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Brain-Computer Interface (BCI) for Enhancement of Attention in Post Stroke Patients – A Pilot Study

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ABSTRACT: Attention problems after stroke are common. Attention is associated with cognitive productivity, post stroke balance, functional impairment and daily living. Improving attention is the key for learning motor skills. Previous studies have made use of methods like APT (Attention Process Training) for enhancement of attention in post stroke subjects. But these approaches have failed to provide real-time feedbacks. This study explores the possibility of BCI-based attention training in improving attention levels and thereby improving the quality of life among post stroke patients. This is a pilot study with an experimental group and a control group with 10 subjects in each group. Participants were 20 survivors of anterior and middle cerebral artery ischemic stroke in the late subacute stage, both right and left hemiplegics, diagnosed for stroke by WHO criteria. The baseline values -- the e sense attention meter score, Bells Test score, and Trail Making Test (TMT) Parts A & B score along with the Stroke Specific Quality of Life scale (SS-QOL) -- were taken before intervention. The intervention involved 3 sessions per week of BCI based attention training for 8 weeks, followed by a maintenance training of 3 sessions per month for the next 12 weeks for the experimental group. Both groups were given standardized physical therapy care for 3 sessions per week through all the 20 weeks. The post intervention assessment values were taken with the same tools used for baseline values at the end of 20 weeks of intervention and at one month follow up. The results of this pilot study confirm that BCI based attention training along with standardized physical therapy care for stroke enhances attention levels in post-stroke subjects. BCI-based attention training for post-stroke patients faces challenges like small sample size, blinding, ethical considerations, and safety.

Keywords: Brain Computer Interface, Stroke, Attention, Bells Test, Trail Making Test, Stroke Specific quality of Life.

INTRODUCTION

Many people have attention problems after stroke. Ability to concentrate for long is lacking in them, and they are easily distractible, as they are unable to focus on a particular task in the midst of competing information. Reviews have concluded that overall, there is insufficient evidence to support or refute the effectiveness of cognitive rehabilitation for attention after stroke (Loetscher and Lincoln 2013; Lincoln *et al.*, 2020; Park and Ingles 2001). Therapeutic activities are computerised activities as well as pencil-and-paper tasks which are designed to restore attention abilities. The alternative approach is to teach the subjects strategies to overcome their attention impairments. The restitution approach for the restoration of basic aspects of attention and attempts to retrain attention skills have been commonly followed, but trials of attention retraining have shown that development of compensatory strategies produce better results (Cicerone *et al.*, 2011). Attention process training (APT) is found to be an effective and viable means of improving attention deficits in post-stroke patients (Barker *et al.*, 2009).

Brain-computer interface (BCI) is a system which connects the brain and a device that uses signals from the brain for some external activity. The interface acts as a pathway to enable communications between the brain and the object to be controlled. Its functioning involves acquiring of brain signals, analyzing them, and translating them into commands which are then relayed to output devices for carrying out the required actions.

Several BCI applications aid in the verbal, motor, sensory, and cognitive rehabilitation of stroke patients. BCI-FES (functional electrical stimulation) therapy activates the body's natural efferent and afferent pathways, thereby inducing plasticity and promoting functional recovery, which in turn facilitates motor learning and neural reorganization (Remsik *et al.*, 2022). BCI combined with VR technology can facilitate recovery of brain function by increasing the appeal of training through individual motivation, providing more effective feedback and thus shortening the training cycle (Wen *et al.,* 2021). EEG-EMG-based BCI technology is useful in hand orthotic neurorehabilitation system (Chowdhury *et al.,* 2019). The exoskeleton-BCI system provides the ability to repeat training exercises and thus enhance rehabilitation by increasing the intensity of movement (Colucci *et al.,* 2022). Many studies have shown that BCI treatment can improve upper limb motor function in subacute and chronic stroke patients. Improvement in upper limb motor function in stroke patients can be achieved by a BCI-supported robotic rehabilitation system based on motor imagery. It can also facilitate rehabilitation of the affected hand and wrist in poststroke patients. A recently developed technology of a robotic arm controlled by a BCI is promising to restore sensorimotor function (Casey *et al.,* 2021). Communication rehabilitation is affected by P300-BCI which enables subjects diagnosed with poststroke aphasia to learn to communicate using a speller (Kleih *et al.*, 2016).

