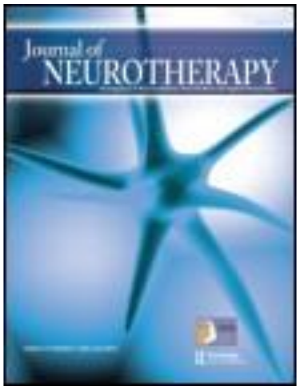


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# NEUROFEEDBACK TRAINING AS AN INTERVENTION IN A SILENT EPIDEMIC: AN INDIAN SCENARIO

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**Traumatic brain injury (TBI) is a "silent epidemic" that creates a significant burden on health care resources across the globe. TBI is a dynamic process that involves damage to the brain, thus leading to behavioral, cognitive, and emotional consequences and poor quality of life. Neurofeedback training (NFT) was employed as an intervention to study its efficacy in post-concussion symptoms, cognitive deficits, and quality of life. A pre-post design was adopted in which the intervention group underwent NFT and the other waitlist group served as a control. NFT was found to be efficacious in ameliorating postconcussion symptoms and cognitive dysfunctions and improving quality of life.**

## INTRODUCTION

India has witnessed rapid urbanization, motorization, industrialization and migration (Gururaj, 2005). An emerging problem due to this demographic, epidemiological, and social transition has been an increase in injuries and the consequent effects. The complex interaction of human, vehicle, and environmental factors along with lack of sustainable prevention programs has contributed to the "silent epidemic" of traumatic brain injuries (Gururaj, 2002). Traumatic brain injury (TBI) has been recognized as an affliction of humankind since the Stone Age (Thorell & Aarabi, 2001). TBI is considered to be an insult or trauma to the brain from an external mechanical force that leads to temporary or permanent impairments of physical, cognitive, emotional, and psychosocial functions with an associated diminished or altered state of consciousness (Whitfield, Thomas, Summers, Whyte, & Hutchinson, 2009). TBI constitutes a significant burden on health care resources in India. It is estimated that every year nearly 1.6 million individuals sustain a TBI. A vehicular accident is reported every 3 min on Indian roads (Gururaj, 2002). Road traffic injuries (RTIs) result in the deaths of more than 100,000 people, 2 million hospitalizations, 7.7 million minor injuries, and an estimated economic loss of 55,000 crore, or nearly 3% of GDP, every year. If the current scenario continues, it is estimated that India will have 185,000 deaths and 3.6 million hospitalizations by 2015. The incidence of TBI alone is 150 per 100,000 (Gururaj & Suryanarayana, 2004). The risk of having a TBI varies in terms of age, gender, and socio-environmental factors. Across studies, the highest numbers of injuries occurs among men, in the economically productive age group of 21 to 49 years of age. In India, 25% to 30%

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of injuries occur between 16 and 20 years of age, 30% to 45% between 21 and 35 years of age, and about 30% in the range of 36 to 49 years of age (Gururaj, 2002). RTIs are the leading cause (60%) of brain injury, followed by falls (20–25%) and violence (10%). Pedestrians, motorcycle riders, and bicyclists are the vulnerable road users of India and account for more than 70% of deaths and injuries in road-related accidents. Indian states with rapid motorization are also witnessing a larger share of deaths and injuries. Many of the deaths and injuries occur in B-grade metros, districts, and towns; peripheral rural areas; and on highways where transportation and motorization rates are increasing (Agarwal, 2005).

## COGNITIVE IMPAIRMENT IN TBI

TBI survivors experience persistent cognitive deficits in attention, concentration, and memory. Studies indicate impaired ability to focus attention (Stuss et al., 1989) and deficits in selective attention, divided attention, and sustained attention (Leclercq et al., 2000; McAvinue, O'Keeffe, McMackin, & Robertson, 2005). A deficit in the speed of information processing is reported by some studies to be a possible effect of head injury (Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000; Rassovsky et al., 2006). Impairment in higher levels of executive functioning, such as reasoning, planning, problem solving, emotional self-regulation, and judgment, is also indicated (Serino et al., 2006). Memory impairment has also been frequently reported in those with a TBI (Dikmen, Machamer, Powell, & Temkin, 2003; Kersel, Marsh, Havill, & Sleigh, 2001). Neuropsychological deficits are found to vary with the severity of the TBI. These studies have examined and evaluated the relationship between injury severity and neurocognitive impairment, as well as the relative contribution of these parameters to functional outcome, thereby resulting in poor quality of life.

