



ORIGINAL ARTICLE

# Development and validation of interpretability cutoffs for the short forms of the Brain Injury Rehabilitation Trust Personality Questionnaires (BIRT-PQs)

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## ABSTRACT

**BACKGROUND:** Previous analyses demonstrated that Italian versions of the five short forms of the Brain Injury Rehabilitation Trust Personality Questionnaires (SF-BIRT-PQs) showed strong psychometric properties. However, evidence on their interpretability lacks.

**AIM:** To calculate cutoffs for each of the SF-BIRT-PQ to discriminate between the subject's behavior that deviates significantly (D+) or not (D-) from the average of healthy individuals.

**DESIGN:** Multicenter prospective study.

**POPULATION:** One hundred and fifty-four subjects with acquired brain injury, their 154 caregivers, and 120 healthy subjects.

**METHODS:** SF-BIRT-PQs and disability measures were administered to the included subjects. Moreover, subjects scored the Satisfaction Profile (SAT-P) and disability measures, while the Caregiver Burden Inventory (CBI) and Frontal Behavioral Inventory (FBI) were administered to caregivers. Cutoffs between scores indicating D- or D+ patients were calculated with Z-scores, and Mann-Whitney Tests were used to assess the scores of the comparator instruments across the two groups (*i.e.*, D+ and D-) generated by the cutoff for each SF-BIRT-PQs separately for the patient (using SAT-P, DRS, LCF) and caregiver samples (using CBI, FBI, DRS, LCF).

**RESULTS:** Cutoffs to discriminate between D+ and D- were identified (SF-BMQ  $\geq 25$  points, SF-BREQ  $\geq 19$  points, SF-BSCQ  $\geq 14$  points, SF-BDQ  $\geq 15$  points, SF-BIQ  $\geq 18$  points indicated D+). Generally, for the patients' sample, between-group comparisons showed significant differences between all SF-BIRT-PQs (except BDQ and BIQ) and the SAT-P subscales ( $P < 0.05$ ) but not with disability measures ( $P > 0.05$ ). In contrast, for the caregivers' sample, between-group comparisons showed significant differences between all SF-BIRT-PQs and the CBI and FBI subscales ( $P < 0.05$ ) but not with disability measures ( $P > 0.05$ ). A digital ruler was devised to convert raw scores into interval measures.

**CONCLUSIONS:** We provided evidence in support of the construct validity of the proposed cutoffs for each SF-BIRT-PQ.  
**CLINICAL REHABILITATION IMPACT:** These cutoffs make the short forms of the BIRT-PQs interpretable by quantifying the amount of the patient's behavior divergence from that of the average healthy individual. The electronic rulers for each BIRT-PQ provide several functions that greatly facilitate the SF-BIRT-PQ administration and interpretation.

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**KEY WORDS:** Brain injuries; Behavioral symptoms; Personality assessment; Health care outcome assessment; Psychometrics; Rehabilitation.

Behavioral disturbances, also known as neurobehavioral disability, are a frequent outcome of acquired brain injury (ABI) of both traumatic (TBI) and non-traumatic (non-TBI) etiology.<sup>1,2</sup> In association with impairments of cognitive functions, or as a phenomenon in itself, they are one of the aspects that most compromise rehabilitation outcomes and patient's social and occupational reintegration.<sup>3</sup> Neurobehavioral deficits are better predictors of subjective family distress than disease severity or cognitive impairments in ABI patients, with a highly familiar and social burden of care.<sup>4</sup> Behavioral changes in a biopsychosocial framework result from neurological, neuropsychological, psychological, and relational mechanisms.<sup>5</sup> Frontal and temporal lobe injuries have long been linked to emotional/personality changes and social behavior. Acquired behavioral disturbances due to acute neurological events showed specific features distinguishing them from behavioral disorders resulting from other etiologies, *e.g.*, dementias.<sup>6,7</sup> According to a systematic review including patients with TBI,<sup>8</sup> four major categories of posttraumatic behavioral symptoms can be defined: disruptive primary behaviors by excess (*i.e.*, agitation, aggression, irritability, alcohol and drug abuse) or by default (*i.e.*, apathy), affective disorders-psycho-sis-anxiety changes (*e.g.*, depression, anxiety), and suicide attempts and suicide.

While many assessment tools have been developed for the neurodegenerative disease population, very few are available for assessing adult patients with acquired brain injury.

In general, tools to assess behavioral disorders are divided into two categories: observational scales and questionnaires to collect a description of the behavioral phenomenology as perceived subjectively by the patient and their caregivers. The undoubted advantage of the latter is the possibility of investigating the behavior in more varied ecological contexts than clinical practice. However, they are considered less objective measures, as they are affected by the subjective perception of the problem. The personal experience of the problem, both of the patient and

the caregiver, is nevertheless very useful from a rehabilitative perspective since it allows an understanding of how the behavioral disorder impacts subjective well-being and the entire family system.

