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Research Article

Beyond brain injury: Examining the neuropsychological and psychosocial sequelae of post-traumatic epilepsy

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Abstract

Objective: This study investigates neuropsychological and psychosocial outcomes in patients with traumatic brain injury (TBI) and post-traumatic epilepsy (PTE) compared to a healthy control group. **Method:** Utilizing a quasi-experimental cross-sectional design, the research involved patients with TBI and PTE referred from a Taiwanese medical center. An age- and education-matched control group of healthy adults without traumatic injuries was also recruited. The study involved analyzing retrospective medical records and applying a comprehensive suite of neuropsychological tests and psychosocial questionnaires. **Results:** Executive function measures revealed significantly reduced performance in both the TBI and PTE groups compared to controls. Specifically, the MoCA scores were lowest in the PTE group, followed by the TBI group, and highest in the controls. Measures of subjective symptomatology showed comparably elevated levels in both the TBI and PTE groups relative to controls. **Conclusion:** The research suggests that PTE may intensify the difficulties faced by individuals with TBI, but its impact on overall recovery might not be significant, considering the trajectory of the brain injury itself. Notably, the MoCA results indicate that cognitive deficits are more pronounced in PTE patients compared to those with TBI, underscoring the necessity for targeted neuropsychological assessments. Further investigation is essential to explore PTE's broader neuropsychological and psychosocial impacts. These findings advocate for tailored care strategies that address both neuropsychological and psychosocial needs, ensuring comprehensive management of TBI and PTE.

Keywords: Brain injuries; behavioral symptoms; epilepsy; neuropsychological tests; quality of life; self report

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Introduction

Traumatic brain injury (TBI) is a leading cause of disability (Rubiano et al., 2015), with effects that are far-reaching and can persist over the long term (Ponsford et al., 2008; Masel & DeWitt, 2010). Epilepsy is a significant neurological complication of TBI that is highly heterogeneous and may develop or recur for years following the initial injury (Agrawal et al., 2006).

Post-traumatic epilepsy (PTE) is diagnosed when a TBI patient experiences at least two unprovoked epileptic seizures linked causally to their brain injury (Wrightson and Gronwall, 1999). The reported prevalence of PTE varies widely, ranging from 2 to 53%, reflecting diverse post-injury outcomes (Christensen, 2015; Frey, 2003). Groups at higher risk for PTE include young children (Asikainen et al., 1998), those over 65 years old (Annegers et al., 2000), individuals with moderate to severe TBI (Annegers and Coan, 2000; Ferguson et al., 2010; Gilad et al., 2013), those with penetrating injuries (Annegers and Coan, 2000; Wang et al., 2008), those who have undergone brain surgery, and those with cardiovascular diseases (Ferguson et al., 2010).

Patients with TBI and epilepsy are recognized to suffer from neuropsychological deficits that affect both basic and advanced functions, as acknowledged in the literature (Mollayeva et al., 2019; Ponsford et al., 2008; Rabinowitz & Levin, 2014; Witt & Helmstaedter, 2015). Impairments in executive function are especially common, even when other neuropsychological measures show normal performance (Stuss, 2011). These impairments extend to various psychosocial domains, such as employment, relationships, and overall life satisfaction (Partanen et al., 2022; Yousefzadeh-Chabok et al., 2021). As a result, there is a viewpoint that patients with PTE may experience more profound consequences than those with TBI alone, potentially due to the additional strain of subsequent neurological events (Bushnik et al., 2004).

Patients with PTE experience a second-hit insult that exacerbates chronic outcomes in neuropsychological and psychosocial functioning (Semple et al., 2019). While research suggests that PTE patients may exhibit impairments in neuropsychological function, the complexity of PTE varies based on patient demographics and the severity of their brain injuries (Agrawal et al., 2006; Yeh et al., 2013). Although neuropsychological assessments provide valid and reliable means to evaluate the outcomes of medical interventions (Witt & Helmstaedter, 2015),

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researching PTE patients' neuropsychological functions faces challenges due to the diverse conditions of the patients, including psychiatric illnesses (Mazzini et al., 2003) and brain diseases other than TBI (Raymont et al., 2010). This diversity leads to inconclusive findings (Kuo & Su, 2023), complicating the optimization of treatment strategies. Furthermore, Witt & Helmstaedter (2013) and Witt et al. (2015) have found that certain medications may negatively impact neuropsychological outcomes, particularly executive functions. Witt and Helmstaedter's (2013) review of monitoring individual responses to antiepileptic drugs emphasizes the importance of focusing on executive functions. This is of particular concern for TBI patients with PTE, highlighting the critical need for prognosis assessments. The insights gleaned can inform a balance between the therapeutic benefits and the possible neuropsychological side effects of PTE management.

