Title: Do Executive Function and Theory of Mind Predict Pragmatic Abilities Following Traumatic Brain Injury? An Analysis of Sincere, Deceitful and Ironic Communicative Acts

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Do Executive Function and Theory of Mind Predict Pragmatic Abilities Following Traumatic Brain Injury? An Analysis of Sincere, Deceitful and Ironic Communicative Acts

RUNNING TITLE: Pragmatic performance in TBI: Inferential ability, ToM and executive functions.

RUNNING TITLE: Pragmatic Ability in TBI: Inferential Ability, ToM and EF.

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Highlights

- Following TBI difficulties in pragmatic comprehension and production are detectable
- The paper investigates the relation between pragmatics, EF and ToM in TBI
- Increasing difficulty is exhibited in the pragmatic phenomena investigated
- ToM and EF have a limited role in explaining TBI pragmatic ability

Abstract

Quality of life and social integration are strongly influenced by the ability to communicate and previous research has shown that pragmatic abilities can be specifically impaired in individuals with traumatic brain injury (TBI). In addition, TBI usually results in damage to the frontotemporal lobes with a consequent impairment of cognitive functions, i.e., attention, memory, executive function (EF) and theory of mind (ToM). The role of the underlying cognitive deficits in determining the communicative-pragmatic difficulties of an individual with TBI is not yet completely clear.

This study examined the relationship between the ability to understand and produce various kinds of communicative acts, (i.e., sincere, deceitful and ironic) and the above-mentioned cognitive and ToM abilities following TBI. Thirty-five individuals with TBI and thirty-five healthy controls were given tasks assessing their ability to comprehend and produce sincere, deceitful and ironic communicative acts belonging to the linguistic and extralinguistic scales of the Assessment Battery for Communication (ABaCo), together with a series of EF and ToM tasks.

The results showed that, when compared to healthy individuals, participants with TBI performed poorly overall in the comprehension and production of all the pragmatic phenomena investigated, (i.e., sincere, deceitful and ironic communicative acts), and they also exhibited impaired performance at the level of all the cognitive functions examined. Individuals with TBI also showed a decreasing trend in performance in dealing with sincere, deceitful and ironic communicative acts, on both the comprehension and production subscales of the linguistic and extralinguistic scales. Furthermore, a hierarchical regression analysis revealed that – in patients with TBI but not in the controls – EF had a significant effect on the comprehension of

linguistic and extralinguistic irony only, while the percentage of explained variance increased with the inclusion of theory of mind. Indeed, ToM had a significant role in determining patients' performance in the extralinguistic production of sincere and deceitful communicative acts, linguistic and extralinguistic comprehension of deceit and the linguistic production of irony. However, with regard to the performance of patients with TBI in the various pragmatic tasks investigated, (i.e., sincere, deceitful and ironic communicative acts), EF was able to explain the pattern of patients' scores in the linguistic and extralinguistic comprehension but not in production ability. Furthermore, ToM seemed not to be able to explain the decreasing trend in the performance of patients in managing the various kinds of communicative acts investigated.

1. Introduction

Following a brain injury, the ability to communicate effectively with others is often compromised, with negative consequences for the quality of life in terms of reintegration into society, participation in social and occupational roles, vocational and academic achievement and interpersonal relationships (Dahlberg et al., 2006; Struchen, Pappadis, Sander, Burrows & Myszka, 2011).

A wide body of literature has shown in recent decades that traumatic brain injury (TBI) may result, among other things, in communicative-pragmatic impairment (Cummings, 2017; Finch, French, Ou & Fleming, 2016; Galetto, Andreetta, Zettin & Marini, 2013; Key-Delyria, 2016; Marini, Zettin, Bencich, Bosco & Galetto, 2017; Murphy, Huang, Montgomery & Turkstra 2015; Rigon, Voss, Turkstra, Mutlu & Duff, 2016). Non-verbal or extralinguistic ability, i.e., the capacity to communicate with another person through gestures, facial expressions and body posture, is also impaired (Bara, Cutica & Tirassa, 2001; Rousseaux,

Verigneaux & Kozlowski, 2010; Turkstra et al., 2017). Individuals with TBI usually have difficulty understanding communicative pragmatic phenomena that require inferences to be drawn (Bosco, Angeleri, Sacco & Bara, 2015), such as indirect speech acts (Evans & Hux, 2011; McDonald, Fisher & Flanagan, 2016), irony (Angeleri et al., 2008; Martin & McDonald, 2005), sarcasm (McDonald, 1999; Channon, Pellijeff & Rule, 2005) and other forms of figurative language (Yang, Fuller, Khodaparast & Krawczyk, 2010). The inferential process refers to the cognitive ability that allows a person to fill the gap that exists between what a speaker literally says, (for example, "You are a really nice person"), and what s/he really means, (for example, when being ironic if the interlocutor was rude) (Dennis, Purvis, Barnes, Wilkinson & Winner, 2001; Grice, 1975; Searle, 1975).

Analysing both linguistic and extralinguistic expressive modalities, Angeleri et al. (2008) reported a trend of decreasing ability among individuals with TBI to appreciate communicative acts uttered with different communicative intentions, i.e., to be sincere, to be deceitful or to be ironic. Following the theory of cognitive pragmatics (Bara, 2010), Angeleri and colleagues (2008) explained this pattern of decreasing ability on the basis of the increasing inferential complexity involved in the different pragmatic tasks examined (see also Bara et al., 2001; Bara, Tirassa & Zettin, 1997).

The theory of cognitive pragmatics provides the framework for analysing and comparing different kinds of pragmatic phenomena according to the inferential ability involved (Bara, 2010). Its theoretical assumptions are valid for explaining pragmatic phenomena expressed using both language and extralinguistic means, for example, gestures (see also Bara & Tirassa, 1999). According to cognitive pragmatics, when two people communicate they are acting on

the basis of a stereotyped pattern of social knowledge, shared between the participants in the dialogue (see also Airenti, Bara & Colombetti, 1993a; 1993b).

In order to comprehend the interlocutor's communicative intentions, a person must recognize this stereotyped pattern of knowledge shared with the interlocutor. Consider the following example from Bara (2010): imagine someone enters an office where a man is working and says: [1] *"It's raining outside."* While there can be no doubt as to the literal meaning of the utterance, the man sitting at his desk in the office would certainly be disoriented. He would only be able to draw the appropriate inferences and provide a meaningful answer if he understood that [1] meant he shouldn't go out or that he should close the window or take his umbrella with him, or if he realized it had been said for a clear reason. In this activity, the inferential process involved in the comprehension and production of a communicative act uttered with the intention of being sincere, deceitful or ironic, can be analysed (see Table 1).

In the comprehension of sincere communicative acts, what the speaker says is in line with his/her private knowledge. Concerning the inferential process involved, to comprehend or produce a sincere communicative act, which is the standard case, the partner simply has to refer the speaker's utterance to the knowledge shared with him (see Bara, 2010). By contrast, in the comprehension and production of deceitful and ironic communicative acts, which are exempla of non-standard communications, more complex inferential processes are required (see Bara, 2010). Specifically, when a speaker performs a deceitful communicative act, his/her intention contrasts with his/her private knowledge, but it is not in contrast with the knowledge s/he shares with the interlocutor. In deceit, the partner must handle the difference between what is said and what the speaker privately knows. In the case of irony, the speaker's communicative

intention again contrasts with his/her private knowledge, as in the previous case, but it is also in conflict with the knowledge s/he shares with the partner. This makes irony more difficult to deal with than deceit (for a more detailed explanation please see also Bara, 2010).

Table 1. Increases in the inferential processes involved in comprehending/producing a sincere, deceitful and ironic communication act (adapted from Bosco et al., 2013).