Oddy *et al.*<sup>9</sup> proposed the Brain Injury Rehabilitation Trust Personality Questionnaires (BIRT-PQs), a set of questionnaires specifically investigating neurobehavioral disability in individuals with ABI. The original BIRT-PQs included five separate questionnaires (each available in parallel forms for patient and caregiver), for a total of 150 items, which assess five different areas of neurobehavioral changes (*i.e.*, motivation, emotional regulation, social cognition, disinhibition, impulsivity) following severe ABI (sABI). In particular, these questionnaires may fill a gap regarding the assessment of some of the behavioral aspects of the orbitofrontal syndrome, although in patients with sABI other symptoms and signs of frontal lobe dysfunction (*e.g.*, impairment of executive functions) may coexist.

The five BIRT-PQs questionnaire was recently adapted and translated into the Italian language;<sup>10</sup> however, analyses according to the classical theory test<sup>11</sup> and Rasch analysis<sup>12</sup> showed that the original versions of the questionnaires generated invalid total scores. After deleting 72 out of 150 items within a Rasch analysis (because of multidimensionality and other biases), each total score of the short version of the BIRT-PQs (SF-BIRT-PQs) showed adequate internal construct validity, and their reliability indexes suggested the compatibility with measurement on single persons; moreover, the burden of administration was reduced as the items number composing each questionnaire was reduced. Furthermore, it was possible to transform the total scores into interval-level measures (whose measurement unit is the logit) using a simple conversion table. The latter allows the measurement of the perception of the neurobehavioral disability on the same metric for patients with s-ABI and their caregivers,<sup>12</sup> also providing an estimate of the measurement uncertainty, as it provides standard errors of measurement for each measuring point.<sup>13</sup> Finally, the logit measurement scale could be converted into a 0-100

transformed-logit range using a simple conversion formula.<sup>14</sup> The latter has the advantage of being more easily understandable by clinicians than the logit scale. Despite all these advantages, it would be important to compare them to normative data on the healthy population to allow proper clinical interpretation of the measures.

Therefore, the objectives of this study were: 1) to make the scores of the SF-BIRT-PQs clinically interpretable by calculating cutoffs for each questionnaire to discriminate between subject's behavior that deviates or not significantly from the average of healthy individuals; 2) to provide evidence supporting the construct validity of the proposed cutoffs; and, 3) to make the SF-BIRT-PQs clinically usable by devising a digital ruler that allows the calculation of total scores and related measures and their clinical interpretation.

## Materials and methods

### Subjects and settings

Detailed information on the study methodology can be retrieved elsewhere.<sup>10-12</sup>

Subjects with ABI and their caregivers were enrolled from eleven Italian neurorehabilitation centers if the patients met the following inclusion criteria: aged between 18-70 years, suffered from a severe ABI characterized at the onset by lack of consciousness (Glasgow Coma Scale  $\leq 8$  points) lasting more than 24 hours, with a Level of Cognitive Functioning score  $\geq 7$  points at the time of enrollment, and were independent before the s-ABI (*i.e.*, modified Barthel Index = 100 points). Patients were excluded if they presented severe aphasia and a history of previous neurological and psychiatric disorders.

Healthy subjects were recruited from among those willing to participate voluntarily in research projects if they were Italian-native speakers without a history of neurological or psychiatric diseases. As described in our previous work,<sup>10</sup> participants were stratified by gender, education, and age. Four age groups were selected (21-30, 31-40, 41-50, and 51-60, with 30 participants per class) and three levels of education (5-12 years of education, 13-16 years of education, and equal or more than 17 years of education, with 40 participants per class). There were 60 male and 60 female participants, with five participants for each typology of group (*e.g.*, five males between 21 and 30 years old with 5-12 years of education, five males between 21 and 30 years old with 13-16 years of education, and so on).

The local Ethical Committees approved the study protocol, which was conducted according to the principles of the Hel-

sinki Declaration. Participants and their respective caregivers gave written informed consent to participate in the study.

### Outcome assessment

#### *Brain Injury Rehabilitation Trust Personality Questionnaires (BIRT-PQs)*

It is composed of the short forms described in Pellicciari *et al.*,<sup>12</sup> assessing several dimensions of personality that might be altered after an ABI. Each item is scored by a 4 or 3-point Likert Scale that summed each other and generated a total score; higher scores indicate a greater degree of personality disturbance. The short form of the BIRT motivation questionnaire (SF-BMQ) assessing motivation comprises 19 questions, and its total score ranges from 0 to 57 points. The short form of the BIRT regulation of emotion questionnaire (SF-BREQ), evaluating emotional regulation, consists of 17 items; its total score varies from 0 to 48 points. The short form of the BIRT social cognition questionnaire (SF-BSCQ), which measures social cognition, comprises 13 items; its total score ranges from 0 to 34 points. The short form of the BIRT disinhibition questionnaire (SF-BDQ) assessing disinhibition includes 13 items, and its total score varies from 0 to 35 points. The short form of the BIRT impulsivity questionnaire (SF-BIQ), measuring impulsivity, consists of 16 items; its total score ranges from 0 to 45 points. Two versions of the SF-BIRT-PQs are available: a self-rated patient version, where the respondent is asked to answer questions regarding his/her aspects of personality, and a caregiver-rated version, identical to the former but self-administered by a caregiver, where the questions taking into account the patient's perception regard the aspects of personality of his/her cared one affected by ABI. The Italian versions of the SF-BIRT-PQs were administered in this study.<sup>12</sup>