Although epilepsy complications may exacerbate recovery challenges for PTE patients, our understanding of the specific neuropsychological and psychosocial outcomes associated with this condition remains incomplete. This study utilizes neuropsychological assessments, focusing on executive function, and psychosocial questionnaires to elucidate the prognosis for patients with PTE. It also seeks to differentiate between outcomes for those with TBI, PTE, and a control group unaffected by brain injuries.

Materials and methods

Participants and procedures

This quasi-experimental, cross-sectional study involved participants above the age of 18 and included three groups: individuals with TBI, those with PTE, and a healthy control group without brain injuries. Referrals for the TBI and PTE groups were from a neurosurgical outpatient clinic in southern Taiwan, with patients undergoing regular three-month follow-ups. All participants with PTE received antiepileptic medications. The control group, consisting of healthy, independently living adults without TBI, was matched with the patient groups in terms of age and education, acknowledging these factors as critical determinants of neuropsychological outcomes. To reduce confounding variables that could impact neuropsychological outcomes, the study applied a uniform set of exclusion criteria across all groups. The exclusion criteria included the following: 1. having an intellectual disability; 2. having a history of psychiatric illness; 3. having a history of neurological illness; 4. having conditions known to affect neuropsychological function, such as dementia; 5. having visual or auditory impairments; 6. having impairment in language comprehension and expression; 7. being unable to communicate in Mandarin or Taiwanese.

Participants entered the study after signing an informed consent form. There were 48 individuals in the TBI group, 22 in the PTE group, and 40 in the healthy control group. The study was conducted following the Declaration of Helsinki and approved by the Institutional Review Board of Chi-Mei Medical Center and Chung-Shan Medical University Hospital (IRB numbers: 11012-014 and CS2-21136).

Measures

Retrospective review of medical records

A multidisciplinary team comprising neurosurgeons and clinical neuropsychologists conducted a thorough review of patient medical records. We gathered demographic information and neurological data, which encompass both injury-related and clinical specifics. Participant demographics, medical condition details, and imaging findings were collected, aligning with the recommendations of the Common Data Elements (CDEs) initiative, as established by the National Institute of Neurological Disorders and Stroke in 2011. Demographic details, such as age, gender, and years of education, were documented. Neurological data encompassed the Glasgow Coma Scale (GCS), Injury Severity Score (ISS), the cause of injury, and traumatic intracranial lesions. The ISS is an assessment scale for the three most critically affected body regions, with a score greater than 15 indicating severe trauma. A neuroradiologist's report on CT scans of trauma-related intracranial lesions, such as skull fractures, epidural hemorrhages (EDH), subdural hematomas (SDH), subarachnoid hemorrhages (SAH), intracerebral hemorrhages (ICH), intraventricular hemorrhages (IVH), and contusions, was one of the imaging parameters.

Neuropsychological assessments and psychosocial questionnaires

A comprehensive suite of neuropsychological assessments and psychosocial questionnaires was employed. A clinical psychologist or trained research staff conducted these assessments in a distraction-free setting. All personnel conducting these tests had received training in standardized testing procedures and oversight from a seasoned clinical neuropsychology supervisor. The battery of tests included the following instruments:

Montreal Cognitive Assessment (MoCA)

The MoCA is a comprehensive neuropsychological screening tool that evaluates various cognitive domains, including attention, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. The Taiwanese version of the MoCA has been validated and is considered reliable for cognitive assessment (Tsai et al., 2012).

Community Mental Status Examination (CMSE)

The CMSE is a neuropsychological functional screening test that has demonstrated good reliability and validity. It includes assessments in naming, language comprehension, categorization, spatial-tactile ability, thinking design, and memory retrieval. The test is scored out of 30, with lower scores indicating poorer neuropsychological function (Wang et al., 2016).