## NEUROFEEDBACK TRAINING

Neurofeedback/EEG neurofeedback training (NFT) is an emerging neuroscience-based clinical application. It requires the individual to learn to modify the amplitude, frequency, or coherence of the electrical activity of his or her brain (Vernon, 2005). Thornton created a normative QEEG database that assessed correlates of effective memory functioning. He compared three patients (two posthead injury and one post-hippocampal surgery) and devised individualized treatment protocols in which patients demonstrated a 68% to 81% improvement in memory (Thornton, 2000). Reddy, Jamuna, Indira Devi, and Thennarasu (2009) examined neuropsychological profiles pre- and post-NFT. A 30-year-old man with mild head injury was given sessions of NFT. The training incorporated video feedback to increase the frequency of alpha waves (8–12 Hz) and theta waves (4–7 Hz). Results indicated improvement in both verbal and visual learning memory in the patient post-NFT. Hoffman and team reported that 80% of mildly posttraumatic head-injured patients demonstrated improvements in self-reported symptoms and neuropsychological measures after an average of 40 sessions of NFT (Hoffman, Stockdale, Hicks, & Schwaninger, 1995). In another study, the effectiveness of QEEG-guided NFT in mildly head-injured patients was examined ($N = 26$). NFT sessions were carried out in sets of five eyes-closed condition sessions using EEG spectrum—Neurocybernetics 3.1 equipment to normalize abnormal QEEG coherence scores. NFT sessions continued until the patient reported improvement as measured by the Global Improvement Scale or a total of 40 sessions were given. Results indicated significant improvement in 88% of the patients (Walker, Norman, & Weber, 2002). Pre- and post-NFT, cognitive abilities were assessed with the Repeatable Battery for the Assessment of Neuropsychological Status for moderate to severe brain injury. Results indicated that all 10 patients showed significant improvement in brain wave power and coherence values following 30 sessions of NFT (Zelek, 2008). Further study used the Neurotherapy System in the treatment of mild to severe closed-head injury. The sample consisted of 12 patients aged 21 to 53; the treatment group received 25 sessions. Comparison of the two groups indicated improvement of depression, fatigue, and measures of cognitive functioning. Follow-up assessments showed that the improvements were maintained after the end of treatment (Moore Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000).

## NEED FOR THE PRESENT STUDY

Head trauma is the leading cause of long-term disability in young persons in their productive years. They present with physical, cognitive, emotional, and social disabilities depending on the severity of TBI. In TBI, impairments in cognitive functioning have a bearing on bio-psycho-social and occupational functioning. Young Indian men in the productive stage of life tend to suffer these consequences of brain damage that disrupt family functioning. This imposes a burden not only on the family but also on the country at large. This imposes greater responsibilities on health care professionals and requires better health care facilities. As cognitive impairments are the most persistent and prominent sequelae of brain injury in patients with TBI, the need for neuropsychological evaluation and retraining becomes evident. Comprehensive neuropsychological rehabilitation seeks to retrain and reeducate patients with disabling injuries to cope with existing problems and to improve the levels of daily functioning (Jamuna, 2007). The rehabilitation needs of brain-injured persons are significantly high and are increasing from year to year in India and other developing countries. Newer, simpler methods and time and cost-effective techniques should be developed to reach all strata of society. NFT has been effective in patients with TBI. As patients have shown improvement in bio-psycho-social functioning, this form of training is cost- and time effective and is not labor intensive. In India, there is paucity of published studies using NFT in clinical conditions, and NFT as a method of cognitive rehabilitation in TBI has not been well researched. Hence, the current study was undertaken to evaluate and examine the effects of NFT that will help TBI patients to reintegrate into society. In India, there is a need to evaluate NFT in TBI.

## METHODOLOGY

The aim of the present study was to examine the efficacy of NFT in patients with TBI. After obtaining informed consent, 102 patients with a diagnosis of TBI were recruited from the National Institute of Mental Health and Neurosciences. Their neuropsychological profiles were analyzed; however, 42 patients dropped out before postassessment was obtained. The remaining 60 patients were recruited to an intervention group (IG) or a waitlist group (WG). The current study adopted a randomized group experimental design with pre- and postintervention assessments. The Edinburgh Handedness Inventory was used to determine handedness. The Rivermead Head Injury Follow-up Questionnaire (RHIFQ; Crawford, Wenden, & Wade, 1996), the Rivermead Post Concussion Symptoms Questionnaire (RPQ; King, Crawford, Wenden, Moss, & Wade, 1995), and the Visual Analog Scale (VAS) were used to assess the postconcussion symptoms. Neuropsychological assessment was conducted using the National Institute of Mental Health and Neurosciences (Rao, Subbakrishna, & Gopukumar, 2004) neuropsychological battery, which measured areas of speed and accuracy, attention, working memory, fluency, planning, concept formation, set shifting, response inhibition, comprehension, visual and verbal learning, and memory. The Quality of Life scale (QOL; WHO Group, 1994) was used and consisted of physical, psychological, environmental, and social areas. Sixty patients were allocated to the IG and WG at random; there were 30 patients in each group. After the preassessment, the IG received NFT and the WG did not receive any treatment. IG patients were given 20 sessions of NFT ($n = 30$). The posttraining assessment was carried out for the IG after completion of 20 sessions of NFT. The RHIFQ, RPQ, VAS, and QOL neuropsychological assessments were readministered for all 60 patients. The assessment for the WG was carried out 1 month after the preassessment.