The interlocutor's communicative act:			
Communicative intention	Contrasts with his/her private knowledge?	Contrasts with the knowledge shared with the partner?	Inferential load
Sincere	No	No	+
Deceit	Yes	No	++
Irony	Yes	Yes	+++

The existence of a trend of increasing difficulty in the comprehension and production of sincere, deceitful and ironic communicative acts has been pointed out in studies with children (Bosco, Angeleri, Colle, Sacco & Bara, 2013; Bosco & Bucciarelli, 2008), patients with schizophrenia (Colle et al., 2013) and those with brain injury, such as TBI (Angeleri et al., 2008), left-brain damage (Gabbatore et al., 2014), right-brain damage (Parola et al., 2016) and autism spectrum disorders (Angeleri, Gabbatore, Bosco, Sacco & Colle, 2016).

1.1. Relation Between Cognitive and ToM Abilities and Pragmatics in Individuals with TBI

In recent years, an increasing body of evidence has shown that TBI may cause problems with theory of mind (Geraci, Surian, Ferraro & Cantagallo, 2010; Milders, Ietswaart, Crawford &

Currie, 2006; Muller et al., 2010; Spikman, Timmerman, Milders, Veenstra & van der Naalt, 2012; Turkstra, Norman, Mutlu & Duff, 2018; for a review see Martin-Rodriguez & Leon-Carrion, 2010), the ability to comprehend one's own and another person's mental states (Premack & Woodruf, 1978). A fully developed (Bosco, Gabbatore & Tirassa, 2014; Brizio, Gabbatore, Tirassa & Bosco, 2015) and intact theory of mind is necessary to understand a partner's communicative intention (Happé & Loth, 2002; Tirassa, Bosco & Colle, 2006a; 2006b). Some authors have suggested that a ToM deficit in individuals with TBI could play a crucial role in explaining their pragmatic difficulty (Byom & Turkstra, 2012; Channon et al. 2005; Happé, Brownell & Winner, 1999; Havet-Thomassin, Allain, Etcharry-Bouyx & Le Gall, 2006; Martin & McDonald, 2003; McDonald, Fisher, Flanagan & Honan, 2017; McDonald & Flanagan, 2004).

In addition, a deficit in terms of executive functioning is a common feature following TBI, as a consequence of impairment in the frontal areas of the brain. The term refers to goal-directed behaviours (Miyake et al. 2000), including working memory, shifting and planning (Ashman, Gordon, Cantor & Hibbard, 2006; Dikmen et al., 2009; Smith & Jonides, 1999; Sullivan, Riccio & Castillo, 2009; Thomas, Snyder, Pietrzak & Maruff, 2014). The above-mentioned abilities seem to have a significant role in the capacity to communicate efficiently, and they may be at least partially responsible for pragmatic impairment in TBI at different levels and to varying extents (McDonald & Pearce, 1998; Channon & Watts, 2003; Key-DeLyria & Altmann, 2016; Marini, Zettin & Galetto, 2014; for a meta-analysis see Rowley et al., 2017). Douglas (2010) investigated pragmatic-communication difficulties in TBI as well as difficulties related to the capacity to handle information and the speed of verbal processing.

The data showed that executive skills might account for a third of the variance in pragmatic performance of people with TBI.

Recently, McDonald and colleagues (2014) detected a unique effect of both ToM and EF – specifically, inhibition and cognitive flexibility – on the performance of TBI patients in a naturalistic speech-production task. These authors' results suggest that ToM does play a role in communicative ability, but only when the communicative task makes high demands on inhibition control. Byom and Turkstra (2017) used a discourse task in which EF and ToM were manipulated across three conditions, i.e., high-ToM, high-EF and baseline conditions. EF was measured as disfluency error rates during the discourse between individuals with TBI and the examiner, and ToM was measured as the number of mental state terms (MSTs) used in the discourse.

Similarly to McDonald et al. (2014), the authors found a reduction of MSTs in the high-EF condition in the TBI group, suggesting that an increased executive demand can reduce the ability of individuals with TBI to consider mental states during the discourse. On the other hand, no differences were found in disfluency error rates between the individuals with TBI and the controls. Finally, in a more recent study, Bosco, Parola, Sacco, Zettin and Angeleri (2017) showed that cognitive and ToM impairment plays a role in explaining both linguistic and extralinguistic communicative performance in individuals with TBI. The authors performed a regression analysis where attention and long-term memory, EF and ToM were entered as predictors of the pragmatic performance of individuals with TBI. The percentage of explained variance increased significantly with the inclusion of ToM and EF (cognitive flexibility, planning and working memory).

Even fewer studies have investigated the extent to which cognitive and ToM impairment in individuals with TBI can affect the comprehension and production of a specific kind of communicative act, such as indirect speech acts, deceit or irony. Channon and Watts (2003) highlighted the significant contribution of inhibitory processes in explaining the ability of individuals with TBI to comprehend indirect speech acts. The authors also included other executive tasks in their investigation, such as working memory (WM) and multitasking. Although difficulties were detected in all the tasks, WM and multitasking performance did not appear to be associated with performance in pragmatic tasks. Martin and McDonald (2005) investigated cognitive correlates of the comprehension of irony. The authors identified physical inferential reasoning, defined as the ability to understand "*complex non-mental inferences by applying the principles of physical causation to a sequence of event*s", as a good predictor of this capacity. By contrast, poor performance on ToM tasks was not able to account for patients' impaired abilities in terms of irony comprehension. The authors also investigated other cognitive components, such as WM, conceptual reasoning and cognitive flexibility, but none of these were shown to be a good predictor of the participant's ability to understand irony. Muller et al. (2010) investigated ToM in individuals with TBI using a set of ToM tasks, including the faux pas test (Stone et al., 1998), a first- and second-order false belief task, a character intention task (Brunet, Sarfati, Hardy-Baylé & Decety, 2000) and the Reading the Mind in the Eyes test (Baron-Cohen, Wheelwright, Hill, Raste & Plumb, 2001). The authors also employed a communicative task taken from the Montreal Evaluation of Communication (MEC) (Joanette et al., 2004), a protocol that requires participants to comprehend direct or indirect speech acts. Their results showed that participants with TBI performed worse than healthy controls on all verbal and non-verbal ToM tasks, with the exception of the first-order belief attribution task,

confirming the difficulty experienced by individuals with TBI in appreciating the mental states of others. Participants with TBI also showed a deficit in the recognition of both direct and indirect speech acts, and in indirect speech act tasks correlated with tasks assessing verbal ToM, i.e., the faux pas test and false belief tasks. The authors interpreted this result as confirming the relationship between ToM impairments and pragmatic communication skills but suggested that other cognitive functions may be responsible at least for the deficits in non-verbal ToM tasks observed in individuals with TBI. On the whole, most of the experimental evidence points to a relationship between communicative-pragmatic ability and cognitive functioning, especially with regard to executive functions (Bosco et al., 2017; McDonald et al., 2014; McDonald, Fisher, Flanagan, & Honan, 2015; Honan et al., 2015; Byom & Turkstra, 2017; LeBlanc et al., 2014; Channon & Watts, 2003) and ToM (Muller et al., 2010; Channon, Pellijeff & Rule, 2005; Douglas, 2010; McDonald et al., 2015), the only exception being the study by Martin and McDonald (2005). Recently Rowley et al. (2017) conducted a meta-analysis showing that EF have a moderate-to-strong correlation with pragmatic comprehension. However, few studies (Martin & McDonald, 2005; Muller et al., 2010; Channon & Watts, 2003) have investigated specifically the relationships of different communicative phenomena, such as indirect speech acts, deceit and irony with executive functioning and theory of mind. No previous study directly compared the comprehension and production of different communicative acts and their relations with executive and ToM functions in the same individuals with TBI. Thus, it is still unknown whether the impairment of specific executive function processes, (e.g., planning, inhibition, working memory and cognitive flexibility) or ToM components, may be associated with the impairment of specific pragmatic phenomena. Finally, no study, as far as we know, has investigated the role of ToM and EF in the ability of

patients with TBI to comprehend and produce pragmatic phenomena, i.e., sincere, deceitful and ironic communicative acts, expressed through extralinguistic means, i.e., gestures and body movements.