Tower of London (ToL)

The ToL test is used to evaluate an individual's capacity for goal-directed planning. The test apparatus includes three differently colored balls and a board with three pegs of varying lengths. It features 12 progressively challenging tasks. Participants must strategize and predict the necessary steps to move the balls onto the pegs one by one, transitioning from their original arrangement to a specified configuration (Ni et al., 2011). The test also identifies two distinct error patterns. A perseverative (P) error is recorded if a participant repeats an action that failed in a previous attempt. A commission (C) error occurs if a participant places the balls on the target peg in an incorrect color order (Krikorian et al., 1994).

Wisconsin Card Sorting Test (WCST)

The Wisconsin Card Sorting Test (WCST) assesses cognitive flexibility, problem-solving, learning, response maintenance, distractibility, shift-of-set, and concept formation abilities. It comprises four stimulus cards and 128 response cards. Participants are tasked with matching these cards based on an unknown

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principle, completing the test either upon sorting into six categories or when all 128 cards are used. To capture the key aspects of the WCST, six indices are utilized: number of trials administered, percentage of errors, percentage of perseverative responses, percentage of perseverative errors, percentage of nonperseverative errors, and percentage of conceptual level responses as outlined by Heaton in 1993.

Digit span

The Digit Span test, part of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS–IV), involves both forward and backward sequences. In the forward condition, the examiner orally presents a series of random digits, which the participant must repeat exactly as heard. In the backward condition, the participant is required to repeat the digits in reverse order (Wechsler, 2003).

Stroop

The Stroop test evaluates inhibitory control by requiring participants to quickly read words or identify ink colors. In the first phase, participants read aloud color names (W). In the second phase, participants name the ink color of each word (C). The third phase challenges participants to identify the ink color, which contrasts with the color denoted by the word (CW), despite the word's suggestion. The predicted color-word (PCW) score is calculated based on the speed of W and C using the formula: $PCW = (W \times C) / (W + C)$. The interference score measures cognitive interference by comparing the actual CW score with the PCW (Golden, 1978).

Checklist of Post-Concussion Symptoms (CPCS)

The CPCS is a questionnaire utilized to assess 16 common symptoms frequently reported after a concussion, including headaches, dizziness, and reduced memory. The questionnaire consists of two indices: one that quantifies the number of post-concussion symptoms present, and another that rates the degree to which these symptoms affect daily living. The questionnaire categorizes these impacts into four levels of severity, with higher scores indicating a greater effect on daily life (Yang et al., 2007).

Daily Executive Behaviors Scale (DEBS)

The DEBS is a self-assessment tool designed to evaluate executive functioning in daily life. Comprising 27 items, each scored on a scale from 1 to 4, the DEBS boasts a high internal consistency, with a Cronbach's alpha of 0.91. A higher cumulative score on the DEBS indicates superior execution of daily executive functions. This measure encompasses five distinct dimensions: control of motivation, organization and planning, regulation of emotions, management of social interaction inhibitions, and surveillance of the environment (Wu et al., 2009).

Center for Epidemiological Studies Depression Scale (CES-D)

The CES-D is a self-report scale used to measure the frequency and severity of depressive symptoms. It demonstrates good internal consistency (Cronbach's alpha = 0.84–0.85) and consists of 20 items. A higher total score indicates more severe depressive symptoms in the respondent (Radloff, 1977).

Taiwan version of the World Health Organization Quality of Life-brief (WHOQOL-BREF)

The WHOQOL-BREF is a questionnaire comprising 28 items that reflect both universally applicable and locally specific aspects. This tool evaluates four domains of quality of life (QoL), including physical health, psychological well-being, social relationships, and environment, offering a multifaceted view of an individual's quality of life (Yao et al., 2002).

Hierarchy of the Care Required (HCR)

The HCR is an assessment tool designed to evaluate various functions of daily living. It includes measures for basic daily activities (Activities of Daily Living, ADLs), household tasks (Instrumental Activities of Daily Living, IADLs), and cognitive and emotional aspects (Cognitive and Emotion, C&E). Each subscale consists of six questions, with each question offering five levels of needs, ranging from low to high. Higher scores indicate a greater need for care from others (Chen et al., 1999).