### NFT

NFT was carried out for 20 sessions. The patients were trained at International 10–20 sites O1 and O2 using an alpha/theta protocol. Patients were educated about the procedure. Each session was 40 min with four to six sessions per week. The alpha/theta (A/T) training protocol involved recording the occurrence of alpha and theta activity while the patients were asked to relax with eyes open. Previous studies of A/T training have proved to be effective in patients with head injury, posttraumatic stress disorder, and alcohol abuse. NFT was carried out in a quiet, dimly lit room. The patient was seated in a comfortable chair in front of the neurofeedback unit. The scalp was cleaned with a gel, and then a 10–20 EEG paste was applied on the scalp. The electrodes were placed on the scalp, and proper connection with the skin was ensured. Similarly, the earlobes and the forehead were cleaned and the electrodes were placed for reference and ground sites, respectively. The wires from the sensors were plugged into the connectors in front of the neurofeedback unit. The Peak2 (A/T training) protocol was selected. The procedure and the goals of the task, which were displayed on the monitor, were explained to the patients. The rewards were given through visual feedback. The reward was in the form of scores on the right side of the screen, and the performance was proportional to the reward system. For the first few sessions, verbal feedback by the investigator was given about the achievement of the goals and the points. Instructions such as, ''Just relax and let yourself feel what it's like when you get a reward'' were used. As patients were directed to relax and pay attention to the feedback, this facilitated the natural process of learning to occur. It was assumed that the brain would spontaneously seek to satisfy the conditions of the feedback training. As the training sessions progressed, the patient would find it possible to go deeper and more consistently into the conditioned state and to maintain this state with less effort. The scores were displayed on the screen from which the patients could obtain the feedback.

## RESULTS

The results obtained on various tests were analyzed using descriptive statistics, such as the mean and standard deviation for continuous variables and frequency and percentages for qualitative variables. The neuropsychological assessment data was analyzed using a nonparametric test, as the distribution for the neuropsychological assessment data were not normal. The effectiveness of the intervention was analyzed using repeated measures (Mann-Whitney). The categorical data were analyzed using a chi-square test; $p < .05$ was considered to be statistically significant. Effect size was calculated to analyze the effect of neurofeedback training. Data were analyzed using SPSS 15.0 for Windows.

The mean age of the IG was $28.27 \pm 7.66$ years and was $30.80 \pm 8.38$ years for the WG. There was not a significant difference in age between the IG and the WG. The mean number of years of education was $11.97 \pm 2.71$ years in the IG and $9.10 \pm 4.41$ in the WG. The number of years of education in the WG was significantly less than in the IG ($p = .041$). However, when considering school versus college-educated patients, in the IG, 16 (53.3%) were college educated and 14 (46.7%) were school educated. In the WG, 20 (66.6%) were school educated and 10 (33.3%) were college educated. There was no statistical difference between the groups in terms of school versus college education rates ($p = .096$). The male-to-female ratio was 27:3 in each group (90% male and 10% female in both the IG and WG). There was not a significant difference in gender between the IG and WG ($p = .665$). There were significant differences between the groups for the following sociodemographic and clinical details: number of years of education, rural verses urban background, TBI severity, and assessment period. Patients in the IG underwent neuropsychological assessment at 1-year post TBI. The mean number of years in the IG was greater than the WG. With respect to background, the majority of the IG was from urban areas, whereas the majority of the WG was from rural areas. There were 20 married patients (66.7%) in the IG, and there were 17 (56.7%) in the WG. There was no statistical difference between the IG and WG with regard to marital status ($p = .591$). There were equal numbers of patients in the IG who were employed and unemployed, with 15 (50%) in each category of employment. In the WG, 18 (60%) were employed. Employment status did not differ significantly between the IG and WG ($p = .302$). With regard to urban versus rural distribution, 24 (80%) were from urban areas in the IG and 11 (36.7%) were from urban areas in the WG. There was a significant difference ($p = .001$) in terms of background. The socioeconomic status was divided into three groups: lower, middle, and upper socioeconomic status. Both the IG and WG had major representations from the middle socioeconomic status, with 14 (46.7%) in the IG and 16 (53.3%) in the WG. Socioeconomic status did not differ significantly between IG and WG ($p = .681$). There were seven (23.3%) mild, six (20%) moderate, and 17 (56.7%) severely injured patients in the IG. In the WG, 12 (40%) were mild, 10 (33.3%) were moderate, and eight (26.7%) were severe TBI. There was no significant difference between the groups in terms of severity ($p = .062$). There were 16 (53.3%) in the IG and 13 (43.3%) in the WG with frontal involvement ($p = .303$). Temporal lobe involvement was found in 16 (53.3%) patients in the IG and in 11 (36.7%) in the WG ($p = .150$). Parietal lobe involvement occurred in nine (30%) patients in the IG and in 10 (33.3%) of the WG ($p = .500$). There was less occipital lobe involvement in both groups with 10% in the IG and 6.7% in the WG ($p = .500$). The groups did not differ with respect to imaging findings. There was a significant difference between the two groups for assessment point 26 (86.7%; $p = .036$) in that the WG underwent neuropsychological assessment within 1 year of the TBI, whereas 19 (63.3%) in the IG underwent assessment within 1 year of the TBI. In terms of surgery, there was no significant difference between the IG and WG. The number of patients who underwent surgery in the IG was 11 patients (36.7%), whereas 13 (43.3%) patients in the WG underwent surgery. In the IG, 16% were left lateralized, 16% were right lateralized, and 23% had bilateral involvement. In the WG, 13% were left lateralized, 30% were right lateralized, and 16% were bilateral. There was no significant difference between the IG and WG groups for lateralization ($p = .653$).