2. The Present Study

The aim of this paper is to investigate the possible role of EF and ToM ability in explaining the capacity of individuals with TBI to comprehend and produce communicative acts expressed with the intention of being sincere, deceitful or ironic and requiring an increased inferential ability. In line with the current literature, we expect that:

i. Individuals with TBI, when compared to healthy controls, will perform worse in the comprehension and in the production of linguistic and extralinguistic communicative pragmatic tasks, i.e., sincere, ironic and deceitful communicative acts.

ii. In both linguistic and extralinguistic communication, individuals with TBI will show a trend of increasing difficulty in the comprehension and production of different kinds of pragmatic phenomena, from the easiest to the most difficult, i.e., sincere, deceitful and ironic communicative acts, based on the increasing inferential load involved.

iii. Individuals with TBI will show more difficulties, when compared to healthy controls, in the cognitive functions investigated, i.e., working memory, attention, long-term memory, planning and theory of mind. We therefore expect to observe a relation between poor performance in the cognitive and ToM tasks and pragmatic skills relating to the comprehension and production of sincere, deceitful and ironic communicative acts.

However, given the role played by the inferential processes involved in the investigated phenomena, we also hypothesize that:

iv. The deficits in such cognitive and ToM abilities alone will not be able to explain the decrease in the TBI patients' ability to understand and produce the various pragmatic tasks, i.e., sincere, deceitful and ironic communicative acts.

3. Methods and Materials

3.1 Participants

A group[1] of 35 participants with TBI (29 males) and a group of 35 healthy individuals took part in the study. The experimental TBI group ranged in age from 20 to 69 years (M = 37.51; SD = 12.25); their education ranged from 5 to 18 years of schooling (M = 10.83; SD = 3.17). The participants' clinical details are presented in Table 2. On the basis of the Glasgow Coma Scale scores, which were between 3 and 13, individuals with TBI were classified as having moderate to severe head injury (see Teasdale & Jennett, 1974). The time after onset ranged from 3 to 312 months (M = 63.57; SD = 74.34). All the participants in the clinical sample

[1] This sample included 10 new participants (5 patients and 5 controls) with Bosco, Parola, Sacco, Zettin, & Angeleri (2017).

Table 2. Demographic and neurological details of individuals with TBI

ID	Sex	Age	Education (years)	Time post-onset (months)	Lesional area	Glasgow Coma Scale
TBI1	M	33	13	138	Right frontoparietal	4
TBI2	F	37	8	15	Right frontoparietotemporal	3
TBI3	F	26	18	30	Right frontoparietotemporal	8
TBI4	M	45	13	74	Bilateral frontoparietal	5
TBI5	F	35	8	228	Bilateral frontal	5
TBI6	M	49	11	64	Right frontotemporoparietal	5
TBI7	M	20	8	41	Frontal-diffuse injury	5
TBI8	M	41	8	36	Right temporal	5
TBI9	M	27	8	35	Left frontal	4
TBI10	M	32	13	51	Right frontotemporoparietal	5
TBI11	M	32	11	23	Left temporal - bilateral parietal	5
TBI12	F	23	13	19	Bilateral frontotemporal	7
TBI13	M	31	11	120	Left frontal	3
TBI14	M	68	5	3	Right frontotemporal	5
TBI15	M	59	11	7	Left frontoparietal	5
TBI16	M	37	8	46	Right frontotemporal	4
TBI17	F	42	13	18	Right frontotemporal	3
TBI18	M	54	18	48	Left frontotemporal	3
TBI19	M	21	8	32	Bilateral frontotemporoparietal	6
TBI20	M	29	13	3	Right frontotemporal	3
TBI21	M	39	8	3	Bilateral frontal	13
TBI22	F	36	13	17	Right frontotemporal	3
TBI23	M	32	10	34	Right parietal	3
TBI24	M	53	18	66	Right frontotemporal	4
TBI25	M	24	8	62	Left frontotemporal	4
TBI26	M	45	13	65	Right frontoparietotemporal	4
TBI27	M	36	10	252	Right parietotemporal	3
TBI28	F	38	8	192	Bilateral frontal	6
TBI29	M	42	13	21	Right frontal	3
TBI30	M	28	13	60	Left frontotemporal	4
TBI31	M	39	8	17	Right temporoparietal	8
TBI32	M	42	8	312	Right temporoparietal	5
TBI33	M	25	8	16	Right parietotemporal	4
TBI34	M	24	11	55	Left frontotemporal	6
TBI35	M	69	11	22	Right frontal	5

reported diffuse brain injuries following traffic accidents. However, an MRI scan detected that most of the participants also suffered from focal damage in various brain areas. All TBI participants were living at home with their caregiver (partner or family) and were in a post-acute phase. None of the individuals with TBI had a history of neurological disease, psychiatric

illness, previous head injury, stroke, use of antipsychotic medication or substance abuse disorder. All the participants were right-handed, and all provided informed consent.

Inclusion criteria for the study included being an Italian native speaker, at least 18 years of age with at least three months having elapsed since brain injury. Moreover, to be included, participants needed to display adequate linguistic and cognitive skills, as tested by the denomination scale of the Aachener Aphasie Test (AAT) (Huber, Poeck, Weniger & Willmes, 1983; cut-off: no deficit), the Mini-Mental State Examination (MMSE) (Folstein, Folstein & McHugh, 1975; cut-off: 24/30) and the Token Test (De Renzi & Vignolo, 1962; cut-off: 5/6). Exclusion criteria for both the clinical and the control group included prior history of TBI or other neurological disease, neuropsychiatric illness or communication problems and premorbid alcohol or drug addiction.

The control group consisted of 35 healthy participants ranging in age from 19 to 64 years (M = 37.26; SD = 11.58); their education ranged from 5 to 18 years of schooling (M = 11.31; SD = 3.19). The healthy controls were closely matched to the TBI individuals in terms of age (t-test: $t_{(1,68)} = .090$; $p = .93$) and schooling (t-test: $t_{(1,68)} = .64$; $p = .53$) as well as gender (29 males). None of them had other brain damage or a history of neurological disorders.

The neuropsychological and communicative-pragmatic tasks were administered individually during three separate experimental sessions, each lasting about one hour. All the patients provided their informed consent to participating in the study. The study was approved by our institutional review board, the Ethics Committee of the Department of Psychology, University of Turin, Italy.

3.2 Communicative-Pragmatic Assessment

We used items belonging to the linguistic and extralinguistic scales of the Assessment Battery for Communication (ABaCo) (Angeleri, Bosco, Gabbatore, Bara & Sacco, 2012; Sacco et al., 2008). Each scale is organized into two subsets of tasks – subscales – assessing comprehension and production abilities respectively. The linguistic scale assesses the comprehension and production of communicative acts expressed primarily using linguistic means. The extralinguistic scale also assesses the comprehension and production of communicative acts, but only expressed using extralinguistic means, (i.e., gestures) only. The two scales include the same communicative acts, and for this reason, the tasks are described together.

We used the following tasks to assess *the comprehension of linguistic and extralinguistic communicative acts.*

- Sincere communicative acts (direct and indirect), deceit and irony. The examiner showed the participants short clips (20-25 seconds each) where two agents were engaged in a communicative exchange. The actor asked a question and the partner replied. The participant was required to understand the communicative act portrayed by the actors. In the tasks on the linguistic scale the actors communicated verbally, whereas in the tasks on the extralinguistic scale they communicated using gestures only. An example of each type of item, in English, is provided in Appendix A.

