Impact of Multimodal Cognitive Training on Cognitive Traits of Children: A Multicentric Interventional Study

Manjunatha R
IIHMR University
Praveen Pankajakshan (praveenpankaj@ieee.org)
Amrita Vishwa Vidyapeetham University
Alphonsa Joseph
Dr. S.R. Chandrasekhar Institute of Speech and Hearing
Gyan Kashyap
IIHMR University
Usha Manjunath
IIHMR University
Krishnamurthy Jayanna
M S Ramaiah University of Applied Sciences

Research Article

Keywords: cognitive traits, behavior, EEG, multimodal cognitive training, unsupervised learning

Posted Date: April 30th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-468572/v1

Abstract

In this article, we evaluate the hypothesis that a multimodal cognitive training (MCT) program, the Brighter Minds, can enhance certain inherent traits of a child and thus bring changes in the external behavior. For the study, 186 children (randomized to 93 each in intervention and control group) aged 10-15 years were enrolled from three different locations. Psychometric tests, parental/caregiver interviews and EEG (electroencephalography) tests were conducted before and after the program. Intervention group showed strong statistical significance for improvements in Mini Mental Status Examination (MMSE) ($P<0.01$) but no significance for Raven's Standard Progrssive Matrices (SPM) or Susan Harter's test. The parental/caregiver reported satistically significant improvements in focus ($P<0.05$), empathy ($P<0.05$), intuition ($P<0.05$), comprehension ($P<0.05$) and understanding of abstract concepts ($P<0.05$) for the intervention group. For the control, Power Spectral Density (PSD) of the baseline eyes-closed (EC) EEG recording, the spectrum below 20Hz exhibited the characteristic "1/f" spectral scaling of the power-law. This signature matches prior reported evidence in literature of those in wakeful state with EC. The intervention group EC PSD, however, exhibited a signature similar to those in a slow sleep state; reflective of the possible transfer effect of the training on other skills like relaxation. We used unsupervised learning methods with dice distance, on the psychometric and interview data, to show the effect of location and the exposure of a few control children to the program.

Introduction

It is a long-held notion that learnings and impressions that are experienced at an early age, as a child, can have impact on the neuroanatomy and several neural structures for a long-term (Teicher et al. 2003). There are several evidences that link genetic, environment and life-style factors to the development or lack of development of the structure and functional aspects of the brain. The cognitive flexibility of a child or the ability to adapt the thoughts and behavior in response to changes in goals or the environment in life (Chevalier et al., 2012) could be attributed to these aspects. With changes in the environmental task demands, the working memory, attention, and response selection also changes accordingly. The degree of the change determines the degree of flexibility. Among children, flexibility develops rapidly during the preschool years and continues to improve across adolescence and young adulthood (Yeniad et al., 2013, Titz and Karbach, 2014). Such cognitive skills, abilities (Hinshaw, 1994) and responses that are developed due to either or both of intrinsic and extrinsic dynamics in the early part of life are bound to prevail as traits throughout the lifespan. However, as the age advances, the cognitive ability to change in response to new extrinsic experiences reduces. The interplay of genes and in-utero experiences might be responsible for some children being born with hypersensitive behavior facilitation (Gray 1987) or an underactive behavioral inhibition system (Scarpal & Raine, 2000). It is thus necessary to develop a balanced approach to emotional, social, cognitive and language development for preparing children to success in school, and later on as adults in family, workplace and community (In Brief: The Science of Early Childhood Development, 2018).

Cognitive Training

The biopsychosocial (BPS) framework (Grinker RR Sr. 1964, Engel 1981), was the earliest to provide an integrative, comprehensive model to human development, health, and functioning. It looks at the interconnection between biology, psychology, and socio-environmental factors, to understand how these influence health, disease and wellness. It has now established itself as the status quo model for contemporary medicine. Engel declared that this model was developed to overcome the limitations and to bring contrast to the biomedical model which was prevalent at that time. It is the claim that the BPS model itself takes its roots from the general systems theory (GST). Critics of the BPS (Ghaemi 2009, Benning 2015 and Bolton 2019) argue that the BPS model is very vague, eclectic and unfaithful to GST, and is not scientific in its approach. Another contention, related to the above subject, is that the GST itself might not be a right framework to address the complexity of the mind (McLaren 1998). These theories and models must be understood in the context of trying to understand or identify the root cause of observed effects such as behavior, disease or health. We acknowledge that it is difficult albeit sometimes impossible to determine the exact causal basis to some of these effects (Karunamuni 2020); because the cause-effect relationship and pathways might be multivariate with latent variables, and highly nonlinear pathways. There are alternative models proposed recently (Ghaemi SN 2009), which focus on the humanistic element to medical treatment, but we focus our attention on the psychological component of the BPS. The idea is to seek a psychological foundation for a behavior or behaviors.