#### *Satisfaction Profile (SAT-P)*<sup>15</sup>

It comprises 32 items investigating the patient's subjective satisfaction with different aspects of functioning. It is composed of five subscales: psychological functioning (10 items), physical functioning (9 items), work (5 items), basic needs and free time (5 items), and social functioning (3 items). Each item was rated by marking a sign over a 10 cm horizontal line with the extremes semantically defined (left completely unsatisfied, right completely satisfied). The total score of each sub-scale is generated by calculating the means of each item score; therefore, it ranges from 0 (indicating the worst satisfaction) to 100 (indicating the best satisfaction) points.

*Caregiver Burden Inventory (CBI)*<sup>16</sup>

It comprises 24 items measuring the burden of care for caregivers of dementia patients. It is composed of five subscales exploring five primary dimensions: time-dependence (5 items), developmental (5 items), physical (4 items), social (5 items), and emotional (5 items) burden. Each item is scored by a 4-point Likert scale, from 0 (not at all descriptive) to 4 (very descriptive) points, where higher scores indicate a more significant caregiver burden. Therefore, all total scores are calculated by adding the score attributed to each item; consequently, they range from 0 to 20 points for all subscales, except for physical burden, which ranges from 0 to 16 points.

*Frontal Behavioral Inventory (FBI)*<sup>17</sup>

It comprises 24 items assessing the personality and behavior changes in patients with dementia from a caregiver's perspective. It consists of two sub-scales where both negative (12 items) and positive behaviors (12 items) are assessed. The total scores of each subscale are generated by summing up the score endorsed to each item; the total score of each subscale varies from 0 to 36 points, where higher scores indicate a higher level of personality and behavioral change. In this study, the Italian version was administered.<sup>18</sup>

*Disability Rating Scale (DRS)*<sup>19</sup>

DRS depicts the recovery of functioning after severe head trauma from 'coma to community'. DRS comprises eight items investigating impairments, activity, and participation, ranging from the level of consciousness to the cognitive ability to perform self-care activities, degree of dependence on others, and employability. Each item is scored using a 3 or 5-point Likert scale, and its total score is generated by summing up the score of each item.

*Levels of Cognitive Functioning (LCF)*<sup>20</sup>

LCF is used to assess neuropsychological functioning in ABI patients. It includes eight levels of cognitive functioning that describe the phases of a typical recovery after a brain injury.

**Procedures**

The demographic and clinical characteristics of the patients with ABI, their respective caregivers, and healthy subjects were collected. The five short forms of the BIRT-PQs were administered independently to all subjects (pa-

tients with ABI, caregivers, and healthy subjects). Also, patients with ABI were required to complete the SAT-P, while caregivers were requested to complete the FBI and CBI.

**Statistical analysis**

Descriptive statistics were computed to describe the samples' demographic and clinical characteristics; mean and standard deviation, median with first and third quartile, and frequencies as percentages were reported for interval, ordinal, and categorical data, respectively. We performed a Chi-square Test for independence (with Yates' Continuity Correction) to assess that there was no association between the sample of the individuals self-administering the questionnaires (healthy controls *versus* patients) and, respectively, gender and education. Furthermore, we assessed eventual differences between the two samples mentioned above in terms of age using an independent sample *t*-test.

**Interpretability of the SF-BIRT-PQs: definition of cutoff scores**

To make the total scores obtained by the patients and caregivers clinically interpretable,<sup>21</sup> we aimed at devising cut-offs between scores indicating that the subject's behavior deviated significantly (D+) or not (D-) from the average of healthy individuals. To reach this aim, the final solutions for each subscale provided by Pellicciari *et al.*<sup>12</sup> were replicated through Rasch analysis in a sample of healthy individuals, including by the previous Italian validation.<sup>10</sup> In particular, the item estimates from the original calibration were exported and anchored to item estimates of the healthy individuals, so it was possible to obtain person ability estimates on the same scale as those from the original calibration. In this way, the healthy individuals' estimates were comparable to those reported by patients and their caregivers.

Following this, 'normality' cutoffs were generated by calculating the corresponding Z-scores, where each logit measure for each subscale was transformed using the following formula:

$$Z \text{ score} = \frac{(\text{location in logit} - \text{mean of all locations in logits})}{\text{standard deviation of all locations in logits}}$$

In particular, a Z-score  $\geq +1.96$  indicated that the subject's behavior deviated significantly (D+) from the average of healthy individuals. In contrast, a Z-score equal to or less than  $+1.95$  suggested that the subject's behavior did not deviate significantly (D-) from the average of healthy individuals.