In order to assess *the production of linguistic and extralinguistic communicative acts, we used the following.*

- Sincere communicative acts, deceit and irony. The examiner showed the participants short clips (20-25 seconds each) where two agents were engaged in a communicative exchange. The actor was communicating something to the partner. The video stopped, and the participant was

asked to assume the partner's perspective in answering the actor. In the tasks on the linguistic scale the communicative interactions occurred in the linguistic modality and the participant was required to reply verbally. In the tasks on the extralinguistic scale the actors performed communicative gestures without any language support and the subject had to reply using gestures only. An example of each type of item, in English, is provided in Appendix A.

Each subscale (*linguistic comprehension, linguistic production, extralinguistic comprehension, extralinguistic production*) contained the same number of experimental tasks:

- four sincere communicative acts
- four deceitful communicative acts
- four ironic communicative acts.

The actors' utterances in each clip contained a controlled number of words (7 ± 2), in order to maintain a constant memory and attention requirement.

The experimenter explained the task at the beginning of the experimental session and the session started only when the participants said they had understood the tasks. Furthermore, the participants were told that they could interrupt the experimental session to ask for clarification at any time. For the items included in the linguistic subscale (both in comprehension and in production) participants had to produce an utterance. Participants used spoken language also for stating their understanding of the items belonging to the extralinguistic comprehension subscale, (e.g., "with that gesture the actor meant..."). For items included in the extralinguistic production subscale, participants had to produce a response using extralinguistic means, i.e., gestures or body movements (see Appendix A for examples).

3.3 Cognitive Functions and Theory of Mind Assessment

Several neuropsychological and theory of mind tests were administered to TBI patients and healthy controls, in order to assess the most important cognitive functions. The following list summarizes the cognitive functions investigated and the corresponding neuropsychological tests chosen (see Appendix B for a detailed description of the tasks).

Basic cognitive functions:

- *Long-term memory*: deferred recall test (Spinnler & Tognoni, 1987)
- *Attention*: attentive matrices (Spinnler & Tognoni, 1987)

Executive functions:

- *Working memory*, defined as the ability to actively maintain and manipulate information (Smith & Jonides, 1999; Conway et al., 2005): disyllabic word repetition test (Spinnler & Tognoni, 1987), Corsi's block-tapping test (Orsini et al., 1987) and immediate recall test (Spinnler & Tognoni, 1987).
- *Cognitive flexibility*, defined as the ability to switch attention and thinking in response to the demands of a specific situation (Arbuthnott & Frank, 2000; Johnco, Wuthrich & Rapee, 2013; Kortte, Horner & Windham, 2002): Trail Making Test (Part B – Part A) (Reitan, 1958).
- *Planning*, defined as the ability to plan a series of actions or thoughts in a sequential order in a goal-directed fashion (Smith & Jonides, 1999; Sullivan, Riccio & Castillo, 2009; Thomas, Snyder, Pietrzak & Maruff, 2014): Tower of London test (Shallice, 1982) and Elithorn's maze test (Elithorn, 1955).

Theory of Mind:

- *First-order theory of mind*: Smarties task (Perner, Frith, Leslie & Leekam, 1989), Sally-Anne task (Baron-Cohen, Leslie & Frith, 1985).
- *Advanced theory of mind*: a selection of six Strange Stories (Happé, 1994), excluding those testing communicative phenomena.

3.4 Procedure

The experimental sessions were recorded on video, and the scoring procedure was performed offline. Two independent raters, blind with respect to the aims of the research, observed the video-recorded administration and coded the answers provided by the participants. The order of the neuropsychological and communicative-pragmatic tasks was randomized and counterbalanced across participants.

According to the ABaCo instruction manual, possible scores were 0 (incorrect) or 1 (correct) for each question. For example, in both the linguistic and extralinguistic scales, the participants obtain a point in the comprehension of sincere communicative acts if they understand what the actor expressed and if they recognize what the utterance/gesture implies. In the production of sincere communicative acts, the participants obtain a point if they have produced a communicative act congruent with the question. More details concerning the structure of the Assessment Battery for Communication and its scoring procedures are provided in Angeleri et al. (2016), Bosco et al. (2013), Parola et al. (2016) and Sacco et al. (2008).

We calculated the level of agreement of the two independent judges using the intraclass

correlation coefficient (ICC). The resulting ICC value of .77 indicates a good agreement between the raters, since according to Altman's criteria (1991), values ranging from .60 to .80 are defined as adequate and indicate substantial agreement. In cases of discrepancies, the judges discussed the scores they had attributed until they reached an agreement.

The neuropsychological and ToM tasks were coded according to the criteria described in the literature.

3.5 Data Analysis

To investigate significant differences in pragmatic performance between the experimental group and control group, participants' scores were submitted to a 2x3 ANOVA, with the type of participant (individual with TBI, healthy control) as the between-subjects factor and the type of phenomenon (sincere, deceitful or ironic) as the within-subjects factor. The same analysis was conducted separately for the linguistic comprehension, linguistic production, extralinguistic comprehension and extralinguistic production subscales of the ABaCo.

In order to investigate the performance of patients in comparison to the performance of controls in neuropsychological tests assessing cognitive functions and ToM, we used a series of independent t-tests. We compared each of the cognitive domains investigated separately, (i.e., WM, long-term memory, attention, cognitive flexibility, planning and overall theory of mind tasks).

To examine the role of the investigated cognitive functions and theory of mind in the understanding and production of different communicative acts, we performed a series of hierarchical regression analyses. As the dependent variable we used the respective scores for the comprehension and production of the different communicative phenomena investigated,

i.e., sincere communicative acts, deceit and irony, separately for the linguistic and extralinguistic scales. Moreover, we inserted basic background cognitive functions – attention and long-term memory, executive functions – WM, cognitive flexibility and planning and theory of mind (ToM) respectively as predictors (see Table 5). In line with Parola, Berardinelli and Bosco (2018) we inserted the cognitive and theory of mind functions in the models in three consecutive stages on the basis of their increasing importance in explaining pragmatic performance. In the first stage of the model we inserted basic background cognitive ability, i.e., attention and long-term memory, as these could be considered the most basic cognitive functions necessary to comprehend and produce each type of communicative act. In the first step we also inserted the post-onset time, to control for whether spontaneous recovery may have also influenced pragmatic performance. In the second stage, we considered executive functions, i.e., WM, cognitive flexibility and planning. We included EF in the second step since some authors (Miyake et al., 2000; Diamond, 2013) had considered EF as a set of top-down cognitive processes necessary for the control and regulation of goal-directed behaviour. In the third and last stage, we included theory of mind. Theory of mind was included in the third and final step since previous studies showed that background cognitive abilities such as attention, as well as executive functions, have a role in explaining the ability to perform this type of task (Honan, McDonald, Gowland, Fisher & Randall, 2015; McDonald et al., 2014).

4. Results

4.1 Pragmatic Performance

Descriptive statistics of the different communicative acts investigated, i.e., sincere communicative acts, deceit and irony, on the comprehension and production subscales of the linguistic and extralinguistic scales, are reported in Table 3.

On the linguistic comprehension subscale, the ANOVA showed a significant main effect of the type of participant ($F_{(1,68)} = 31.62$; $p < .001$; $\eta^2_p = .32$). The experimental group performed significantly worse than the control group on the linguistic comprehension subscale. The main effect of the type of pragmatic phenomenon was also significant ($F_{(2,136)} = 9.04$; $p < .001$; $\eta^2_p = .12$). The interaction between the type of participant and the type of pragmatic phenomenon was not significant ($F_{(2, 136)} = 2.87$; $p = .06$; $\eta^2_p = .041$). We performed a linear contrast which revealed a linear decrease in scores depending on the type of pragmatic phenomenon ($F_{(1,68)} = 10.13$; $p = .002$; $\eta^2_p = .13$). The highest scores were obtained in the tasks concerning the sincere communicative acts, followed by deceit and irony (see Table 3). Pairwise post hoc comparisons revealed that participants obtained higher scores in linguistic comprehension of sincere communicative acts compared to linguistic comprehension of irony (p = .007), while no difference was found between linguistic comprehension of sincere communicative acts and deceit (p = 1.0). Participants found linguistic comprehension of irony more difficult than linguistic comprehension of deceit (p = .001).