Statistical analysis

Independent sample t-tests or one-way analysis of variance (ANOVA) were used to analyze differences in demographic characteristics and neurological characteristics between groups. Categorical variables, including gender (male or female), brain surgery (yes or no), Injury Severity Score (ISS≥16 or ISS<16), and each type of traumatic intracranial lesion (yes or no), were analyzed using chi-square tests.

Neuropsychological tests and psychosocial questionnaires were given to all three groups, and their scores were compared using ANOVA. After that, Fisher's Least Significant Difference was used to find specific differences. Furthermore, eta squared (η^2) was calculated to investigate effect sizes. Cohen's guidelines (1988) classify the magnitude of effect sizes as small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$).

Results

A total of 110 individuals agreed to participate in the study, with 48 in the TBI group, 22 in the PTE group, and 40 in the healthy control group. Demographic and neurological data are shown in Table 1.

Demographic and neurological characteristics

Participants were 48.2% male, with an average age of 42.56 (SD = 16.63) and an average of 12.54 years of education (SD = 2.93). There were no significant differences among the three groups in terms of gender, age, or years of education.

In the trauma group, the average GCS score was 11.59 (SD = 4.35), with 42.9% having an ISS greater than 15. A car accident was the primary cause of brain injury (88.6%). A smaller proportion of TBI patients underwent neurosurgery (43.8%) compared to PTE patients (81.8%). TBI patients also had a significantly shorter average duration since injury (M = 1.51 years, SD = 2.77) than PTE patients (M = 7.97 years, SD = 6.62). For those with PTE, the average duration since the first seizure was 6.32 years (SD = 5.48). Additionally, 22.7% of patients were on multiple anticonvulsant drugs.

Neuroimaging data revealed no significant differences within the trauma group regarding the number of patients with skull fractures, EDH, SAH, or IVH. However, a significantly higher proportion of PTE patients had SDH, ICH, and contusions when compared to the TBI group. In the TBI group, SDH accounted for 47.9% of the lesions, making it the most prevalent type of traumatic intracranial lesion, whereas ICH was the most common among the PTE group, with a frequency of 81.8%.

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Table 1. Demographic and neurological characteristics of patients with traumatic brain injury, patients with posttraumatic epilepsy, and healthy controls

	TBI ($n = 48$)	PTE ($n = 22$)	Control ($n = 40$)	p-value (t/F/χ^2)
Mean age, y (SD)	42.77 (17.73)	42.05 (16.87)	42.60 (15.52)	0.986
Gender, male (%)	23 (47.92%)	15 (68.2%)	16 (40%)	0.102
Education, y (SD)	12.40 (3.46)	11.86 (3.09)	13.08 (1.95)	0.218
Mean GCS (SD)	11.88 (4.48)	11.00 (4.15)	–	0.859
Mean duration of brain injury, y (SD)	1.51 (2.77)	7.97 (6.62)	–	<0.001***
Brain surgery, *n* (%)	21 (43.8%)	18 (81.8%)	–	0.010*
ISS ≥16, *n* (%)	18 (37.5%)	12 (54.5%)	–	0.542
Skull fracture, *n* (%)	19 (39.6%)	11 (50.0%)	–	0.527
EDH, *n* (%)	5 (10.4%)	4 (18.2%)	–	0.447
SDH, *n* (%)	23 (47.9%)	18 (81.8%)	–	0.026*
SAH, *n* (%)	21 (43.8%)	11 (50.0%)	–	0.586
ICH, *n* (%)	20 (41.7%)	18 (81.8%)	–	0.006**
IVH, *n* (%)	1 (2.0%)	1 (4.5%)	–	0.519
Contusion, *n* (%)	15 (31.3%)	14 (63.6%)	–	0.034*

Note: TBI = traumatic brain injury; PTE = posttraumatic epilepsy; GCS = Glasgow Coma Score; ISS = Injury Severity Score; ISS = Injury Severity Score; EDH = epidural hematoma; SDH = subdural hemorrhage; SAH = subarachnoid hemorrhage; ICH = intracerebral hemorrhage; IVH = Intraventricular hemorrhage. *$P < .05$, **$P < .01$, ***$P < .001$.