The use of BCIs to improve attention has not been much explored. There are some studies on the effectiveness of the BCI in enhancing attention in attention deficit hyperactivity disorder (ADHD), Amyotrophic Lateral Sclerosis (ALS), Autistic Spectrum Disorder (ASD), and dementia subjects as well as in healthy adults and elderly. BCI holds promise for poststroke patients by recording and decoding brain activity while trying to perform motor and cognitive tasks. It can instigate movement, provide feedback on motor imagery, and monitor the comprehensive level of attention in performing tasks and the level of inter-hemispheric balance. The amount of mental workload is an important issue in motor learning and how hard the brain is working to meet task demands (Ayaz *et al.,* 2012). Near infra-red spectroscopy (NIRS) measured activity over the prefrontal cortex could discriminate between low and moderate levels of workload (Mandrick *et al.,* 2013) with a plateau effect towards higher levels of workload. Studies have shown that it is possible to monitor changes in attention during BCI training. BCI along with exoskeleton technology has been investigated to bring about multimodal stimulation in the rehabilitation of stroke subjects (Sun *et al.,* 2022) Subjects showed better improvement in memory, attention, and other skills.

More than half of stroke survivors suffer from cognitive defects, which determine broader outcomes than physical disability. Cognitive productivity can be reduced by impaired attention, even when other cognitive functions are intact. Attention is also associated with balance, functional independence and daily living. Hence attention training using BCI is undoubtedly a useful tool in post-stroke rehabilitation.

MATERIAL AND METHODS

This is a pilot study with an experimental group and a control group in an allocation ratio of 1:1 with 10 subjects in each of the two groups.

1. Participants

Participants were 20 survivors of anterior and middle cerebral artery ischemic stroke in the age group 55-65, in the late subacute stage, both right and left hemiplegics, diagnosed for stroke by WHO criteria, from hospitals and clinics in and around Salem. Individuals were excluded if they were unable to give informed consent; experienced severe cognitive deficits precluding participation (Mini-Mental State Examination [MMSE] < 20); were not medically stable (eg, heart failure); or had any other condition that could impact results (unilateral neglect, hemianopia, visual agnosia, or any other co-existing psychiatric disorders). Eligible stroke survivors were approached 3 months after stroke onset. Written informed consent was provided by all participants, and approval by the institutional ethics committee was obtained. Participants included all those individuals who completed initial screening for potential attention deficit. As seen in Table 2, the sample was roughly half male and half female, aged 55-62, and right-handed. The strokes were ischemic, with slightly more having occurred within the right hemisphere.

2. Intervention Programme

Those who were considered eligible for the study underwent an attention screening with Attention e-sense meter on the Neuroview research tool by NeuroSky. Attention deficit is defined as performance less than 40 in Attention e-sense meter on the Neuroview research tool by NeuroSky.

Along with the screening, the selected participants underwent a demographic data collection which included the Bells Test, Trail Making Test (TMT) Parts A & B and Stroke Specific Quality of Life Scale (SS-QOL) for the baseline assessment values.

10 subjects were then randomly assigned to the experimental group for BCI based attention training and standard care of physical therapy management and 10 subjects were randomly assigned to control group for only the standard care of physical therapy management.

The intervention involved 3 sessions per week of BCI based attention training for 8 weeks, followed by a maintenance training of 3 sessions per month for the next 12 weeks for the experimental group. Both groups were given standardized physical therapy care for 3 sessions per week through all the 20 weeks. The post intervention assessment values were taken with the same tools used for baseline values along with the SS-QOL at the end of 20 weeks of intervention and at 1 month follow up.

RESULTS AND DISCUSSION

Initially, a comparison of the background variables such as age, duration of stroke, attention e-sense, gender, side affected and dominant hand of post stroke patients in both the experimental and control groups was made to ascertain uniformity in the subjects selected for study, so that the impact of the experiment on the experimental group will be more reliable. The results are tabulated in Table 2.

It is seen that all the assessed background variables are non-significant for both the groups and that subjects in both groups are right dominant. The homogeneity in the variables makes the study valid and reliable.

Baseline assessment values -- the e sense attention meter score, Bells Test score, TMT Parts A & B score and SS-QOL score – were taken for both the experimental group and the control group. The same tests with the same tools used for baseline values were repeated after 20 weeks of intervention -- BCI based attention training and standardized physical therapy care for stroke for the experimental group and only standardized physical therapy care for stroke for the control group. The post intervention assessment values were then compared with the baseline assessment values taken before the intervention. The results are reported in Table 3.

Table 1: Intervention Protocol for the Study.