As regards the linguistic production subscale, the ANOVA showed a main effect of the type of participant ($F_{(1,68)} = 36.95$; $p < .001$; $\eta^2_p = .35$). The experimental group performed significantly worse than the control group on the linguistic production subscale. The results showed a main effect of the type of pragmatic phenomenon ($F_{(2,136)} = 33.98$; $p < .001$; $\eta^2_p =$

.33). The interaction between the type of participant and the type of pragmatic phenomenon was significant ($F_{(2, 136)}$ =10.78; $p < .001$; $\eta^2_p = .137$). In this case also, the results revealed a linear decrease in scores depending on the type of pragmatic phenomenon considered ($F_{(1,68)}$ = 56.79; $p < .001$; $\eta^2_p = .46$). Higher scores were obtained for the production of sincere communicative acts compared to the production of deceit and irony (see Table 3). Pairwise post hoc comparisons revealed that individuals with TBI performed as well as the controls in linguistic production of sincere communicative acts (p = .10), while their performance was worse than that of the controls in linguistic production of deceit (p < .001) and irony (p < .001).

On the extralinguistic comprehension subscale, the ANOVA showed a main effect of the type of participant ($F_{(1,68)}$ =27.67; $p < .001$; $\eta^2_p = .29$). Overall, as for the case of comprehension, TBI patients performed significantly worse than controls on the extralinguistic comprehension subscale. In both the experimental and control groups we found a main effect of the type of pragmatic phenomenon investigated ($F_{(2,136)} = 56.99$; $p < .001$; $\eta^2_p = .46$). The interaction between the type of participant and the type of pragmatic phenomenon was not significant ($F_{(2,136)}$ =2.71; $p = .070$; $\eta^2_p = .038$). The linear contrast revealed a linear decrease in scores depending on the type of pragmatic phenomenon ($F_{(1,68)}$ = 112.80; $p < .001$; $\eta^2_p = .62$). Higher scores were obtained in the comprehension of sincere communicative acts compared to comprehension of deceit and irony (see Table 3). Pairwise post hoc comparisons revealed that participants obtained higher scores better in extralinguistic comprehension of sincere communicative acts compared to deceit (p < .001) and irony (p < .001), and in extralinguistic comprehension of deceit compared to irony (p = .001).

With regard to the extralinguistic production subscale, analysis showed a main effect of the type of participant ($F_{(1,68)}$ = 80.32; $p < .001$; $\eta^2_p = .54$). Overall, the experimental group

obtained a significantly worse performance than the control group on the extralinguistic production subscale. Results showed a main effect of the type of pragmatic phenomenon ($F_{(2,136)} = 52.51$; $p < .001$; $\eta^2_p = .44$) in both the experimental group and the control group.

The interaction between the type of participant and the type of pragmatic phenomenon was significant ($F_{(2, 136)} = 15.86$; $p < .001$; $\eta^2_p = .189$). We performed a linear contrast that revealed a linear decrease in scores based on the type of pragmatic phenomenon considered ($F_{(1,68)} = 68.13$; $p < .001$; $\eta^2_p = .50$). The highest scores were obtained in the tasks concerning sincere communicative acts, followed by deceit and irony (see Table 3). Pairwise post hoc comparisons revealed that individuals with TBI performed worse than controls in extralinguistic production of sincere communicative acts ($p < .001$), deceit ($p < .001$) and irony ($p < .001$).

Table 3. Means and standard deviations for comprehension and production of sincere, deceitful and ironic communicative acts on the linguistic and extralinguistic scales.

		TBI (n = 35)		HC (n = 35)	
		Mean	SD	Mean	SD
Linguistic Comprehension	Sincere	.81	.20	.91	.19
	Deceit	.77	.28	.95	.10
	Irony	.58	.34	.85	.20
Linguistic Production	Sincere	.89	.21	.96	.17
	Deceit	.75	.28	.96	.09
	Irony	.42	.40	.84	.19
Extralinguistic Comprehension	Sincere	.87	.16	.99	.06
	Deceit	.58	.31	.84	.17
	Irony	.43	.33	.68	.27
Extralinguistic Production	Sincere	.74	.31	.96	.09
	Deceit	.68	.26	.97	.08
	Irony	.27	.34	.84	.17

4.2 Cognitive Functions and Theory of Mind Assessment

The performances of individuals with TBI and healthy controls in the different cognitive domains are shown in Table 4. The performance of individuals with TBI was significantly different from that of healthy controls in all the cognitive domains: attention, working memory (WM), long-term memory (LTM), planning, cognitive flexibility and ToM (t-test: $t_{(68)}$ = 3.44 - 8.84; all p values < .001).

Table 4. Means and standard deviations of tests evaluating cognitive functions.

Cognitive and ToM abilities	TBI		HC			
	Mean	SD	Mean	SD	t-value	Level of significance
Attention	.24	.32	.81	.20	8.84	$p < .001$
Long-term memory	.29	.22	.66	.14	8.21	$p < .001$
Working memory	.46	.26	.66	.23	3.44	$p = .001$
Cognitive flexibility	.5	.38	.96	.10	6.93	$p < .001$
Planning	.53	.28	.90	.10	7.44	$p < .001$
Overall ToM	.76	.21	.97	.08	5.48	$p < .001$

4.3 Role of Cognitive Functions and ToM in Explaining Pragmatic Performance in TBI Participants and Healthy Individuals

Table 5 – Hierarchical regression analysis for variables predicting performance of TBI participants in comprehension and production of sincere, deceitful and ironic communicative acts on both linguistic and extralinguistic scales: Model 1 (attention, long-term memory, post-onset time), Model 2 (working memory, planning, cognitive flexibility), Model 3 (overall theory of mind). The table shows adjusted regression coefficients (R^2_{Adj}) for each predictor variable, the change in R^2 after the addition of planning and theory of mind variables (R^2_{Change}), the change in F (F_{Change}) and its significance value (Sig. F_{Change}).

DVs	IVs	R^2	R^2_{Change}	F_{Change}	Sig. F_{Change}
Linguistic Comprehension					
Sincere	Model 1	.10	.10	1.20	.325
	Model 2	.23	.12	1.49	.238
	Model 3	.29	.06	2.24	.146
Deceit	Model 1	.05	.05	.49	.689
	Model 2	.27	.22	2.80	.058
	Model 3	.53	.26	15.13	**.001**
Irony	Model 1	.10	.10	1.20	.327
	Model 2	.43	.33	5.39	**.005**
	Model 3	.44	.01	.35	.561
Linguistic Production					
Sincere	Model 1	.11	.11	1.30	.292
	Model 2	.29	.18	2.41	.088

	Model 3	.34	.04	1.75	.197
	Model 1	.03	.03	.33	.804
Deceit	Model 2	.18	.15	1.70	.189
	Model 3	.20	.02	.70	.410
	Model 1	.03	.03	.32	.810
Irony	Model 2	.22	.19	2.23	.107
	Model 3	.33	.11	4.34	**.047**
Extralinguistic Comprehension					
	Model 1	.04	.04	.43	.732
Sincere	Model 2	.23	.19	2.24	.105
	Model 3	.25	.03	.93	.342
	Model 1	.11	.02	1.26	.304
Deceit	Model 2	.25	.08	1.71	.188
	Model 3	.41	.25	7.23	**.012**
	Model 1	.15	.15	1.80	.168
Irony	**Model 2**	.37	.22	3.20	**.039**
	Model 3	.37	.01	.41	.525
Extralinguistic Production					
	Model 1	.02	.02	.22	.880
Sincere	Model 2	.20	.17	2.03	.132
	Model 3	.38	.18	7.91	**.009**
	Model 1	.06	.06	.63	.601
Deceit	Model 2	.19	.13	1.50	.237
	Model 3	.45	.27	13.25	**.001**
	Model 1	.08	.08	.89	.457
Irony	Model 2	.22	.14	1.73	.184
	Model 3	.23	.01	.35	.558

Note: The values in bold indicate a statistically significant F_{Change}.