Neuropsychological assessments

Table 2 presents a comparative analysis of neuropsychological assessments among the three groups. The ToL and WCST showed no significant differences across the groups. Conversely, the healthy control group outperformed both the TBI and PTE groups on the MoCA, CMSE, Digit Span, and Stroop tests. The MoCA indicated a large effect size in group differences ($F(2,107) = 60.018$, $p < 0.001$, $\eta^2 = 0.529$). On the MoCA, patients with PTE performed worse than those with TBI. The Digit Span Forward Test ($F(2,107) = 13.827$, $p < 0.001$, $\eta^2 = 0.205$) and Digit Span Backward Test ($F(2,107) = 9.296$, $p < 0.001$, $\eta^2 = 0.148$) also showed significant differences. Stroop Test scores for W ($F(2,107) = 11.533$, $p < 0.001$, $\eta^2 = 0.177$), C ($F(2,107) = 17.093$, $p < 0.001$, $\eta^2 = 0.242$), CW ($F(2,107) = 10.164$, $p < 0.001$, $\eta^2 = 0.160$), and PCW ($F(2,107) = 16.485$, $p < 0.001$, $\eta^2 = 0.236$) also presented significant differences. The CMSE showed a medium effect size ($F(2,107) = 6.950$, $p = 0.001$, $\eta^2 = 0.115$).

Psychosocial questionnaires

Table 3 presents the comparisons among groups for psychosocial questionnaires. We found no significant differences among the groups for CES-D. Conversely, the healthy control group outperformed the trauma group (TBI and PTE) in other questionnaires, notably the DEBS, WHOQOL-BREF, and HCR.

The WHOQOL-BREF questionnaire had a medium effect size difference ($F(2,107) = 9.275$, $p < 0.001$, $\eta^2 = 0.148$), as did the DEBS questionnaire ($F(2,107) = 4.242$, $p = 0.017$, $\eta^2 = 0.073$), especially in the planning dimension ($F(2,107) = 5.807$, $p = 0.004$, $\eta^2 = 0.098$) and the motivation control dimension ($F(2,107) = 4.239$, $p = 0.017$, $\eta^2 = 0.073$). The HCR also indicated medium effect size differences in the IADL ($F(2,107) = 5.566$, $p = 0.005$, $\eta^2 = 0.094$) and C&E ($F(2,107) = 5.527$, $p = 0.005$, $\eta^2 = 0.094$) subscales. Also, there were medium effect sizes in the WHOQOL-BREF's physical domain ($F(2,107) = 6.229$, $p = 0.003$, $\eta^2 = 0.104$), psychological domain ($F(2,107) = 5.365$, $p = 0.006$, $\eta^2 = 0.091$), social domain ($F(2,107) = 7.906$, $p < 0.001$, $\eta^2 = 0.129$), and environmental domain ($F(2,107) = 7.822$, $p < 0.001$, $\eta^2 = 0.128$). A small effect size was found in CES-D ($F(2,107) = 3.225$, $p = 0.044$, $\eta^2 = 0.057$), suggesting distinct impacts on these areas of functioning between healthy adults and those with TBI and PTE. Psychosocial questionnaires revealed no significant differences between TBI and PTE patients.

Discussion

The current study aims to expand the body of research on the neuropsychological and psychosocial prognosis for patients with PTE, which is often considered a secondary insult. Our findings indicate that individuals with TBI and PTE experience significant impairments in various neuropsychological functions compared to a control group without a history of brain injury, with the most notable differences observed in the MoCA. The MoCA scores between patients with and without PTE showed the only significant differences nearly eight years post-injury. Furthermore, the trauma group, encompassing both TBI and PTE patients, reported lower executive functions, more severe depressive symptoms, diminished quality of life, and a heightened need for caregiving support in daily living activities as well as cognitive-emotional domains.

Research has widely recognized that individuals with cerebral hemorrhages or contusions, those who have undergone brain surgery, or those over the age of 65 are at a higher risk of developing PTE (Annegers and Coan, 2000; Wang et al., 2008). Yeh and colleagues' study noted that contusions were associated with a 1.6% risk of epilepsy, while the risk rose to 7.8% with SDH. ICH presents the highest risk at 10.2%. ICH and SDH have a higher probability of causing serious brain tissue injuries compared to other brain injuries, making them the most predictive of PTE (Yeh et al., 2012). This study revealed that 81.8% of PTE patients specifically had ICH and SDH, confirming the results obtained by Yeh and colleagues. Furthermore, adult populations were found to have an increased risk of PTE for 4 years (Yeh et al., 2012), highlighting the necessity for regular follow-up.