### Baseline Comparison Between IG and WG

Groups were comparable on postconcussion symptoms; there were no significant differences between the IG and WG. However, patients in the IG reported significantly more symptoms on the Visual Analog Scale than did the waitlist group ($p = .031$). Patients in the IG and WG were comparable on the domains of psychological, social, and environmental QOL, though there was a significant difference in the physical domain of QOL (IG $M = 17 \pm 3.42$; WG $= 19.67 \pm 3.19$; $p = .003$). The physical domain score of the QOL scale in the WG was greater than in the IG.

The IG and WG were comparable on the neuropsychological variables of motor speed, mental speed, attention, executive functions, and visual memory. There was a significant difference between variables such as verbal learning and memory and visuo-constructive ability. The IG scores were $6.68 \pm 3.48$ for immediate recall (IR) and $6.21 \pm 3.40$ for delayed recall (DR), whereas for the WG, IR was $8.87 \pm 3.48$ and DR was $8.33 \pm 3.43$. At baseline, the raw scores of the WG on the Auditory Verbal Learning Test (AVLT) IR ($p = .048$) and AVLT DR ($p = .014$) were higher than those of the IG. The copy scores on the Complex Figure Test (CFT) were higher in the WG than in the IG ($30.50 \pm 9.13$ in the IG and $30.97 \pm 6.23$ in the WG; $p = .017$). There was a statistically significant difference between the IG and WG groups on verbal memory and visuo-constructive ability (see Table 1). The mean percentile score

**TABLE 1.** Comparison of Pre and Post Concussion Symptoms PCS and QOL in the IG and WG

| | Pre IG | | Post IG | | | Pre WG | | Post WG | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | *M* | *SD* | *M* | *SD* | *p* | *M* | *SD* | *M* | *SD* | *p* |
| VAS | 7.87 | 2.22 | 2.83 | 2.13 | <.001 | 6.20 | 3.02 | 5.77 | 3.07 | .032 |
| RHIFQ | 30.20 | 7.59 | 13.20 | 7.85 | <.001 | 26.57 | 10.29 | 22.27 | 10.15 | .012 |
| RPQ | 41.33 | 9.80 | 12.90 | 7.02 | <.001 | 38.40 | 11.94 | 35.33 | 12.62 | .015 |
| QOL Physical | 17.00 | 3.42 | 22.90 | 2.02 | <.001 | 19.67 | 3.19 | 19.77 | 3.52 | .924 |
| QOL Psychological | 15.17 | 3.05 | 19.10 | 1.82 | <.001 | 16.73 | 2.59 | 17.27 | 3.23 | .168 |
| QOL Social | 8.47 | 1.97 | 10.47 | 0.97 | <.001 | 8.97 | 1.45 | 9.33 | 1.47 | .286 |
| QOL Environment | 28.00 | 5.11 | 30.77 | 2.81 | .000 | 27.80 | 3.56 | 27.80 | 3.38 | .882 |
| Total QOL | 68.63 | 11.85 | 83.23 | 5.68 | <.001 | 73.16 | 8.38 | 74.16 | 9.28 | .330 |

*Note:* $N = 60$, 30 in the intervention group (IG) and 30 in the waitlist group (WG). VAS = Visual Analog Scale; RHIFQ = Rivermead Head Injury Follow-up Questionnaire; RPQ = Rivermead Post-Concussion Questionnaire; QOL = Quality of Life.

of the IG on the AVLT was $6.54 \pm 5.13$. The mean percentile score of the WG on the AVLT was $13.00 \pm 10.55$ ($p = .001$). The mean percentile score on the AVLT IR was $10.64 \pm 14.67$ in the IG, whereas in the WG, it was $20.83 \pm 17.22$ ($p = .002$). The AVLT DR mean percentile score for the IG was $8.14 \pm 7.99$; the mean score of the WG was $8.90 \pm 3.55$ ($p = .002$). The mean percentile of the IG on the CFT DR was $17.64 \pm 23.93$; the mean percentile of the WG was $30.33 \pm 29.15$ ($p = .040$). In terms of percentile scores, there was a significant difference between the groups with regard to verbal learning and memory and visual memory.