### Construct-based validation of the cutoff scores

To validate these cutoff scores, we sought evidence supporting the proposed interpretation of the measures by generating hypotheses based on the supposed theoretical implications associated with the measured constructs.<sup>21</sup> In particular, we hypothesized that for the patient's SF-BIRT-PQs, above the cutoffs would be associated with lower degrees of satisfaction across the various domains of the SAT-P. Furthermore, we formulated the hypotheses that the measures of the caregiver's SF-BIRT-PQs above the various cutoffs would be significantly associated with higher levels of burden of care and personality and behavior change, as measured by CBI and FBI, respectively. Finally, we hypothesized a significant association between the level of cognitive functioning and disability as quantified, respectively, by LCF and DRS, although we expected larger differences in the caregiver's versions.

To test these hypotheses, we assessed the differences between the scores of the comparator instruments across the two groups (*i.e.*, D+ and D-) generated for each SF-BIRT-PQ. In particular, for each patient's SF-BIRT-PQ, we conducted several Mann-Whitney U Tests to assess the differences in the total scores of SAT-P, DRS, and LCF across the D- and D+ groups. The same procedure was followed for the caregiver's SF-BIRT-PQ, although the comparator instruments in this case were CBI, FBI, DRS, and LCF. The magnitude of each difference was assessed by calculating an *r* with the following formula:<sup>22</sup>

$$r = \frac{z - \text{score}}{\sqrt{N}}$$

where *N* is the total number of cases. For interpreting this effect size, we followed Cohen's criteria,<sup>23</sup> indicating  $\rho > |0.10$ ,  $\rho > |0.30$ , and  $\rho > |0.50|$  for small, medium, and large differences, respectively.

### Making the SF-BIRT-PQ clinically usable: construction of measurement rulers

Finally, a practical ruler (*i.e.*, a nomogram) was developed to allow the interpretability of the SF-BIRT-PQ measures.<sup>24, 25</sup> In detail, this ruler incorporated the following functions:

- conversion of each item score of the original SF-BIRT-PQ to the items scores of the short versions;
- calculation of the total scores of the 5 SF-BIRT-PQ;
- conversion of the short version total scores into linear measures of the degree of neuro-behavioral disability measured by each SF-BIRT-PQ with their relative 95% confidence interval;

- visual display of the location of the individual patients/caregivers with respect to the normality cutoff (*i.e.*, D+ vs. D-);
- visual display of the so-called distinct levels of performance ability (DLPA),<sup>12, 26</sup> which divide the measurement range into discrete and statistically distinct 'levels' of increasing neuro-behavioral disability.
- visual comparison of the measure obtained with the displayed items' response pattern to acquire further information on the measurement quality (*e.g.*, unexpected item response patterns given a certain total score).

### Statistical notes and softwares

Rasch analysis was performed with RUMM2030 software. The group differences analyses were performed using SPSS software (version 21 for Windows; SPSS Inc., Chicago, IL, USA; 2004). Considering an average *r* effect size of 0.300 (equal to a Cohen's *d* effect size of 0.629), an alpha equal to 0.05 and a power of 0.80, a minimum sample size of 134 subjects was deemed sufficient for all comparisons to detect any difference between groups using Mann-Whitney U Tests. The sample size calculation was performed with G-Power (version 3.1 for Windows). The level of significance was set at  $P < 0.05$ .

### Data availability statement

The raw data associated with the article are publicly available for download from in [www.zenodo.org](http://www.zenodo.org) (according to the license Creative Commons Attribution 4.0 International) from the following link: <https://doi.org/10.5281/zenodo.17424005>.

## Results

### Sample characteristics

In this study, we included 154 persons with s-ABI (mean age: 41.9±14.4 years; 68.8% males) and their 154 respective caregivers (mean age: 52.1±12.3 years; 31.2% males). Furthermore, one hundred twenty healthy subjects (mean age: 40.6±11.5 years; 50.0% males) were also included. The main demographic and clinical characteristics of participants are shown in Table I. Further detailed characteristics are available elsewhere.<sup>10, 12</sup>

We found a significant association between the sample (*i.e.*, healthy controls *versus* patients) and, respectively, gender ( $\chi^2_{df}=7.490_1$ ;  $P=0.006$ ) and education level ( $\chi^2_{df}=18.563_1$ ;  $P<0.001$ ). Instead, there was no significant difference between the two samples when considering participants' age ( $t_{df}=0.808_{272}$ ;  $P=0.420$ ).

**Interpretability of the SF-BIRT-PQs: definition of cutoff scores**

The calculation of the Z-Score suggested that (Table II) (Supplementary Digital Material 1: Supplementary Table I):

- for SF-BMQ, a score  $\geq 25$  points indicated a significant deviation from the average of healthy individuals (D+);
- in the SF-BREQ, a score  $\geq 19$  points indicated D+;
- for SF-BSCQ, a score  $\geq 14$  points indicated D+;
- in SF-BDQ, D+ was indicated by a score  $\geq 15$  points;
- finally, for SF-BIQ, a score  $\geq 18$  points indicated D+.

TABLE I.—Main demographic and clinical characteristics of the sample.