Sr. No.	Groups	No of Subjects	Intervention
1	Group A Experimental Group	10	BCI based attention training and standardized physical therapy care for stroke
2	Group B Control Group	10	Only standardized physical therapy care

Table 2: Description of background variables of post stroke patients in both the groups.

Sr. No.	Background Variable	Experimental (n=10)		Control (n = 10)		Unpaired t-test
		Range	Mean ± SD	Range	Mean ± SD	
1	Age (yrs)	55-62	58.30 ± 2.21	55-62	58.20±1.22	t=0.125 p=0.902,NS
2	Duration of stroke in months	3-6	3.80 ± 1.98	3--6	3.50± 1.50	t=0.380, p=0.768,NS
3	Attention E sense	12-38	24.70 ± 8.68	14-39	27.40±9.90	t=0.648, p=0.525,NS
4	MMSE	27-30	28.10 ± 1.19	27-30	28.70± 1.16	t=1.138, p=0.270,NS
5	Gender (M/F)		7 (70.0%)/ 3(30.0%)		5 (50.0%)/ 5(50.0 %)	Chi-square value=0.833, df=1, p=0.361
6	Side affected (Left/Right)		7(70.0%)/ 3(30.0 %)		8 (80.0%)/ 2(20.0 %)	Chi-square value=0.267, df=1, p=0.606
7	Dominance hand (Right/Left)	In both the groups all are right dominant				

Note: S-Significant at 5% level (p<0.05) and NS-Not significant at 5% level (p>0.05).

Table 3: Comparison of Pre and Post-test (at the end of 20 weeks of intervention) outcomes of post stroke patients in both the groups.

Sr. No.	Outcome measures	Group	Pre-test Mean ± SD	Post-test-1 Mean ± SD	Paired t-test
1	e sense attention meter score	Experimental	24.70 ± 8.68	70.30 ± 15.21	t= 20.521, p=0.000, S
		Control	27.00 ± 10.47	29.20 ± 9.60	t= 0.517, p=0.618, NS
2	Bells Test score	Experimental	5.054 ± 1.81	4.33 ± 1.61	t= 3.996, p=0.003, S
		Control	3.85 ± 2.18	3.88 ± 2.21	t=0.418, p=0.686, NS
3	TMT Part-A score	Experimental	3.22 ± 2.09	2.95 ± 1.69	t= 1.594, p=0.145, NS
		Control	2.48 ± 1.70	2.47 ± 1.69	t= 2.092, p=0.066, NS
4	TMT Part-B score	Experimental	3.59 ± 1.80	3.13 ± 1.87	t=1.837, p=0.099, NS
		Control	3.29 ± 1.46	3.60 ± 1.82	t= 1.396, p=0.196, NS
5	SS-QOL score	Experimental	172.40 ± 33.03	180.80 ± 28.0	t= 3.274, p=0.010, S
		Control	177.30 ± 36.95	200.30 ± 26.40	t=4.921, p=0.001, S

Note: S-Significant at 5% level (p<0.05) and NS-Not significant at 5% level (p>0.05).

The baseline assessment tools were then used to assess the subjects of both the experimental and control groups at a one month follow up. The assessment scores after one month follow up were then compared with the respective scores at the end of 20 weeks of intervention. The results are tabulated in Table 4.

Table 4: Comparison of Post-test (at the end of 20 weeks of intervention) and follow up (1month after intervention) of post stroke patients in both the groups.

Sr. No.	Outcome measures	Group	Post-test-1	Post-test-2	Paired t-test
			Mean ± SD	Mean ± SD	
1	e sense attention meter score	Experimental	70.30 ± 15.21	70.00 ± 15.62	t= 0.537, p=0.604, NS
		Control	29.20 ± 9.60	26.60 ± 9.77	t= 1.040, p=0.325, NS
2	Bells Test score	Experimental	4.33 ± 1.61	4.22 ± 1.65	t= 1.894, p=0.091, NS
		Control	3.88 ± 2.21	3.87 ± 2.21	t=1.778, p=0.109, NS
3	TMT Part-A score	Experimental	2.95 ± 1.69	2.93 ± 1.78	t= 0.381, p=0.712, NS
		Control	2.47 ± 1.69	2.53 ± 1.63	t= 1.554, p=0.155, NS
4	TMT Part-B score	Experimental	3.13 ± 1.87	3.11 ± 1.67	t=1.236, p=0.120, NS
		Control	3.60 ± 1.82	3.68 ± 1.75	t= 1.302, p=0.225, NS
5	SS-QOL score	Experimental	180.80 ± 28.0	180.90 ± 27.31	t= 0.218, p=0.832, NS
		Control	200.30 ± 26.40	195.30 ± 22.10	t=2.076, p=0.66, NS

Note: S-Significant at 5% level ($p<0.05$) and NS-Not significant at 5% level ($p>0.05$).