### Comparison of the IG and WG Post-NFT

There was a significant difference between pre- and postassessment measures in the IG and WG for postconcussion symptoms (PCS). The IG pre and post means and standard deviations are as follows: pre VAS was $7.87 \pm 2.22$, post $2.83 \pm 2.13$ ($p \leq .001$); pre RHIFQ was $30.20 \pm 7.59$, post $13.20 \pm 7.85$ ($p \leq .001$); and pre RPQ was $41.33 \pm 9.80$, post $12.90 \pm 7.02$ ($p \leq .001$). The pre and post scores in the WG are as follows: VAS was $6.20 \pm 3.02$, post $5.77 \pm 3.07$ ($p = .032$); pre RHIFQ was $26.57 \pm 10.29$, post $22.27 \pm 10.15$ ($p = .012$); and pre RPQ was $38.40 \pm 11.94$, post $35.33 \pm 12.62$ ($p = .015$). These results indicate a significant reduction in PCS from pre- to postassessment in the IG and WG. The pre and post mean scores on the QOL domains in the IG are as follows: physical QOL $17.00 \pm 3.42$ and $22.90 \pm 2.02$ ($p \leq .001$); psychological $15.17 \pm 3.05$ and $19.10 \pm 1.82$ ($p \leq .001$); social $8.47 \pm 1.97$ and $10.47 \pm .97$ ($p \leq 0.001$); environment $28.00 \pm 5.11$ and $30.77 \pm 2.81$ ($p = .001$); and total QOL $68.63 \pm 11.85$ and $83.23 \pm 5.68$ ($p \leq .001$). In the WG, the pre and post mean scores on the QOL scale are as follows: physical QOL $19.67 \pm 3.19$ and $19.77 \pm 3.52$ ($p = .924$); psychological $16.73 \pm 2.59$ and $17.27 \pm 3.23$ ($p = .168$); social $8.97 \pm 1.45$ and $9.33 \pm 1.47$ ($p = .286$); environment $27.80 \pm 3.56$ and $27.80 \pm 3.38$ ($p = .882$); and total QOL $73.16 \pm 8.38$ and $74.16 \pm 9.28$ ($p = .330$). These results indicate that there is a statistically significant difference between the pre and post scores across all domains of QOL in the IG, and there was minimal improvement in the WG from pre to post as the mean scores were not statistically significant for QOL (see Table 1).

The IG mean raw scores on the pre and post neuropsychological tests showed significant improvement from baseline in the following variables: motor speed, mental speed of information processing, sustained attention, category fluency, working memory, planning, concept formation, ability to shift set, response inhibition, verbal comprehension, visuoconstructive ability, verbal and visual learning, and memory (see Figure 1). In contrast, the planning and concept formation percentile scores of the IG were not statistically significant when comparing the pre- and postassessment

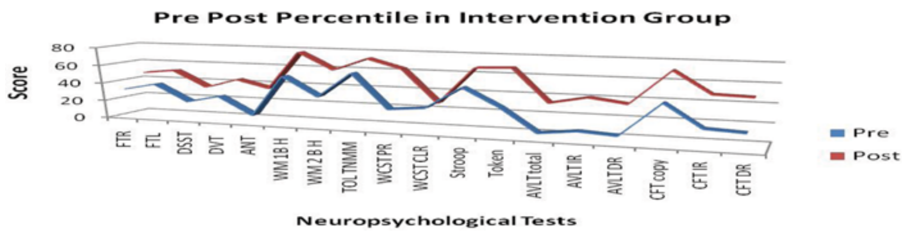


**FIGURE 1.** Pre-post neuropsychological test percentile scores for the intervention group ($n = 30$). (Color figure available online.)

scores. In the WG, mental speed ($p = .041$), set-shifting ability ($p = .041$), verbal learning ($p = .008$), and visual memory (CFT IR, $p = .012$ and CFT DR, $p = .040$) improved significantly in the postassessment as compared to the baseline assessment (see Tables 2 and 3). There were no statistically significant differences in motor speed, category fluency, working memory, concept formation, or verbal and visual memory in the WG when comparing pre- and postassessment scores (see Figure 2).

Effect sizes were calculated assess the degree of changes that occurred post NFT. The results show that postconcussion symptoms on the RHIFQ (ES = 1.47) and RPQ (ES = 2.79), the Visual Analog Scale (ES = 3.25), and the Quality of Life Total (ES = 1.43) had large effect sizes. On neuropsychological variables, motor speed for the right hand (ES = 0.87), verbal working memory (ES = 1.16), set shifting ability (WCST PR ES = 0.76), and verbal learning and memory (AVLT total ES = 1.06, AVLT IR ES = 1.62, AVLT DR ES = 1.56) were found to have a large effect size. Motor speed for left hand (ES = 0.58), concept formation (ES = 0.36), visuo-constructive ability (ES = 0.41), visual learning and memory (CFT IR ES = 0.57, CFT DR ES = 0.66), had medium effect size. Mental speed

**TABLE 2.** Comparison of Pre-Post Neuropsychological Variables in the Intervention Group

| | Pre | | Post | | |
|---|---|---|---|---|---|
| Neuropsychological variables | *M* | *SD* | *M* | *SD* | *p* |
| FTR | 42.14 | 9.07 | 47.93 | 7.29 | <.001 |
| FTL | 39.51 | 6.94 | 42.75 | 7.04 | .005 |
| DSST | 347.61 | 176.90 | 287.86 | 137.41 | <.001 |
| DVT | 748.32 | 264.94 | 554.68 | 220.73 | <.001 |
| ANT | 9.21 | 3.19 | 10.67 | 3.28 | .005 |
| WM 1B H | 8.11 | 1.06 | 8.64 | 0.62 | .021 |
| WM 2 B H | 5.41 | 1.94 | 7.19 | 1.21 | <.001 |
| TOL | 7.63 | 2.78 | 9.15 | 1.79 | .007 |
| WCST PR | 47.85 | 32.64 | 18.54 | 14.34 | <.001 |
| WCST CLR | 42.42 | 21.76 | 57.85 | 14.59 | .005 |
| Stroop | 184.42 | 131.93 | 122.43 | 86.79 | <.001 |
| Token | 29.45 | 7.50 | 34.52 | 2.16 | <.001 |
| AVLT Total | 33.50 | 11.48 | 50.68 | 9.90 | <.001 |
| AVLT IR | 6.68 | 3.48 | 11.14 | 3.06 | <.001 |
| AVLT DR | 6.21 | 3.40 | 10.86 | 3.34 | <.001 |
| CFT Copy | 30.50 | 9.13 | 34.11 | 4.58 | <.001 |
| CFT IR | 13.57 | 7.95 | 23.32 | 8.64 | <.001 |
| CFT DR | 14.18 | 7.63 | 23.61 | 8.23 | <.001 |