In this study, patients with PTE exhibited a longer duration post-injury, suggesting more severe initial injuries and a need for long-term, regular follow-up in a neurosurgical outpatient clinic. The largest improvements typically occur within the first year post-injury (Sigurdardottir et al., 2020), and as time passes since the injury progresses, the recovery tends to plateau (Mollayeva et al., 2019). Neuropsychological performance trends after brain injury depend on the brain's ability to recover function (Dhandapani et al., 2012), assessment timing, neuropsychological domains

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Table 2. Summary of group differences in neuropsychological function

	Group					
	TBI (n = 48)	PTE (n = 22)	Control (n = 40)	F-test		
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*p*-value	Post-hoc	η^2
MoCA	24.02 (3.60)	21.36 (5.65)	31.48 (3.09)	<0.001***	Control > TBI > PTE	0.529
CMSE	38.58 (9.68)	40.55 (4.71)	44.15 (3.13)	0.001**	Control > TBI	0.115
TOL	30.79 (3.82)	31.09 (2.91)	31.90 (2.30)	0.256	–	–
Digit Span						
DSF	10.75 (2.27)	11.23 (2.64)	13.28 (2.15)	<0.001***	Control > TBI = PTE	0.205
DSB	7.50 (2.68)	6.77 (3.01)	9.73 (3.20)	<0.001***	Control > TBI = PTE	0.148
WCST						
Number of Trails Administered	93.57 (21.63)	84.10 (24.03)	91.77 (21.21)	0.255	–	–
Percent of Errors	56.94 (32.41)	59.25 (25.35)	58.38 (25.72)	0.948	–	–
Percent Perseverative Responses	64.60 (35.47)	69.19 (27.40)	63.85 (26.64)	0.803	–	–
Percent Perseverative Errors	61.81 (36.47)	68.29 (27.75)	66.38 (25.56)	0.674	–	–
Percent Nonperseverative Errors	52.87 (31.01)	57.10 (21.49)	59.51 (27.91)	0.691	–	–
Percent Conceptual Level Responses	59.09 (33.79)	62.86 (28.00)	57.52 (25.68)	0.804	–	–
Stroop						
W	66.65 (19.66)	66.64 (19.78)	85.28 (19.35)	<0.001***	Control > TBI = PTE	0.177
C	48.42 (14.52)	50.59 (17.82)	67.63 (16.76)	<0.001***	Control > TBI = PTE	0.242
CW	30.33 (9.99)	35.32 (13.35)	41.43 (12.09)	<0.001***	Control > TBI = PTE	0.160
PCW	27.58 (8.12)	28.40 (8.97)	37.41 (8.49)	<0.001***	Control > TBI = PTE	0.236
Interference	2.75 (6.29)	6.92 (6.84)	4.01 (9.14)	0.105	–	–

Note: C = color of ink that each word is printed. CW = the words were written in ink that differed in color from the word; CMSE = Community Mental Status Examination; DSF = Digit Span Forward Test; DSB = Digit Span Backward Test; MoCA = Montreal Cognitive Assessment; PCW = predicted color-word; S.D. = standard deviation; ToL = Tower of Landon. WCST = Wisconsin Card Sorting Test; W = color names of each word. *$P < .05$, **$P < .01$, ***$P < .001$.