Overall, pragmatic performance on each individual pragmatic phenomenon appears to have been affected by different cognitive functions. Attention, LTM and post-onset time – Model 1 – were involved in every task to a certain extent, but their contribution in explaining pragmatic performance remains modest at best, and does not significantly increase the level of explained variance. The inclusion of Model 2 – executive functions (cognitive flexibility, working memory and planning) – in the analysis increased the amount of explained variance for comprehension of linguistic irony ($F_{(3,29)} = 5.39$; $p = .005$) and extralinguistic irony ($F_{(3,29)}$

= 3.20; p = .039). On including Model 3 – theory of mind abilities – there was a significant change in R^2 for extralinguistic production of sincere communicative acts ($F_{(3,29)}$ = 7.91; p = .009), for linguistic comprehension of deceit ($F_{(1,28)}$ = 15.13; p = .001), for the extralinguistic comprehension of deceit ($F_{(3,29)}$ = 7.23; p = .012), for the extralinguistic production of deceit ($F_{(3,29)}$ = 13.25; p = .001) and for the for the linguistic production of irony ($F_{(1,28)}$ = 4.34; p = .047).

Moreover, the analyses also show that when considering Model 2, including EF, R^2 only partially follows the trend of decreasing performance difficulty exhibited by the individuals with TBI in dealing with the pragmatic tasks investigated. The R^2 values indicate how much variance is explained by a certain variable. Indeed, there is an increase in R^2, which is in line with the detected performance in sincere, deceitful and ironic acts only with respect to comprehension ability, both in linguistic and extralinguistic modalities (linguistic comprehension: sincere, R^2 = .23, deceitful, R^2 = .27, ironic R^2 = .43; extralinguistic comprehension: sincere, R^2 = .23, deceitful, R^2 = .25, ironic R^2 = .37). This does not apply to the production ability where, within Model 2 (EF), R^2 does not increase in line with the pattern of performance exhibited by the individuals with TBI in sincere, deceitful and ironic acts, in either the linguistic or extralinguistic modality (linguistic production: sincere, R^2 = .29, deceitful, R^2 = .18, ironic R^2 = .22; extralinguistic production: sincere, R^2 = .20, deceitful, R^2 = .19, ironic R^2 = .22).

A similar pattern of results holds for Model 3 (ToM), where the R^2 values did not increase in line with the trend of performance exhibited by the individuals with TBI in dealing with the sincere, deceitful and ironic tasks, either in comprehension or in production (see Table 5). If EF and/or ToM were the factors best able to explain the increasing trend of difficulty detected

among the pragmatic tasks, we would expect the R^2 values to follow the trend of performance detected in the comprehension and production of the linguistic and extralinguistic pragmatic acts investigated.

For the control group, we performed multiple regression analyses using the same criteria. Overall, different cognitive functions appear to have had a slight effect on the pragmatic performance of healthy participants. As in the TBI group, attention and LTM were involved in every task; however, their predictive role remained almost constant throughout the tasks, explaining no more than 10% of the variance and remaining, at best, very modest and not significant. When including Model 2 in the analyses, there were no significant changes in R^2. The inclusion of Model 3 to explain performance in pragmatic tasks increased the level of explained variance, but theory of mind was only significant for extralinguistic production of deceit ($F_{(1,28)} = 4.73$; $p = .038$).

5. Discussion

This paper focuses on the roles that cognitive functions, and in particular EF and ToM, might play in explaining the ability of individuals with TBI to comprehend and produce communicative acts expressed with the intention of being sincere, deceitful or ironic. In order to obtain an overview of the communicative-pragmatic ability of individuals with TBI, we compared their performance with that of a control group. On both the comprehension and production subscales of the linguistic and extralinguistic scales of the ABaCo (Angeleri et al., 2012), individuals with TBI performed worse than controls for all the investigated phenomena, namely, sincere, deceitful and ironic communicative acts. This result is in line with previous

investigations (Angeleri et al., 2008; Bara et al., 2001; Bara et al., 1997). Results also showed an interaction effect between the group (individuals with TBI vs controls) and type of pragmatic phenomenon (standard communicative acts, deceit and irony) in linguistic and extralinguistic production tasks, showing that the individuals with TBI were more impaired in comprehension and production of the most demanding communicative phenomena, namely, deceit and irony, while they performed similarly to the controls in comprehension and production of sincere communicative acts.

In line with this result, we detected a decreasing trend of performance in managing different types of pragmatic phenomena involving an increasing inferential load for understanding and production, i.e., sincere, deceitful and ironic communicative acts. This pattern of results held for both the linguistic and the extralinguistic scales, and for both the comprehension and the production subscales. This trend of difficulty in the performance of individuals with TBI is in line with that reported by Angeleri et al. (2008) and, as they proposed, it seems to suggest that following TBI a specific impairment in manipulating inferential ability can be observed (see also Bosco et al., 2015). The inferential process refers to the cognitive ability allowing a person to fill the gap that exists between what a speaker literally says and what he/she communicatively means. According to cognitive pragmatic theory (Bara, 2010) handling sincere (standard), deceitful and ironic communicative acts requires an increasing inferential ability for both production and understanding. The same trend of decreasing performance in managing sincere, deceitful and ironic communicative acts – explained on the basis of the increasing inferential load necessary to perform the tasks – has also been detected in children with typical (Bosco & Bucciarelli, 2008; Bosco et al., 2013) and atypical development, (autism spectrum disorder) (Angeleri et al., 2016), in individuals with

left-brain (Gabbatore et al., 2014) and right-brain (Parola et al., 2016) damage, and in those with psychiatric disorders (schizophrenia) (Colle et al., 2013). Furthermore, Bosco, Parola, Valentini and Morese (2017) recently found that different brain areas are involved in the comprehension of the same speech acts when uttered with the intention of being sincere, deceitful or ironic.

TBI predominantly results in damage to the frontotemporal brain areas, and deficits in terms of attention, memory and executive functioning are the most common subsequent neurocognitive outcomes (Arciniegas, Held & Wagner, 2002; Stuss, 2011). Moreover, previous findings have pointed to a deficit in the capacity to comprehend mental states (ToM) following TBI, (e.g., Muller et al., 2010). As expected, and according to the relevant literature (Bibby & McDonald, 2005; Happé et al., 1999; Havet-Thomassin et al., 2006; Martin & McDonald, 2003), our results also revealed that individuals with TBI performed less well, compared with healthy controls, in all the investigated cognitive components, i.e., attention, long-term memory, working memory, cognitive flexibility, planning and ToM.

We performed a multiple regression analysis for each individual pragmatic task, (i.e., sincere, deceitful and ironic communicative acts) with each separate subscale (linguistic comprehension, linguistic production, extralinguistic comprehension, extralinguistic production) as the dependent variable and with the cognitive factors as predictors. Overall, pragmatic performance for each single phenomenon appeared to be only partially affected by the different cognitive functions. Attention and LTM were involved in each task to a certain extent, but their contributions to explaining the pragmatic performance of individuals with TBI were very modest and not significant.

The percentage of explained variance increased significantly with the inclusion of cognitive flexibility, working memory and planning. We observed a significant effect for the comprehension of linguistic and extralinguistic ironic communicative acts. The percentage of explained variance tended to increase with the inclusion of theory of mind, which was found to be a significant predictor of the performance of individuals with TBI in the comprehension of linguistic and extralinguistic deceits and in the production of linguistic irony as well as extralinguistic sincere and deceitful acts. This result is in line with previous research demonstrating the relationship between cognitive functions and pragmatic ability in individuals with TBI (Bosco et al., 2017; Honan et al., 2015; Martin & McDonald, 2005; McDonald et al., 2014). Globally, Model 1 was able to explain only a relatively small amount of the variance for each of the pragmatic phenomena considered. By contrast, globally considered, Model 2 (inclusion of EF) and Model 3 (inclusion of ToM) explained a moderate amount of the variance in pragmatic performance of individuals with TBI for comprehension and production of irony and deceit. This result seems to indicate the importance of considering the role of cognitive factors, especially ToM and EF, when we approach pragmatic disorders in a clinical setting, since these cognitive factors might contribute to different extents to affecting the pragmatic performance as a whole of individuals with TBI.