*Note:* $N = 30$. FTR = Finger Tapping Test (Right); FTL = Finger Tapping Test (Left); DSST = Digit Symbol Substitution Test; DVT = Digit Vigilance Test; ANT = Animal Names Test; WM 1 B H = Working Memory 1 Back Hits; WM 2 B H = Working Memory 2 Back Hits; TOL = Tower of London Test; WCST PR = Wisconsin Card Sorting Test (Perseverative Responses); WCST CLR = Wisconsin Card Sorting Test (Conceptual Level Responses); STROOP = Stroop Test–; AVLT = Auditory Verbal Learning Test (IR = Immediate Recall; DR = Delayed Recall); CFT = Complex Figure Test (IR = Immediate Recall; DR = Delayed Recall).

**TABLE 3.** Comparison of Pre-Post Neuropsychological Variables in the WG

| | Pre | | Post | | |
|---|---|---|---|---|---|
| Neuropsychological variables | *M* | *SD* | *M* | *SD* | *p* |
| FTR | 44.59 | 8.63 | 44.62 | 10.08 | .270 |
| FTL | 41.56 | 6.55 | 41.70 | 8.38 | .459 |
| DSST | 405.17 | 245.25 | 355.77 | 159.77 | .041 |
| DVT | 722.67 | 303.08 | 689.77 | 306.45 | .153 |
| ANT | 10.13 | 3.812 | 10.17 | 3.260 | .935 |
| WM 1B H | 8.10 | 0.97 | 8.17 | 1.10 | .683 |
| WM 2 B H | 5.90 | 1.80 | 5.34 | 2.12 | .118 |
| TOL TNMM | 8.68 | 2.51 | 8.75 | 1.80 | .594 |
| WCST PR | 41.68 | 26.54 | 35.1 | 21.22 | .041 |
| WCST CLR | 36.15 | 17.87 | 39.96 | 18.30 | .782 |
| Stroop | 172.14 | 115.95 | 148.41 | 109.74 | .200 |
| Token | 32.17 | 3.68 | 32.07 | 4.19 | .456 |
| AVLT total | 38.30 | 13.34 | 43.43 | 15.55 | .008 |
| AVLT IR | 8.87 | 3.48 | 8.87 | 3.78 | .943 |
| AVLT DR | 8.33 | 3.43 | 8.90 | 3.55 | .204 |
| CFT copy | 30.97 | 6.23 | 31.86 | 3.89 | .411 |
| CFT IR | 16.37 | 8.42 | 20.13 | 8.10 | .012 |
| CFT DR | 16.97 | 8.35 | 19.60 | 8.62 | .040 |

*Note.* $N = 30$. FTR = Finger Tapping Test (Right); FTL = Finger Tapping Test (Left); DSST = Digit Symbol Substitution Test; DVT = Digit Vigilance Test; ANT = Animal Names Test; WM 1 B H = Working Memory 1 Back Hits; WM 2 B H = Working Memory 2 Back Hits; TOL = Tower of London Test; WCST PR = Wisconsin Card Sorting Test (Perseverative Responses); WCST CLR = Wisconsin Card Sorting Test (Conceptual Level Responses); STROOP = Stroop Test–; AVLT = Auditory Verbal Learning Test (IR = Immediate Recall; DR = Delayed Recall); CFT = Complex Figure Test (IR = Immediate Recall; DR = Delayed Recall.

on DSST (ES = 0.29) and category fluency (ES = 0.27) had small effect size. There was no significant effect size with sustained attention or response inhibition on the Stroop test. The baseline assessment indicated that patients in the IG performed worse than the WG. The large effect size on memory indicates that NFT is effective in ameliorating deficits in memory.