Table 3. Summary of group differences in subjective measures

	Group					
	TBI (*n* = 40)	PTE (*n* = 22)	Control (*n* = 40)	F-test		
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	*p*-value	Post-hoc	η^2
CPCS						
Increased number of symptoms	7.00 (4.55)	6.63 (3.96)	–	0.769	–	–
Severity of increased symptoms	9.35 (9.81)	9.63 (11.74)	–	0.927	–	–
DEBS						
Planning	7.81 (2.80)	7.50 (3.20)	6.00 (1.74)	0.004**	PTE = TBI > Control	0.098
Motivation control	8.73 (2.62)	8.55 (3.33)	7.15 (2.23)	0.017*	PTE = TBI > Control	0.073
Emotion control	6.29 (2.65)	6.73 (2.73)	5.73 (1.83)	0.256	–	–
Inhibition of social interaction	13.23 (3.24)	13.09 (4.90)	12.13 (2.60)	0.298	–	–
Environmental monitor	8.00 (2.40)	7.86 (3.26)	7.05 (1.91)	0.172	–	–
Total score	44.06 (10.19)	43.68 (14.01)	38.05 (7.47)	0.017*	PTE = TBI > Control	0.073
CES-D	17.98 (10.50)	15.32 (11.23)	12.58 (8.41)	0.044*	TBI > Control	0.057
WHOQOL_BREF						
Physical domain	21.42 (4.30)	23.14 (3.21)	24.33 (3.66)	0.003*	Control > TBI	0.104
Psychological domain	17.98 (3.50)	18.18 (3.08)	20.35 (3.87)	0.006*	Control > TBI = PTE	0.091
Social domain	12.79 (2.25)	12.68 (2.38)	14.58 (2.34)	0.001**	Control > TBI = PTE	0.129
Environmental domain	29.27 (4.89)	30.32(5.05)	33.63(5.72)	0.001**	Control > TBI = PTE	0.128
Total score	87.60 (13.51)	90.59 (11.82)	99.90 (14.51)	<0.001***	Control > TBI = PTE	0.148
HCR						
ADLs	6.71 (1.85)	6.50 (1.92)	6.00 (0.00)	0.085	–	–
IADLs	7.94 (3.83)	7.27 (2.25)	6.00 (0.00)	0.005**	TBI > Control	0.094
C&E	7.29 (2.70)	7.18 (1.53)	6.00 (0.00)	0.005**	TBI = PTE > Control	0.094

Note: ADLs = Activities of Daily Living; C&E = Cognitive and Emotion; CES-D = Center for Epidemiological Studies Depression Scale; CPCS = Checklist of Post-Concussion Symptoms; DEBS = Daily Executive Behaviors Scale; HCR = Hierarchy of the Care Required; IADLs = Instrumental Activities of Daily Living; S.D. = standard deviation; WHOQOL_BREF = World Health Organization Quality of Life-brief Taiwan version. *$P < .05$, **$P < .01$, ***$P < .001$.

(Millis et al., 2001; Mollayeva et al., 2019), emotional status (Sigurdardottir et al., 2020), and post-injury treatment (Cicerone et al., 2019). Although the situation grows increasingly complex with time, TBI may expedite neuropsychological decline and increase the risk of dementia (Gardner et al., 2014). The study discovered no substantial differences in neuropsychological or psychosocial outcomes between the PTE and TBI groups, with a focus on executive function areas. While our findings do not exclude the potential for PTE to become more restrictive for those who experience it persistently, it seems that the impact of PTE may be relatively minor when compared to the overall progression of brain injury.

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Consistent with prior findings, this study confirms that neuropsychological impairments are common after TBI (Guo et al., 2023; Ponsford et al., 2008; Rabinowitz & Levin, 2014). The trauma group (TBI and PTE) showed significant impairments on a wide spectrum when compared to the non-brain injured control group. Nevertheless, there were no marked differences observed in the performance of the ToL and WCST. The ToL (Lezak et al., 2012; Mollayeva et al., 2019) and WCST (Gómez-de-Reg, 2020; Lezak et al., 2012) are renowned tools in clinical and research settings for evaluating executive functions such as planning and cognitive flexibility. Patients with TBI showed persistent deficits in attention, memory, fluency, and processing speed (Millis et al., 2001; Till et al., 2008). Despite executive dysfunction being typical in TBI survivors, improvements were observed in WCST performance, suggesting a potential for recovery (Millis et al., 2001). The variability in recovery may depend on factors such as the time since injury, its severity, and the specific neuropsychological domains assessed (Mollayeva et al., 2019).

The findings of the current study were consistent with previous studies. Haltiner et al. (1996) observed that individuals with late PTE had inferior neuropsychological test outcomes across various assessments at 1-year post-injury compared to those without late PTE. However, these differences were no longer statistically significant when factors related to the severity of the injury were considered. Another investigation found no discernible differences in neuropsychological test scores when comparing groups with and without PTE, suggesting similar neuropsychological outcomes for both patients 1 year after TBI (Mazzini et al., 2003). Existing studies may not have fully captured the long-term neuropsychological impact of PTE due to the brief recovery periods analyzed. PTE development can require considerable time post-injury, potentially delaying the emergence of neuropsychological effects. Our research, which assesses the average duration of nearly eight years post-PTE, indicates that seizures do not significantly influence neuropsychological outcomes, especially executive functions, within this timeframe.