However, the novelty of the present study is that it investigates the possible role of such cognitive functions in explaining the increasing difficulty of individuals with TBI in comprehending and producing a specific pragmatic phenomenon, comparing different types of tasks, i.e., sincere, deceitful and ironic communicative acts. Apart from the above-mentioned contribution and analysing the R^2 values indicating how much variance is explained by a certain variable, the role of such cognitive functions in specifically explaining the decreasing

trend of performance in patients with TBI across sincere, deceitful and ironic communicative acts, is more limited. The model including EF seems to be able to explain the decreasing trend in performance in the pragmatic phenomena investigated (irony < deceit < sincere communicative acts) in linguistic and extralinguistic comprehension, although it is not able to explain the decreasing performance of patients in the linguistic and extralinguistic production of sincere, deceitful and ironic communicative acts. Regarding ToM ability, this seems not to have a crucial role in explaining the decreasing trend of performance of patients in sincere, deceitful and ironic pragmatic tasks.

For explorative purposes, we conducted the same analysis in the control sample. As for the TBI group, attention and LTM were involved in each task to a certain extent, and their predictive roles remained almost constant throughout all the investigated pragmatic phenomena, though significance was never reached. The inclusion of WM, cognitive flexibility and planning did not reveal any significant results, and nor did the inclusion of ToM as a predictor.

Our results concerning the role played by ToM in explaining the ability to manage deceit seem to be in line with those of other authors suggesting the importance of this type of cognitive function in deceit comprehension and production (Peskin, 1996). By contrast, our results do not seem to support those of previous studies conducted on children (Winner & Leekman, 1991) or on individuals with right-hemisphere brain damage (Winner, Brownell, Happé, Blum & Pincus, 1998), suggesting that a ToM deficit is the principal factor in explaining difficulty in the understanding of verbal irony. In particular, our results are not in accordance with the hypothesis that ToM is the cognitive factor that might explain the increasing difficulty of managing irony in comparison to deceit (Winner & Leekman, 1991).

For a similar pattern of results or conclusions see also Bosco, Bono and Bara (2012) and Bosco and Gabbatore (2017a; 2017b).

To summarize, our multiple regression analysis suggests that the linear decreasing trend of performance we observed for sincere, deceitful and ironic communicative acts is not explained by the increasing role of a pattern of specific cognitive factors, (i.e., attention + LTM, planning + shifting + WM and ToM). We suggest that this decreasing trend of performance could be better explained by considering the increasing inferential load underlying sincere, deceitful and ironic communicative acts for both the linguistic and the extralinguistic expressive modalities, in both comprehension and in production. In particular, our results seem not to support the role of ToM in explaining the increasing degree of difficulty experienced by individuals with TBI in managing deceit compared with managing irony. Specifically, our results show that a deficit of ToM seems to be specifically related to patients' difficulty in producing and comprehending deceit; nevertheless, ToM alone is not able to explain the difference in performance in managing deceit compared with irony in individuals with TBI.

A limitation of the present study is the fact that the sample of individuals with TBI was not homogenous. Furthermore, future studies should include, in addition to the pragmatic tasks, independent tests focusing on inferential ability, allowing for the possibility of providing correlation analyses between these two measures.

To conclude, considering our results as a whole, we suggest that in addition to cognitive factors such as attention, WM, LTM, working memory, shifting, planning and theory of mind, the role of the (increasing) inferential processes involved in a specific pragmatic phenomenon (see also Bosco, Bono & Bara, 2012; Bosco & Gabbatore, 2017a) should also be taken into

consideration in order to understand more fully the communicative-pragmatic difficulty that individuals may experience as a consequence of TBI.

Moreover, taking a wider perspective, the results of the present study might also have clinical implications for the development of efficient rehabilitation programmes. Indeed, our results suggest the possibility that, in addition to programmes focused on attention, memory, executive functions and ToM, an effective and comprehensive rehabilitative plan for individuals with TBI might also benefit from the inclusion of specific interventions focused on helping the patients to improve their communicative-pragmatic performance. Such rehabilitative programmes focused on communicative-pragmatic skills should take into consideration the role played by the ability to manage inferences of increasing complexity. Indeed, this ability seems to be required for comprehending and producing both linguistic and extralinguistic complex communicative acts, for example, irony. Therefore, these rehabilitative programmes (see for example, Bosco, Gabbatore, Gastaldo & Sacco, 2016; Gabbatore et al., 2015; Gabbatore, Bosco et al., 2017; Sacco et al. 2016; Bosco, Parola, Angeleri, Galetto, Zettin, Gabbatore, 2018) should include also activities specifically devoted to improving the patients' ability to go beyond the literal meaning of a communicative act, whether expressed via language or gestures.

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Appendix A

Examples of Items of the Assessment Battery for Communication

Linguistic communicative acts – comprehension	Extralinguistic communicative acts – comprehension
Sincere: Frank, Paula and Claire are sitting at the table having dinner. Frank says: "Mmm, this pasta is delicious! Who made it?" Paula replies: "I made it!" ▪ *What did the girl mean?* If the participant repeats what the character said: ▪ *Who made the pasta?* **Correct:** "She is the one who made the pasta." **Incorrect:** "I don't know/She is hungry."	***Sincere:*** The scene opens with David who is in the kitchen and has just finished cooking some pasta. He moves towards the door and looks into the study, where we can see Scarlett, sitting at the desk, intent on listening to some music through headphones and writing a letter. David shows her the plate and nods, perhaps also accompanied by a gesture with his arm, as if to say, "Are you coming?" and Scarlett nods in assent. ▪ *In your opinion, what did the girl want to say to the boy?* If the participant repeats the actor's reply: ▪ *Will the girl go to sit at the table?* **Correct:** "She is joining him soon." **Incorrect:** "She has stomach ache/She is busy."
Deceit: Ryan is enjoying some cookies, taking them from a small plate on the table. Hearing that his sister Julia is coming, Ryan pushes away the empty plate. Julia enters the room, looks at the empty plate, and asks: "Who finished my cookies?" Ryan replies: "I'm on a diet!" ▪ *What did the boy mean?* If the participant repeats what the character said: ▪ *What does it mean?* **Correct:** "He didn't eat the cookies" **Incorrect:** "He wants to lose some weight" ▪ *Did the boy say the truth?* **Correct:** "No." **Incorrect:** "Yes." ▪ *Why did the boy say that to the girl?* **Correct:** "To deceive her, by convincing her he didn't touch the cookies." **Incorrect:** "To let her know he is on a diet/I don't know."	***Deceit:*** Naomi and Josh are arguing, having a pillow fight in their bedroom. In all the confusion, Naomi hits the lamp on the bedside table, and it falls onto the floor. Having heard the noise, their dad comes to their room, puts his hands on his hips and with a questioning air and at the same time assuming a cross expression, as if to say, "What's going on?", he points with his finger to the lamp on the floor. Naomi immediately picks up a book and shows it to her dad, as if to say, "I was reading." ▪ *What did the girl want to say to her dad?* If the participant repeats the actor's reply: ▪ *What does that mean?* **Correct:** "It's not her fault, she was just quietly reading." **Incorrect:** "She got a new book." ▪ *Did the girl tell the truth?* **Correct:** "No." **Incorrect:** "Yes." ▪ *Why did the girl answer her dad with that gesture?* **Correct:** "She didn't want the dad to find out it was her fault." **Incorrect:** "To make a joke."
Irony: Sarah and James are in a dress shop. Sarah is trying on a dress which is clearly too tight for her. Sarah asks James: "How does this fit me?" James replies: "Well, it looks kind of big for you!" ▪ *What did the boy mean?* If the participant repeats what the character said: ▪ *What does it mean?* **Correct:** "The dress doesn't fit her."	***Irony:*** The scene opens with Peter and Alice in the kitchen, sitting at a table that has been laid. Alice gets up to fetch a pan, which she brings to the table, and pours a ladle of soup into the dishes. They taste a spoonful, and both pull a disgusted face, as if the soup were uneatable. Alice looks questioningly at Peter and Peter takes his fingers to his mouth and kisses his fingertips with an expression as if to say "Delicious!"