Variable	Healthy subjects (N.=120)	Patients (N.=154)	Caregivers (N.=154)
Age (years)	40.6±11.5	41.9±14.4	52.1±12.3
Gender			
Males	50.0%	68.8%	31.2%
Females	50.0%	31.2%	57.8%
Missing	0.0%	0.0%	11.0%
Education			
Primary	0.0%	2.6%	5.8%
Secondary	19.2%	31.2%	30.5%
High	41.7%	48.7%	37.7%
Degree	28.3%	16.9%	13.6%
Post-degree	10.8%	0.0%	1.3%
Missing	0.0%	0.6%	11.0%
Etiology			
Traumatic brain injury	-	61.0%	-
Intracerebral hemorrhage	-	13.0%	-
Subarachnoid hemorrhage	-	9.7%	-
Ischemic stroke	-	6.5%	-
Anoxia	-	4.5%	-
Other	-	5.2%	-
Time since lesion (months)	-	26.3±19.6	-
SF-BIRT-PQs (logit estimates) <sup>a</sup>			
Motivation	-1.2±0.7	-1.1±0.9	-0.8±1.2
Emotional regulation	-1.8±0.9	-1.8±1.3	-1.7±1.4
Social cognition	-1.3±0.8	-1.3±0.9	-1.5±1.3
Disinhibition	-1.5±0.8	-1.6±1.0	-1.5±1.2
Impulsivity	-1.6±0.8	-1.6±1.1	-1.6±1.1
SAT-P total scores <sup>b</sup>			
Psychological Functioning (range 0-100)	-	63.4 [50.4, 78.1]	-
Physical Functioning (range 0-100)	-	53.2 [39.9, 66.9]	-
Work (range 0-100)	-	64.1 [45.0, 84.1]	-
Basic Needs and Free Time (range 0-100)	-	68.0 [55.0, 81.6]	-
Social Functioning (range 0-100)	-	71.0 [54.5, 86.9]	-
CBI total scores <sup>c</sup>			
Time Dependence (range 0-20)	-	-	4.0 [1.0, 9.0]
Social (range 0-20)	-	-	4.0 [1.0, 10.0]
Physical (range 0-16)	-	-	3.0 [1.0, 7.0]
Developmental (range 0-20)	-	-	2.0 [0.0, 6.0]
Emotional (range 0-20)	-	-	1.0 [0.0, 3.0]
FBI <sup>d</sup>			
Negative Behaviors (range 0-36)	-	-	10.0 [4.0, 16.0]
Positive Behaviors (range 0-36)	-	-	4.0 [1.0, 10.0]
DRS (range 0-29) <sup>e</sup>	-	3.0 [1.0, 4.0]	-
LCF (range 1-8) <sup>f</sup>	-	8.0 [7.0, 8.0]	-
BI (range 0-100) <sup>g</sup>	-	100.0 [97.0, 100.0]	-

SF-BIRT-PQ: short form of the Brain Injury Rehabilitation Trust Personality Questionnaire; N: number of cases; SAT-P: Satisfaction Profile; CBI: Caregiver Burden Inventory; FBI: Frontal Behavioral Inventory; DRS: Disability Rating Scale; LCF: Level of Cognitive Functioning; BI: Barthel Index

Data are reported as a percentage, mean±SD or median [interquartile range]. <sup>a</sup> The highest values indicate a higher level of behavioral disturbance; <sup>b</sup> the highest values indicate a higher level of subjective satisfaction; <sup>c</sup> the highest values indicate a higher level of charge for caregivers; <sup>d</sup> the highest values indicate a higher level of personality and behavior changes; <sup>e</sup> the higher values indicate a lower level of disability; <sup>f</sup> the highest values indicate a higher level of cognitive functioning; <sup>g</sup> the highest values indicate a higher level of independence.

TABLE II.—Cut-off score for each total score of each short form of the subscale of the Brain Injury Rehabilitation Trust Personality Questionnaires to categorize the subject's behavior in deviates (D+) or not (D-) significantly from the average of healthy individuals

Score	SF-BMQ	SF-BREQ	SF-BSCQ	SF-BDQ	SF-BIQ
Total score range	0-57	0-48	0-34	0-35	0-45
Cut-off for D+	≥25	≥13	≥14	≥15	≥18
Cut-off for D-	≤24	≤12	≤13	≤14	≤17

SF-BMQ: short form of the BIRT Motivation Questionnaire; SF-BREQ: short form of the BIRT Emotional Regulation Questionnaire; SF-BSCQ: short form of the BIRT Social Cognition Questionnaire; SF-BDQ: short form of the BIRT Disinhibition Questionnaire; SF-BIQ: short form of the BIRT Impulsivity Questionnaire; D-: not significantly deviating from average of healthy individuals; D+: significantly deviating from average of healthy individuals.

### Construct-based validation of the cutoff scores

For patients' SF-BIRT-PQs (Supplementary Digital Material 2: Supplementary Table II), the between-group comparisons showed significant differences (with effect sizes ranging from small to large) in satisfaction levels (as measured by the SAT-P subscales when the scoring of SF-BMQ was above the D+ cutoff. Regarding SF-BREQ and SF-BSCQ, we also found significant differences across the cutoff for the scores of all SAT-P subscales, with the exception of the work subscale. There were no significant differences in satisfaction levels across the SF-BDQ and SF-BIQ cutoffs.