In summary, patients in the IG reported more symptoms on the Visual Analog Scale than those in the WG. There was a significant difference on the physical domain of the Quality of Life measure. The physical domain of the QOL scale was greater in the IG than in the WG. The IG and WG were comparable on most neuropsychological variables except for verbal memory and visuo-constructive ability. The verbal memory scores were higher in the WG than the IG. Post NFT, there was significant reduction in postconcussion symptoms in both the IG and WG, indicating improvement of postconcussion symptoms experienced in these patients. QOL improved significantly in the IG when compared to the WG. In the IG, there was significant improvement when comparing baseline and postintervention scores in the

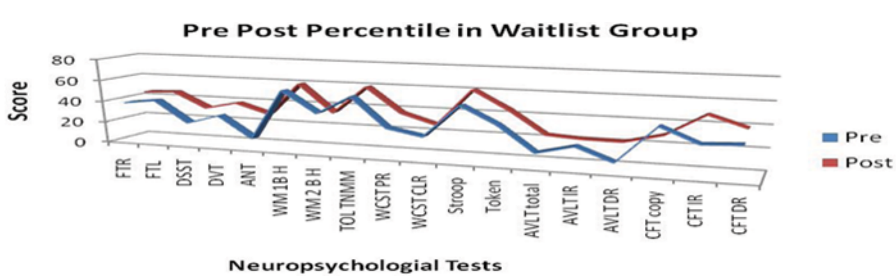


**FIGURE 2.** Pre-post neuropsychological test percentile scores for the waitlist group ($n = 30$). (Color figure available online.)

following areas: motor speed, mental speed, sustained attention, category fluency, working memory, planning, concept formation, ability to shift set, response inhibition, verbal comprehension, visuo-constructive ability, verbal and visual learning, and memory. In the WG, there was minimal improvement for motor speed, mental speed, working memory, planning, conceptual level responses, and verbal memory scores, whereas set shifting, verbal learning and visual memory improved significantly. There was not statistically significant improvement in the EEG post neurofeedback. Working memory, verbal learning and memory were found to have large effect sizes. Motor speed in the left hand, concept formation, visuo-constructive ability, visual learning, and memory had medium effect sizes. Category fluency and mental speed had small effect sizes. No effect size was found with sustained attention and response inhibition. Large effect sizes were found for postconcussion symptoms on the Visual Analog Scale and Quality of Life scores (physical, psychological, and environmental domains and total). The social domain of the QOL measure had a medium effect size. The first hypothesis that there would be no significant difference between the IG and WG on the behavioral symptoms post NFT was accepted. Post NFT, there was significant improvement in the IG and WG. However, the effect size of NFT was large for postconcussion symptoms in the IG. The second hypothesis that there would be no significant difference between the IG and WG on QOL post NFT was rejected. As compared to the WG, there was significant improvement in the IG on QOL. The third hypothesis that there would be no significant difference between the IG and WG on the neuropsychological variables post NFT was rejected. Post NFT, there was significant improvement in the IG both within and between groups.

## DISCUSSION

An important aspect of this study is that it is the first to use NFT in patients with TBI in India. As TBI is on the rise in India, this study has demonstrated that NFT is effective in ameliorating cognitive dysfunction and improving QOL in patients with TBI. It is cost- and time effective and is less labor intensive than other treatment modalities.

The limitations of the study are that the distribution of gender and the severity of injury were not equal in the IG and WG, and pre-post EEGs were not recorded for the WG. In addition, follow-up assessment could not be carried out for all the patients to measure the long-term effectiveness of the NFT. Follow-up for some patients was made over the telephone. Patients and their families reported maintenance of gains post NFT. Improvements were corroborated with clinical interviews with patients and significant others post NFT.

One objective of the current study was to compare the behavioral symptoms in IG and WG pre and post NFT. Research to date indicates that neuropsychological rehabilitation facilitates the reduction of concussive symptoms (Kumar, 1999). The current study indicates that NFT as a cognitive rehabilitation method was effective in reducing postconcussive symptoms in patients with TBI. However, improvements in PCS were also seen in the WG, possibly due to employment status and type of injury. Sixty percent of the patients in the WG were employed, whereas only 50% were employed in the IG. It is postulated that employment could have improved functionality, thus also improving PCS. Similarly, more than 40% of the WG had mild TBI, but only 23.3% of the IG had mild injuries; hence the recovery in the WG could be attributed to neuroplasticity effects (see Table 1).

Another objective of this study was to compare QOL in the IG and WG before and after NFT. The QOL scale measured changes in the areas of physical, psychological, social, and environmental domains. The results indicated that there were statistically significant differences between the pre and post scores across all domains of QOL in the IG, but there was only minimal (nonsignificant) improvement in the WG. These results suggest that

NFT is effective in enhancing QOL in patients with TBI. These findings are corroborated by a study conducted by Reddy, Jamuna, Bagavathula, and Kandavel in 2010.

The neuropsychological assessment results obtained in this study indicate that NFT influenced the recovery of all the cognitive functions that were assessed (motor speed, mental speed of information processing, sustained attention, category fluency, working memory, planning, concept formation, ability to shift set, response inhibition, verbal comprehension, visuo-constructive ability, verbal and visual learning, and memory). It is postulated that head trauma is underpinned by neurophysiological mechanisms that are associated with diencephalon and mesencephalon fiber disruption, alteration of cerebral blood flow, altered neurotransmitter metabolism, and psychosomatic or neurotic factors. Retraining brainwave patterns through operant conditioning of the EEG has been shown to be an effective method of reprogramming neuronal firing patterns. It is proposed that EEG feedback directly intervenes with central nervous system damage, and inhibits the abnormal activity associated with symptoms. NFT effectiveness is based on operant conditioning of bioelectrical neuro-regulation. When patients receive reinforcement, neurons communicate or fire more rapidly, thereby facilitating connections among neurons. NFT resembles pharmacological approaches in which stimulants facilitate the utilization of neurotransmitters. NFT utilizes the relationship between mental states and brainwave frequencies. Activation and arousal of the central nervous system are related to the rhythmic activity of neuronal firing patterns. The findings of the present study are corroborated by studies where NFT was found to be effective in enhancing cognitive functions (Ayers, 1991; Keller, 2001; Moore Sohlberg, 2000; Thornton, 2000; Vernon, 2003; Walker et al., 2002).