Incorrect: "I don't know/He doesn't like the dress."

▪ *Was the boy serious when he said that?*
Correct: "No he wasn't."
Incorrect: "Yes."

▪ *Why did the boy say that to the girl?*
Correct: "To make fun of the girl/To be ironic."
Incorrect: "To suggest she doesn't buy the dress."

▪ *What did the boy want to say to the girl?*
If the participant repeats the actor's reply:
▪ *What does that mean?*
Correct: "That the soup is very good, but it was a joke."
Incorrect: "A kiss."

▪ *Was he speaking seriously?*
Correct: "No, it was to make fun of her/to make a joke."
Incorrect: "Yes."

▪ *Why did the boy answer the girl with that gesture?*
Correct: "To make a joke."
Incorrect: "To deceive her/I don't know."

Linguistic communicative acts – production	Extralinguistic communicative acts – production
Sincere: Mark and Caroline are on the couch reading magazines. At some point, Mark goes to the window and looks at the beautiful sunny day outside. Mark asks Caroline: "What do you want to do this afternoon?" ▪ *What could the girl say?* (When in doubt): ▪ *What does that mean?* **Correct:** "We could go out for a walk." **Incorrect:** "I bought a book."	***Sincere:*** Derek's car is parked in a deserted country lane. Derek looks as if he has been there a long time (he keeps looking at his watch, raising his hand above his eyes as if on the lookout for someone coming; he is on edge...). At last he sees a car coming... ▪ *The boy needs help. What gesture could he make?* (When in doubt): *What does that mean?* **Correct:** The subject moves the hands in a clear way/hitch-hiking. **Incorrect:** The subject makes a generic and not directly intelligible gesture with the hands.
Deceit: Richard is shaving in the bathroom when he drops a bottle of perfume in the sink. He quickly wipes his face and goes to his room. Shortly after, his sister Stephanie enters the room, shows him the empty bottle of perfume, and asks: "Who spilled my perfume?" ▪ *The boy does not want to be discovered. What could he say?* (When in doubt): ▪ *What does it mean?* **Correct:** "I was here in my room/I didn't touch your perfume." **Incorrect:** "I'm sorry."	***Deceit:*** Two little girls are playing in a yard. After a while Claire hits with her hand a vase of flowers that was standing on a table. Having heard the noise, her dad arrives, and he puts his hands on his hips as if to ask her what has happened. ▪ *The girl doesn't want to be discovered. What gesture could she make?* (When in doubt): *What does that mean?* **Correct:** The subject raises his hands as if to say, "not my fault". **Incorrect:** Generic and not intelligible gesture with the hands/I don't know.
Irony: Arianna – who is wearing her glasses on her head – is looking for something in the room, holding a book in her hand. She tries to read a page but can't do it without glasses. She asks Nathan: "Have you seen my glasses around?" ▪ *What could the boy say to be funny?* (When in doubt): ▪ *What does it mean?* **Correct:** "Try on your head.../have you checked your own head?" **Incorrect:** "No, sorry/maybe you lost them somewhere."	***Irony:*** Alisha and John are in the kitchen emptying their shopping bags and putting everything in the cupboards. John absent-mindedly drops an egg he was about to put away. The egg breaks, making a mess on the table… ▪ *Imagine the girl wants to make fun of the boy. What gesture could she make?* (When in doubt): ▪ *What does that mean?* **Correct:** The subject claps/makes a sarcastic gesture to scold him. **Incorrect:** The subject makes a generic or undefined gesture with the hands/says he doesn't know.

Appendix B

Neuropsychological tasks

Cognitive domain	*Test*	*Description*	*Reference*
Attention	Attentional matrices	The task evaluates selective attention. The participant has to bar target digits in three different matrices made up of 11 rows of 10 digits each. The participant has 45 seconds to complete each matrix	Della Sala, Nespoli, Ronchetti and Spinnler (1984); Spinnler and Tognoni (1987)
Working memory	Disyllabic word repetition test	The task measures verbal working memory span. The examiner reads aloud a list of disyllabic words of increasing length, and the participant must repeat the words in the same order.	Spinnler and Tognoni (1987)
	Corsi's block-tapping test	The task evaluates visuospatial working memory. The examiner taps a sequence of up to nine square blocks positioned on a wooden board, and the participants is asked to repeat the sequence in the same order.	Spinnler and Tognoni (1987)
	Story recall test (immediate recall)	The task evaluates immediate and deferred recall. The experimenter reads aloud a story made of 28 mnemonic units. To assess immediate recall, the participant is asked to recall the story immediately after hearing it.	Novelli, Papagno, Capitani and Laiacona (1986)
Long-term memory	Story recall test (deferred recall)	After the participant recalled the story, the examiner reads it again. To assess deferred recall, the participant is asked to recall the story after 15 minutes, during which s/he has been involved in unrelated non-verbal tasks.	Novelli, Papagno, Capitani and Laiacona (1986)
Flexibility	Trail Making Test (B-A)	The task indexes cognitive flexibility in a visual-motor sequencing task. The participant must draw lines to connect 25 circles distributed over a sheet of paper. In Part A, the circles are numbered from 1 to 25, and the participant must connect the circles in ascending order. In Part B, the circles include both numbers (from 1 to 13) and letters (from A to L); the participant is required to connect the circles in an ascending order but alternating between the numbers and letters. The difference in completion time between part B and part A is used as an index of cognitive flexibility (switching).	Reitan (1958)
Planning	Tower of London	This task evaluates planning abilities. Task materials comprise a wooden board with three pegs of different lengths mounted on it; the participant is asked to move three beads of different colours (blue, red and green) between the pegs to reproduce the figure shown by the examiner. The participant must	Shallice (1982)

		reproduce the figure in a prescribed number of moves to correctly solve the task.	
	Elithorn's maze test	The test is an index of spatial planning abilities. The task comprises eight mazes depicted on a sheet of paper. The participant must trace a line on the sheet starting from the bottom of each maze in an upward direction and passing through a prescribed target number of dots.	Elithorn (1955; 1964); Spinnler and Tognoni (1987)
Theory of mind	Smarties task	This task evaluates the understanding of false belief g. The examiner shows the participant a Smarties box that contains a pencil rather than the expected sweets. The participant is then asked what another person – who has not seen the actual contents – will think is inside the tube, before it is opened.	Perner, Frith, Leslie and Leekam (1989)
	Sally-Anne task	The task assesses false-belief understanding using a location-change task. The participant is shown a scenario in which a doll (Sally) puts a marble in a basket and then leaves the room. While she is gone, another doll enters the room (Anne) and moves the marble from the basket to a box. The participant is then asked where Sally will look for her marble when she comes back. The participant correctly solves the task if he/she recognizes that Sally will look for the marble where she thinks the marble was located, i.e., in the basket.	Baron-Cohen, Leslie and Frith (1985)
	Strange Stories	The task assesses theory of mind abilities. Participants are read aloud a series of stories that end up with one of the protagonists producing an utterance, (e.g., pretence, double-bluff). The participant is asked if what the character said was true, and why the character said that.	Happé (1994)