When considering the caregivers' SF-BIRT-PQs (Supplementary Digital Material 3: Supplementary Table III), there were significant differences in the level of perceived caregiver's burden (as measured by the subscales of the CBI) when the scoring of each SF-BIRT-PQs was above the D+ cutoff. In particular, the largest differences were reported for SF-BREQ, SF-BSCQ, and SF-BIQ. There were also significant differences (with medium to large effect sizes) in the perceived degree of personality and behavioral change (as measured by the subscales of the FBI) when the scoring of each SF-BIRT-PQ was above the D+ cutoff.

Moreover, there were significant differences (with small effect sizes) in the disability level (as measured by DRS) across the cutoff of SF-BMQ, SF-BSCQ, and SF-BDQ of the patients' versions and for SF-BMQ, SF-BREQ, SF-BSCQ, and SF-BIQ for the caregivers' versions. Finally, significant differences were found in the level of cognitive functioning (as measured by LCF) only for SF-BREQ and SF-BIQ (with small to medium effect sizes) for the patients' version (Supplementary Table II). In contrast, there were significant differences (with small to medium effect sizes) across all the caregiver's versions of all SF-BIRT-PQs (Supplementary Table III).

### Interpretability of the measures

A ruler to convert BIRT subscale total scores into linear estimates of neurobehavioral changes was built for each

questionnaire. A working example of the SF-BMQ ruler is presented in Figure 1, a blank version of the ruler for each BIRT short-form questionnaire can be downloaded at the following link: <https://doi.org/10.5281/zenodo.17424005>. Finally, an instruction manual is reported in Supplementary Digital Material 4 (Supplementary Text File 1, Supplementary Figure 1-11).

### Discussion

The BIRT-PQs have been successfully translated and cross-culturally adapted into Italian.<sup>10</sup> However, administering these instruments (totaling 150 items) imposed an important administration burden that limited their use in clinical practice. Furthermore, our recent study<sup>11</sup> showed the lack of unidimensionality of the five BIRT subscales. Thus, within a Rasch analysis, we obtained five SF-BIRTQs (by deleting about 50% of the items) that complied with the strict measurement requirements of the Rasch model (*i.e.*, invariance, local independence, unidimensionality, and monotonicity), with reliability indices suitable for measurement on a single individual.<sup>12</sup> Within this study, we provided cutoffs for each SF-BIRT-PQ to identify subjects whose behavior deviated significantly from the average of healthy individuals (D+). Furthermore, we provided external evidence of the validity of these cutoffs. Finally, we devised a measurement ruler to construct and interpret clinically the measures obtained for individual patients and/or caregivers.

One of the main goals of this study was to facilitate the clinical interpretation of the results of the administration of a given SF-BIRT-PQ by defining meaningful cutoffs.<sup>21</sup> Practically, we calculated the cutoffs based on Z-scores to distinguish a behavioral performance significantly deviating from the average expected from healthy individuals (D+). The use of Z-scores, which are parametric statistics based on means and standard deviations, was made it possible given that the Rasch analysis provided a conversion table from ordinal total scores to continuous measures,<sup>12</sup> which were then employed for the calculations. However, for improving their interpretability, we converted back