Cognitive Training (CT) aims at exploring the central idea that the neuronal structure and function can be changed by altering either the environment or experience or both. Some of the earliest results from literature (Douglas, V.I. et al. 1976) (Shaw, C., Lanius, R., & Doel, K.V., 1994) provide light along these directions. As an alternative to pharmaceutical interventions, parents are turning to CT for their children and adolescents to enhance cognitive abilities. Similarly, caregivers of elderly citizens are turning to CT for reducing the onset of age related dementia. Studies have reported the effects of CT on changes in cognition and behavior, across multiple disciplines: developmental psychology, social psychology, clinical psychology, educational psychology, and cognitive psychology (Jedlicka, 2017). Numerous techniques conceptualize how children's cognitive ability can be enhanced through CT (Jedlicka, 2017; Madhavi & Jayanna, 2019). In Rabipour, Sheida & Raz, Amir. 2012, the authors review published literature on CT for Attention Training (AT), Working Memory Training (WMT), inhibitory control, and transfer effects such as fluid intelligence and behavior control. Another study, a Meta-analysis pointed toward the positive effect of cognitive training on preschool children's executive functions (EFs) in the age range of 3 to 6 years, without any risk (Nicoletta *et al.*, 2019). There are some findings documented from a similar study conducted by Nezla *et al.* in 2017 which reported significant ADHD core symptom improvements with multimodal treatment at a 6-month follow-up, and those results were better compared to those with single medication treatment (Nezla *et al.*, 2017). Rehabilitation programs for brain injuries (Sohlberg, M. M., & Mateer, C. A. (1987)) or Alzheimer (Gates, N. J., & Sachdev, P. (2014)) have also had success in either mild injuries or early onsets. Early training or differential experience (Rosenzweig 1996) can influence health, wellness, brain development, or successful aging.

For children, a large body of prior studies is dedicated to improving learning struggles and cognitive deficits. The mode of delivery of such programs is online. The impact assessment and reception of online digital CT programs, in the scientific literature, has been mixed. The FDA's recent approval of a CT game to treat ADHD might be an acknowledgment of the potential of a certain of these. Any article on cognitive enhancement cannot be complete without discussing on the ethics of cognitive enhancement. Much of the concerns raised on ethics looks at pharmacological interventions and advocates for increased discussion on proper public policy or regulation (Bostrom, N., Sandberg, A 2009).

Brighter Minds

The study presented in this article is related to examining a multimodal cognitive training (MCT) program, the Brighter Minds (BM) (Madhavi Bongarala, 2019), through a direct classroom mode of delivery to children with the help of trained school teachers. The study by Joseph *et al.* has documented that, use of recommended practices for developing skills can help in positive improvements in program outcomes in such school-based programs. (Joseph *et al.*, 2011). Earlier school-based study program on universal social and emotional learning (SEL) involving 270,034 kindergartens through high school students concluded that school teaching staff can successfully conduct SEL programs. The BM is an 8-week program, in-classroom sessions, with two consecutive sessions in the first week and seven follow up sessions, each session lasting between 3 hours to 3.5 hours. It requires a total of at least thirty hours of training, and provides a learning environment based on joy, positivity, and love. It incorporates a series of interactive proprietary tools and activities such as progressive muscle relaxation, breathing exercises, brain exercises and music entrainment (Siddaramappa, 2019), aerobic exercise, eye exercises and others (Jacbobson 1987, Zaccaro 2018, Rogge 2017). For children from rural or from lower socio-economic strata, the program is offered without any charge by mobilization of funds through corporate social responsibility (CSR) partners and donors. Through the BM, many young children are encouraged and trained to improve cognitive skills that help them meet future challenges as children and adults in family, work and community. We look at the cause-effect relationship in the framework of focused BPS by varying one or more parameters and observing the effect on traits and short-term behaviors. Traits in a child may include focus, memory, intuitive thinking, self-confidence, comprehension, and others. We assume that all others influencing the effect such as social or biological parameters are constant during this study as all the participating children are from a similar background. In (Rueda, M. et al. 2005), the authors had studied the effect of executive attention training on temperament through children's behavior questionnaires (CBQ) (Rothbart, M. et al. 1994). We explore the hypothesis that improvement in a child's traits by MCT can bring about changes to behavior (Fig. 1).

Methods

Study Design (Controlled before and after study)

In Fig. 2, we show the set of inclusion criteria for selection of the intervention and control group based on a randomized design. Both the groups were tested before and after the BM training program. The terms intervention and case are used interchangeably during this article.

Sample Size

The sample size is selected based on some assumptions from prior literature (Madhavi Bongarala, 2019) that at least 33% will show positive improvement in the sample for the majority of the cognitive abilities. In considering this, a sample size of 168 students (84 intervention and 84 controls) were chosen for the study. Sample size was increased by 10% to accommodate sample loss due to various reasons and the final sample size included for the study were 186 (93 intervention and 93 controls) students.