From Table 3 it is evident that the changes in scores in e-sense attention meter, which measures sustained attention, over the 20 weeks intervention for the experimental group are statistically significant, while the same for the control group are not significant. The scores in e-sense attention meter after one month follow up in both groups are statistically not significant as reported in Table 4, confirming that the benefits of the intervention in attention in the experimental group were sustained even after a gap of one month. Fig. 1 is a graphical representation of the change in mean and standard deviation of scores in e-sense attention meter in both experimental and control groups over the pre-test, the 20 weeks intervention and the one month follow up of the study. From Fig. 1 it is evident that the attention training with BCI has improved the attention of the post stroke subjects quite significantly, and that their attention level is maintained even after one month. On the other hand, the control group which received standardized physical therapy only, did not show any significant improvement in attention.

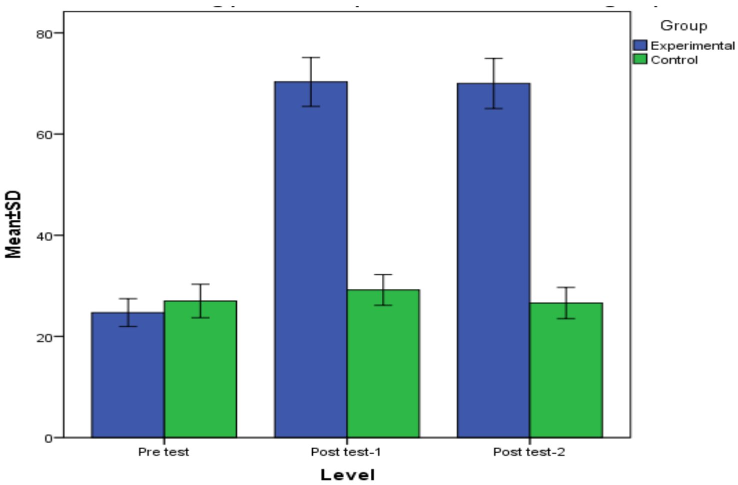

Fig. 1. Mean and SD of pre and post tests of e-sense attention meter scores among post stoke patients in between the groups.

The Bells Test is a cancellation task requiring attention and is used for assessment of both focused and selective attention. The Bells Test scores conducted on the post-stroke subjects of both the experimental and control groups before the intervention and after the 20 weeks' intervention are compared in Table 3. The results show that the scores of the experimental group after the 20 weeks intervention compared with baseline values are statistically significant, whereas the comparative values of the pre-test and post-intervention for the control group are statistically not significant. The Bells Test scores after one month follow up in both groups as reported in Table 4 are statistically not significant which shows that attention levels are retained even over a period of one month. Fig. 2 is a graphical representation of the change in mean and standard deviation of scores in the Bells Test in both experimental and control groups over the pre-test, the 20 weeks intervention and the one month follow up of the study.

It is seen from Fig. 2. that the time taken for the experimental group to complete the Bells Test is considerably reduced due to the BCI intervention in the experimental group, proving that their attention is improved. On the other hand, the control group shows no variation in the time taken to complete the Bells Test, showing that the attention level is not affected by the standardized physical therapy care. In the Trail Making Tests, the subjects were required to connect consecutive targets arranged in a specific geometric pattern, for assessment of alternating attention. It is seen from Table 3 that in both TMT Parts A and B, the differences in scores of the post-stroke subjects before and after the intervention were statistically not significant for both the experimental and control groups. The difference in TMT scores over 20 weeks of intervention and at 1 month follow up was also statistically not significant for both the experimental and the control groups as reported in Table 4. Figs. 3 and 4 are graphical representations of the change in mean and standard deviation of scores in the Trail Making Tests Parts A and B in both experimental and control groups over the pre-test, the 20 weeks intervention and the one month follow up of the study.