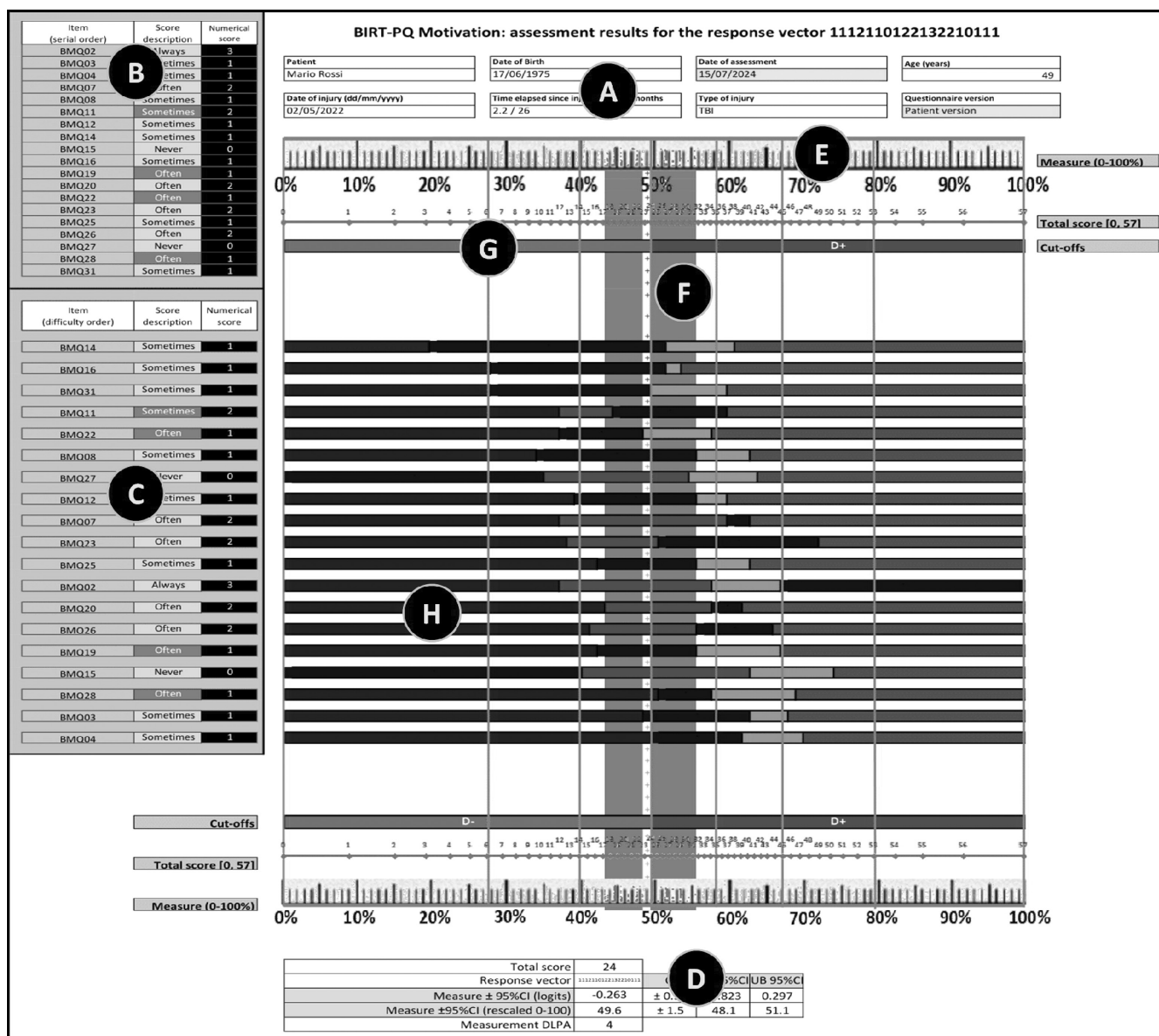


Figure 1.—A working example of the BIRT ruler for the short form of the BIRT Motivation Questionnaire. In the (A) area, demographic (*i.e.*, patient name and date of birth) and clinical (*i.e.*, type of injury, date of injury, date of assessment, and time elapsed since injury) data are reported. The short form of the BIRT Motivation Questionnaire scores is keyed in within the (B) section (left-hand side of the ruler). The (C) area reports the item scores ordered by progressively increasing difficulty from top to bottom. The (D) section reports the calculated total score, the logit measure and the rescaled logit measure on a 0 to 100 scale, all with their respective 95% confidence intervals. The rescaled logit scale is represented graphically by the ruler (E). The person measure is represented by the vertical dotted white bar (F), where the gray area represent the 95% confidence interval. The horizontal bar (G) shows whether the person's measure is, respectively, below (D-) and above (D+) the average measure of healthy individuals (in this case is above). Finally, the (H) area allows to assess graphically the relationship between the person's measure and the item response pattern that generated it, for measurement quality purposes. Further details can be found in Supplementary Digital Material 4.

the logit measure defining the cut-off into the corresponding raw score, using the same conversion table. Considering that the total scores of the patient's and caregivers' versions are invariant (*i.e.*, are not influenced by differ-

ent raters but only by the amount of the neuro-disability perceived by the responder), it is possible to compare any eventual divergence of their point of views using the cutoff as a frame of reference.

To validate these cutoffs, we adopted a construct validity approach, testing hypotheses generated on the basis of the supposed theoretical implications associated with the constructs being measured.<sup>21</sup> Regarding the caregivers' SF-BIRT-PQs, scores above the D+ cutoffs were associated with a higher burden of care from the caregiver's perspective. As expected, higher degrees of caregiver burden seemed to be associated particularly with emotional dysregulation (SF-BREQ) and problems in social cognition (SF-BSCQ), followed by impulsivity (SF-BIQ) and lack of motivation (SF-BMQ), as shown by the magnitude of effect sizes. Quite surprisingly, higher degrees of disinhibition (SF-BDQ) were associated with effect sizes of lower magnitude across all CBI domains. This aspect could be explained by the fact that disinhibition is likely to have a more significant and potentially severe impact on the patient's social relationships outside the family context. Thus, disinhibition may not necessarily translate into a burden for the caregivers, who suffer more from other behavioral alterations such as aggression. As expected, there were also substantial associations between the personality and behavior changes measured by the FBI and scores above the D+ cutoffs for all SF-BIRT-PQs, with the largest effect sizes ( $p > 0.50$ ) for emotional dysregulation (SF-BREQ) and impulsivity (SF-BIQ). However, the effect sizes were in the medium range for all the remaining SF-BIRT-PQs. These data provide strong evidence of the construct validity of the proposed cutoffs, considering that the constructs measured by the FBI are probably closer to those measured by the SF-BIRT-PQs in comparison to the other instruments.