Our findings are consistent with those from previous neuropsychological assessment studies. For example, Raymont et al.'s research, which used the Armed Forces Qualification Test to assess intelligence in Vietnam War veterans, showed that patients with PTE scored significantly lower. In our study, the MoCA revealed noticeable post-injury differences between patients with PTE and those with TBI. The MoCA is an extensive neuropsychological screening instrument that captures behaviors indicative of a patient's functional limitations. Such screening tests are crucial for detecting neuropsychological impairments and guiding the need for further evaluation or intervention (Lezak et al., 2012). However, there were some scoring issues. Whether using an intelligence test or a neuropsychological battery, the overall score integrates a range of subtests measuring different complex mental functions, reflecting general neuropsychological ability. This approach can cause problems when brain injuries affect certain tests within a battery, potentially reducing the composite score's sensitivity to the injury's severity. Additionally, averaging scores may mask lower performances in certain domains, reducing their impact on the overall score (Boake, 2002; Martin et al., 2000; Roebuck-Spencer et al., 2017).

Adverse psychosocial consequences were experienced in those patients with TBI, which was consistent with the previous studies, including severe depressive symptoms, poor quality of life (Semple et al., 2019), and higher needs for caregiving (Stiekema et al., 2020). However, no differences between the TBI and PTE groups were found in this study, which was inconsistent with other studies. Compared to patients with TBI, patients with PTE reported more behavioral and cognitive symptoms, such as lack of initiative and inability to plan (Mazzini et al., 2003), and more emotional problems (Burke et al., 2021). Participant characteristics may lead to variability in study results. For example, Mazzini and colleagues' study did not exclude cases of drug abuse and alcoholism, which could be factors contributing to executive dysfunction behavior (Verdejo-García et al., 2006). Moreover, Burke and colleagues' study included PTE patients with self-reported diagnoses, potentially incorporating those with psychogenic nonepileptic seizures. This could lead to significant discrepancies or misunderstandings regarding functional prognosis (Willment et al., 2015).

The limitations of this study, including its cross-sectional nature and varied post-injury times among TBI and PTE subjects, add complexity to the interpretation of neuropsychological and psychosocial outcomes. This emphasizes the importance of matching groups more precisely by injury duration and conducting ongoing neuropsychological and psychosocial assessments for PTE. Even though medicated PTE patients show similar results to those with TBI, the research calls for a detailed comparison between medicated and non-medicated states to understand treatment effects. The study indicates that the trauma group faced greater challenges, yet the presence of a second-hit effect from PTE remains ambiguous. Therefore, expansive future research with diverse neuropsychological evaluations, such as memory or processing speed, is essential to decode the intricate effects of PTE, enhance our grasp of its potential compounded impact, and inform more nuanced interventions that address the unique needs stemming from epilepsy as well as the underlying brain trauma. It also stresses the importance of developing tailored neuropsychological assessments that can more sensitively detect and differentiate the neuropsychological and psychosocial profiles unique to PTE patients.

In summary, this study has shown that the trauma group, which includes both TBI and PTE patients, presented with more significant neuropsychological challenges, especially in executive functions, and faced more psychosocial difficulties compared to a healthy control group. However, it is yet to be definitively proven whether PTE patients suffer a second hit due to the added burden of epilepsy on top of TBI. While neuropsychological screening tests suggest such an effect, the current data only partly support this finding. This emphasizes the necessity for a wider spectrum of assessments and further investigation to completely understand PTE's impact within the TBI context. Clinicians must be mindful of the varied recovery pathways and potential cumulative effects of PTE, while also recognizing the limitations of neuropsychological screening tests. Healthcare providers should conduct comprehensive and continual evaluations to fully understand the breadth of PTE's impact and develop interventions tailored to address both epilepsy and the underlying brain injury, thereby providing the most effective patient care. Personalized care strategies are crucial, considering the complex relationship between neuropsychological deficits and overall quality of life. These strategies should not only support the neuropsychological and emotional well-being of TBI and PTE patients but also be flexible to their evolving needs throughout recovery, ensuring enduring support for both patients and their caregivers.

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