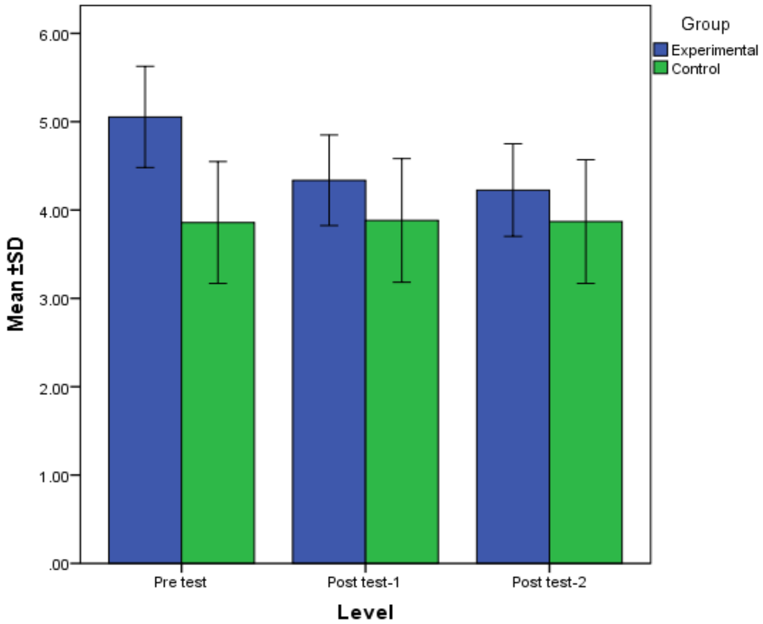

Fig. 2. Mean and SD of pre and post-tests of Bells Test scores among post stoke patients in between the groups.

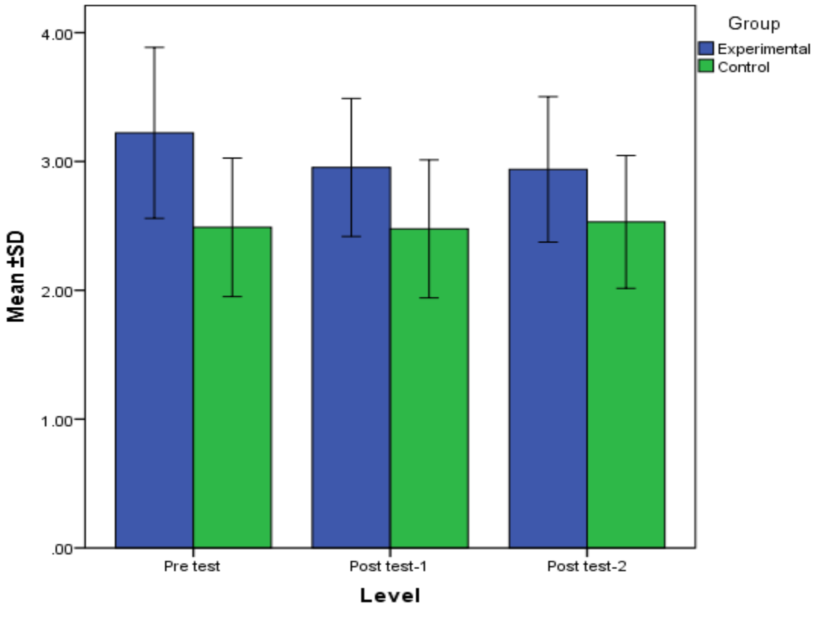

Fig. 3. Mean and SD of pre and post-tests of TMT Part-A scores among post stoke patients in between the groups.

Figs. 3 and 4, which show the difference between the pre-test and the two post-tests reveal a slight reduction in the time taken for the experimental group to complete the task, but as seen from the comparison in Table 3 between the pre-test and the post-test after 20 weeks intervention, the change is not statistically significant. However, this cannot be a valid conclusion since the sample size is too small. A larger study may highlight significant changes in the experimental group.

The SS-QOL is a self-report questionnaire consisting of 49 items in the 12 domains of energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper extremity (UE) function, vision, and work/productivity. From Table 3 it is seen that the SS-QOL scores of both the experimental and control groups after the 20 weeks intervention are significant compared to the baseline values. As several factors are involved in improving quality of life in stroke patients, the standardized physical therapy protocol given to both groups has enhanced their quality of life, and increased attention adds to it. The difference in SS-QOL scores over 20 weeks of intervention and after one month of intervention was statistically not significant for both the experimental and the control groups as reported in Table 4. The change in mean and standard deviation of scores in the SS-QOL in both experimental and control groups over the pre-test, the 20 weeks intervention and the one month follow up of the study is graphically represented in Fig. 5. From Fig. 5 it may be observed that the improvement in the quality of life of the post-stroke subjects is statistically not significant for both groups, while a comparison was made at all 3 levels- the pre-test scores, scores after 20 weeks of intervention and at 1 month follow up. However as seen in Table 3, a significant improvement in quality of life was found in both groups while comparing only the pre-test scores and the scores after 20 weeks intervention.