We observed significant associations between lower levels of satisfaction from the patient's perspective and some but not all B SF-IRT-PQ scores above the D+ cutoffs. In particular, higher levels of lack of motivation were associated with significantly lower levels of satisfaction across all domains of SAT-P (moderate to large effect sizes), followed by problems in emotional regulation (SF-BREQ) and in social cognition (SF-BSC), although with effect sizes from medium to small and not across all SAT-P domains. Quite interestingly, levels of impulsivity (SF-BIQ) and disinhibition (SF-BDQ) above the D+ cutoff were not associated at all with lower levels of satisfaction. These findings are in line with previous works indicating that satisfaction after brain injury is mainly linked to emotional stability and sociability.<sup>27</sup> Moreover, the lack of correlation of satisfaction with impulsivity and disinhibition could be explained by assuming that these dimensions, given their more episodic nature, are less likely to

reach the patient's horizon of awareness. Furthermore, it is also likely that dimensions such as motivation, emotional regulation, or social cognition are more likely to receive more constant external feedback from the patients' social-relational network.<sup>27</sup>

Scores above the D+ cutoffs on the caregiver SF-BIRT-PQs were associated with higher levels of disability and lower levels of cognitive functioning (as measured respectively by DRS and LCF), with the only exception of the disinhibition domain (SF-BDQ), which was not associated with higher scores on the DRS. On the other hand, the significant associations with higher disability and lower levels of cognitive functioning were definitely patchier, given the lower levels of neuro-disability awareness that could be expected in this population. Thus, also these data provide some further evidence of construct validity of the proposed cut-offs.

The SF-BIRT-PQs rulers proposed in this article were devised with the intent of facilitating the administration and the interpretation of the SF-BIRT-PQ measures. Indeed, they provide a quick and automated method for transforming the ordinal item scores into total scores and, from those, generating the corresponding linear measures of neurobehavioral disability. The interpretation of the measures is facilitated in two ways. First, because it is possible to match visually the obtained measure against the interpretability cutoffs. Second, the ruler provides an additional visual reference for the interpretation of the measure by incorporating also the DLPA for each SF-BIRT-PQ identified by Pellicciari *et al.*<sup>12</sup> following the Rasch analysis. Furthermore, the rulers can inform the clinician of important aspects that can influence the assessment and treatment of the individual patient. Indeed, they provide a visual quality control method for each measure in a variety of ways: 1) by examining the item response pattern, it may be possible to uncover inconsistencies in the ratings and look for their most likely causes; 2) in the event of an inconsistency in the ratings, this approach can provide clinicians with valuable information that can be used in a subsequent interview of the subjects to probe possible reasons explaining that inconsistency; 3) the assessment of the individual response pattern can uncover strengths and weaknesses of the individual's performance on a questionnaire (*i.e.*, rating above or below the patient's measurement area) that could provide insight and guide for building tailored treatment plans to promote personal changes. All these features make the BIRT-PQs ruler a comprehensive clinical assessment tool. Finally, the rulers do not allow the calculation of the total scores and related measures

in the presence of missing item scores, which could otherwise lead to a systematic underestimation of the patient's abilities.

### Limitations of the study

This study presents limitations that deserve to be discussed. Firstly, the cutoffs were generated by employing Z-scores based on the sample used for the initial validation of the Italian version of the SF-BIRT-PQs.<sup>10</sup> In this respect, it should be noted that these controls did not match the caregivers' and patients' samples employed for the Rasch analysis of the SF-BIRT-PQs.<sup>12</sup> This could have influenced the accuracy of cutoffs. The latter could have been influenced also by the fact that we did not employ, as external comparators, professionally administered instruments to assess the neuropsychological profile of the patients. Third, although the logit estimates provided by the Rasch analysis are sample-independent within the same frame of reference (*i.e.*, within the same population), the external validity evidence cannot be considered as such, as they rely on parameters of the sample distribution.<sup>28, 29</sup> Thus, the generalizability of these results needs to be confirmed within other samples. Finally, the lack of a repeated measurement design did not allow us to provide evidence of the responsiveness of the SF-BIRT-PQs, which is important, as it could demonstrate that the instruments can capture changes related to the natural history or induced by treatment. Thus, it is envisaged that larger, multi-center studies involving different settings and case mixes could address these issues and fill the corresponding research gaps.

### Conclusions

In conclusion, notwithstanding some limitations, this paper provided evidence in support of the construct validity of the proposed cutoffs for each SF-BIRT-PQ (*i.e.*, SF-BMQ $\geq$ 25 points, SF-BREQ $\geq$ 19 points, SF-BSCQ $\geq$ 14 points, SF-BDQ $\geq$ 15 points, SF-BIQ $\geq$ 18 points indicated D+). These cutoffs make the SF-BIRT-PQs interpretable by quantifying the amount of the divergence of the patient's behavior from that of the average healthy individual. The electronic rulers for each SF-BIRT-PQ provide several functions that greatly facilitate the administration and interpretation of the questionnaires. These features, together with their reduced administrative burden, greatly encourage their application in the clinical and research settings for assessing neuro-behavioral disability of adult patients with sABI.

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#### *Conflicts of interest*

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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#### *Supplementary data*

For supplementary materials, please see the HTML version of this article at [www.minervamedica.it](http://www.minervamedica.it)