The neuropsychological assessment showed motor speed, working memory, planning, concept formation, and verbal memory scores improved but did not improve significantly in the WG. Executive functions and verbal memory did not show significant change as compared to preassessment in the WG. The mental speed, set shifting ability, verbal learning and memory, and visual memory scores improved significantly from pre to post in the WG. These improvements could be due to natural recovery or neuroplasticity. The process of neuroplasticity is the ability of the brain to change, in response to either experience or injury. Research has emphasized that this takes place via local restitution as well as reorganization and compensatory reassignment (Raymont & Grafman, 2006). Plasticity could also be influenced by synaptic connectivity, nonsynaptic transmission such as volume transmission (Bach-y-Rita & Aiello, 1996), regeneration, and/or multiplexing (Bach-y-Rita & Bach-y-Rita, 1990).

This study was carried out with the aim of increasing alpha waves and theta waves via NFT in the IG group. Although the pre-post comparison indicates that alpha at O1 and O2 actually decreased, theta waves also decreased but were higher relative to alpha indicating a crossover effect. The phase when theta activity becomes more dominant than alpha (theta/alpha crossover) is usually associated with loss of consciousness and the onset of stage one sleep, but the aim of A/T feedback is to facilitate a state of deep relaxation by teaching individuals to raise theta above alpha activity while not falling asleep. Thus, A/T feedback training allows individuals to consciously enter a mental state that would normally be unconscious (Egner, Strawson, & Gruzelier, 2002). Peniston and Kulkosky (1991) found that alpha-theta neurofeedback counteracts increased beta-endorphin levels related to stress (Saxby & Peniston, 1995). Our results indicated that TBI patients learned to relax and thus reduce levels of stress, which directly or indirectly facilitated the enhancement of the cognitive functioning.

The NFT protocol used as a cognitive rehabilitation procedure in this study was intended to encourage the patients to relax. This relaxation, in turn, appeared to reduce the stress levels experienced by these patients. The reduction in stress contributed to positive perception of self, improvement in subjective well-being, and an increased awareness of PCS due to TBI. The reduction in PCS improved QOL. It may be that the improvement in QOL and the decrease in PCS contributed to improvement in cognitive functions. The NFT procedure, along with neuroplasticity, appears to have contributed to these improvements. The Liner Model of QOL (Heinemann & Whiteneck, 1995) indicates that disability or impairment due to TBI leads to poor cognitive functioning, which in turn leads to poor QOL. In accordance with this model, cognitive dysfunction in TBI patients improved significantly following NFT in the present study, thereby improving QOL. TBI has both cognitive and bio-psychosocial consequences that decrease quality of life. Following a TBI, the brain is able to heal and recover some cognitive functions due to neuroplasticity, though the patient is often left with some residual symptoms and cognitive dysfunction. If NFT is introduced, the recovery process is facilitated by improved autoregulation skills and homeostasis, thus normalizing the EEG frequencies. The neurophysiological changes that take place as a result of NFT lead to improvement in neuropsychological functioning, which in turn improves QOL (see Figure 3).

In conclusion, the patients in the IG improved significantly. The PCS reduced significantly. QOL across all domains improved significantly. The neuropsychological functions improved significantly from pre to post NFT. The patients in the WG improved minimally. Hence, NFT appears to be effective in ameliorating deficits in cognitive functioning and enhancing QOL in patients with TBI. Suggestions for future study are to undertake research in understanding the mechanisms and processes of NFT and to study NFT with other forms of cognitive rehabilitation.

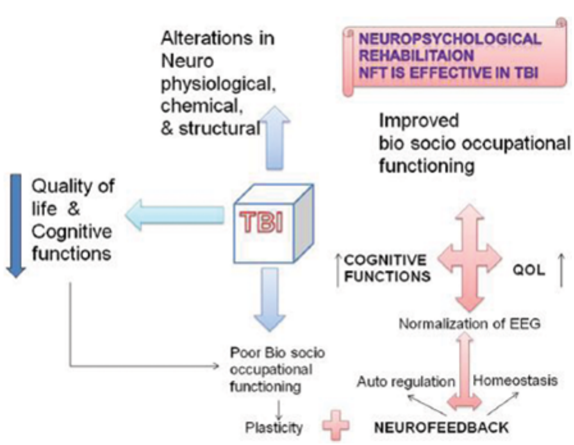


**FIGURE 3.** Proposed model of how neurofeedback training (NFT) improves cognitive and behavioral dysfunction in traumatic brain injury (TBI). (Color figure available online.)

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