, at least for clinical purposes. The postulate that patients with frontal lobe and right hemisphere lesions pass low-level ToM tasks may overlook the fact that these patients could fail more advance ToM tasks, such as understanding IS or faux pas. Finally, further systematic review analysis will clarify the role of frontal cortex sub-divisions, as well as other posterior cortices, such as temporo-parietal junction or distinct regions in the temporal lobe (Frith & Frith, 2003).

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FIGURE LEGENDS

Figure 1. Forest plots displaying weighted effect sizes that correspond to the four ToM tasks. A visual inspection of these plots suggests that effect size is bigger for IS, followed by faux pas, SOTOM and finally, FOTOM.

Table 1. Characteristics for each study included in the meta-analyses. Studies are ordered chronologically. Black dots indicate that study used the task to assess ToM.

	FOTOM	SOTOM	IS	FAUX PAS	*n* ABI	*n* controls
STUDY						
McDonald & Pearce, 1996			●		10	20
Bara et al., 1997	●		●		13	13
Winner et al., 1998	●	●			20	13
Stone et al., 1998	●	●		●	9	5
Happé et al., 1999			●		19	19
Channon & Crawford, 2000			●		31	60
Rowe et al., 2001	●	●			31	31
Milders et al., 2003				●	17	17
Shamay-Tsoory et al., 2003				●	19	19
Turkstra et al., 2004		●			22	48
Apperly et al., 2004	●				12	3
Shaw et al., 2004 (excluding early damage group)		●	●	●	25	38
McDonald & Flanagan, 2004	●	●	●		34	34
Bibby & McDonald, 2005	●	●			15	15
Channon et al., 2005	●		●		19	19
Martin & McDonald, 2005		●			16	16
Shamay-Tsoory et al., 2005a			●	●	41	17
Griffin et al., 2006	●	●			11	20
Igliori & Damasceno, 2006	●	●			18	10
Martin & McDonald, 2006	●	●	●		21	21
Milders et al., 2006				●	30	31
Shamay-Tsoory et al., 2006		●	●		44	18
Channon et al., 2007			●		45	26
Shamay-Tsoory et al., 2007a	●		●		48	35
Shamay-Tsoory et al., 2007b	●	●			49	44

Shaw et al., 2007				●	19	19
TOTAL	**13**	**13**	**12**	**7**	**659**	**632**

Table 2. Demographic data for the four ToM tasks.

ToM tasks	***n* patients**	***n* healthy controls**	**Gender (mean % Male)**		**Mean age**		**Mean years of study**	
			Patients	Controls	Patients	Controls	Patients	Controls
FOTOM	300	263	67.3	56.3	48.3	50.1	12.4	12.5
SOTOM	354	326	67.6	56.8	44.7	43.5	12	12.7
IS	309	303	64.4	58.7	42.6	44.5	12.6	14.4
Faux Pas	173	142	62.2	63.3	37.8	32.7	12.5	13.3

Table 3. Results from meta-regression analyses on the impact of continuous moderator variables on effect sizes. *R*-squared statistic, sign of slope and *P* value, when significant, are provided.

	FOTOM			**SOTOM**			**IS**			**Faux pas**		
	R-Squared	Slope	*P*	*R*-Squared	Slope	*P*	*R*-Squared	Slope	*P*	*R*-Squared	Slope	*P*
Age	0.01	-0.1	n.s.	0.02	-0.15	n.s.	<0.01	-0.06	n.s.	0.3	0.54	n.s.
Proportion of males	0.11	-0.01	n.s.	0.02	0.13	n.s.	0.03	-1.17	n.s.	0.23	-0.02	n.s.
Years of education	0.19	0.43	n.s.	0.28	0.38	n.s.	0.18	-0.42	n.s.	0.11	-0.32	n.s.
TBI ratio	0.01	-0.05	n.s.	<0.001	-0.03	n.s.	0.06	0.24	n.s.	0.63	0.79	0.06
FLP ratio	0.08	0.28	n.s.	0.04	0.2	n.s.	0.09	0.31	n.s.	0.86	0.93	0.02
RHP ratio	0.18	-0.42	n.s.	0.03	0.19	n.s.	0.68	0.82	<0.01	0.85	-0.92	0.04

TBI = Traumatic Brain Injury; FLP = Frontal Lobe Patients; RHP = Right Hemisphere Patients; n.s. = not significant.

Figure 1
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