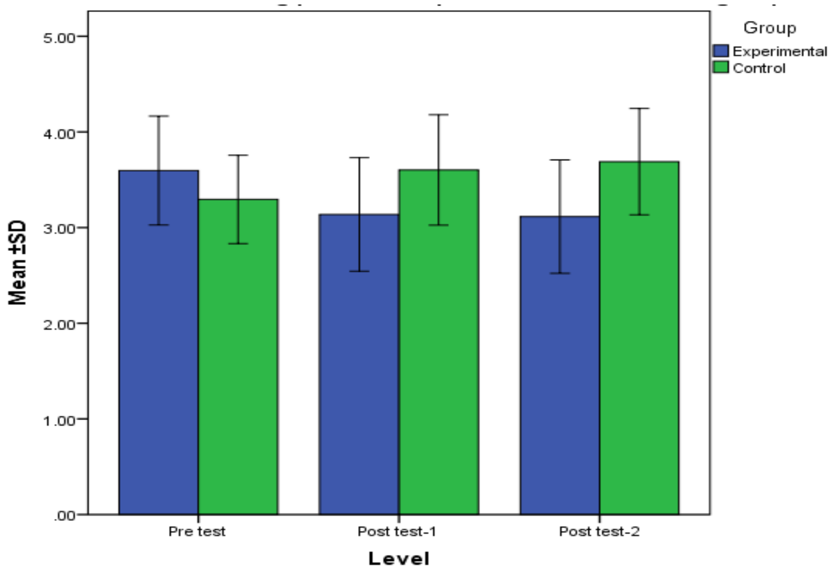

Fig. 4. Mean and SD of pre and post-tests of TMT Part-B scores among post stoke patients in between the groups.

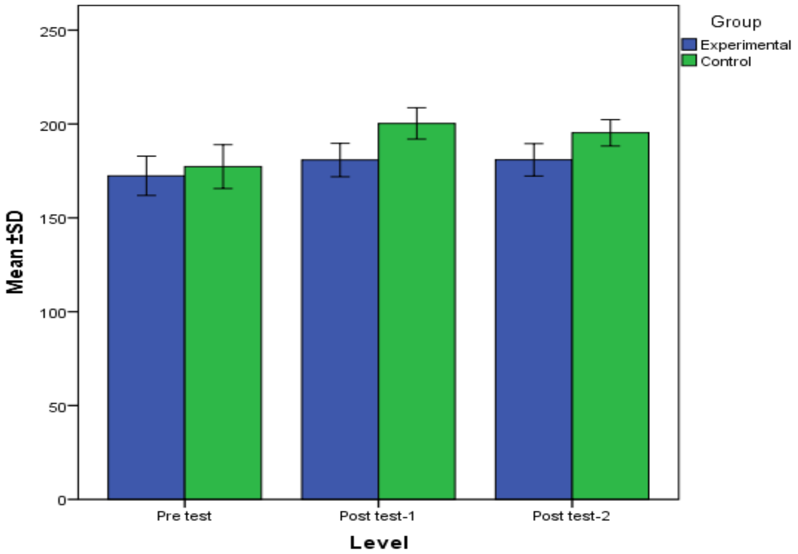

Fig. 5. Mean and SD of pre and post-tests of SS-QOL score among post stoke patients in between the groups.

CONCLUSION

The results of this pilot study confirm that BCI based attention training along with standardized physical therapy care for stroke enhances attention levels in post-stroke subjects compared to those post-stroke subjects given only standardized physical therapy care. The readings after following up show that the benefits of the intervention in attention in the experimental group were sustained even after a gap of one month. As several factors are involved in improving quality of life in stroke patients, the standardized physical therapy protocol given to both groups has enhanced their quality of life, and increased attention adds to it. However, a valid conclusion cannot be arrived at, since the sample size is too small. A larger trial is needed to better evaluate the efficacy of the BCI-based attention training programme.

FUTURE SCOPE

Overall, the future scope of the described work involves further research, refinement of intervention protocols, development of real-time feedback systems, integration into rehabilitation settings, individualization of training programs, long-term follow-up, and the integration of technology and telemedicine. By exploring these areas, the aim is to advance the field of BCI-based attention training, enhance stroke rehabilitation outcomes, and ultimately improve the quality of life for post-stroke patients.

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Conflict of interest. None

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