Inclusion and Exclusion Criteria

Children, between the age of 10–15 years of age, who had signed up for an ongoing BM program were included for the study. Those children who might not be regular or had a risk of discontinuing the program mid-way were excluded.

Sampling Technique

Three locations (Gangtok, Mahabubnagar, Bangalore) were selected with purposive sampling from different sites of India, where children were enrolled into the training program. Within each of the study locations, *multistage random sampling technique* was used to select the children for the study

Study Tools

We have used several tools to assess the impact and these are listed below:

A) Similar to CBQ (Rothbart, M. et al. 1994), structured interviews were used to record parental/ caregivers' observations and to collect socio-demographic details (For Parents/ Caregivers – Both pre- and post-intervention)

B) The psychometric tests used in this study are usually recognized to screen the self-esteem, memory, abstract, verbal, spatial, and mathematical reasoning ability (Phillip *et al.*, 2014; Madhavi *et al.*, 2019; van der Donk, 2016; Karch et al., 2013).

C) Electroencephalogram (EEG) tests were conducted among 26 randomly selected children from the sample of control and intervention. To account for dropouts, about 10%, the final numbers enrolled were 28.

Self-esteem might refer to an individual's subjective evaluation of his or her worth as a person. It might not refelect on that child's innate skills, talents or abilities or even how the child might be perceived by others.

Psychometric Tests

1. **Raven's Standard Progressive Matrices (SPM)** is a strong diagnostic indicator of abstract, verbal, spatial, and mathematical reasoning ability, an indicator of school achievement, and overall self-concept of children (Raven J, Raven, J. C., & Court, J. H., 1984)
2. **Mini Mental State (MMSE)** intuitive capacity, alertness, speech, and thought content. It also assesses different cognitive abilities, including memory, attention and language of children. (Folstein MF, Folstein SE, McHugh PR, 1975) & (Rovner BW, Folstein MF, 1987)
3. **Memory** (Nonverbal recall test) assesses the ability to code process and retrieve information that one has been exposed to in a short interval. (Hirisave Uma, Oommen Anna, Kapur Malvika, 2011 and Bandla, S *et al.*, 2017)
4. **Susan Harter's Test** assesses self-worth and self-competence in different settings like scholastics, social acceptance, athletic competence, physical appearance and behavioral conduct. (Harter, S. 1982) & (Harter, S, 2012)

In Fig. 2, the sampling frame and workflow is illustrated.

Statistical Analysis and Unsupervised Learning

Given the two groups, the control and intervention, the paired t-test on the pre and post 8-week data is used to test the null hypothesis that the two groups have identical average (expected) values (or the difference between the expectation is zero) for the Psychometric and interview data. The *p* values for the statistical analysis provides an evidence to reject or not reject the above null hypothesis, and the threshold is fixed at 0.05.

The Factor Analysis of Mixed Data (FAMD), like the Principal Component Analysis (PCA), is usually used to analyze a dataset having mixed variables that are both qualitative and quantitative. The qualitative variables, obtained from both the Psychometric tests and the interview results, are converted to numerical values by encoding them. The corresponding loadings and scores, in the reduced dimension, is further analysed for insights.

Although the data is labelled as control and intervention, in order to study the effect of the exposure of the control to the training program or study the effect of location, we assumed that the data is unlabeled and analyzed the data using unsupervised learning methods.

Electroencephalogram Studies

Electroencephalogram (EEG) was selected in this study for the ease of administering in remote locations where laboratory access is limited and for the high temporal resolution. There is a wider acceptability of EEG to study improvements in cognitive functions (Wakeman & Henson, 2015; Heinrich *et al.*, 2018; Marthe *et al.*, 2015). Twenty-eight children were chosen at random from the original pool of children (with equidistribution of control and intervention) from the Mahbubnagar district in Southern India, accounting for 10% drop rates. 18 female and 10 male participants were picked up after excluding the following factors: presence of any neurological disease, hearing disorders or prior musical training or consumption of any psychoactive drugs. The average age for this sub-study was about 14.18 years with a standard deviation of about 1.34 years. The facilitators and the students were briefed about the purpose of the study and the experimental design in their local languages. These children were then randomly assigned to the control or intervention group. Baseline EEG readings were collected with eyes closed using a five-electrode research-grade EEG device (Krigolson O E 2017) that uses dry electrodes. The electrodes are placed at the following locations: AF7, AF8, AF9, TP9 and TP10 as per the 10–20 International Standards, and with the electrode Fpz marked as the reference electrode. The data sampling rate for the acquisition was fixed at 256 Hz (> > Nyquist frequency) for all the subjects. The participants were seated on a chair comfortably, in a noise-free room, with no external stimulus. The room where the recordings were taken were kept ambient noise free but were not sound-proof, and so any external disturbances or external auditory inputs were manually edited out or the readings entirely discarded. The baseline EEG data was recorded, with eyes closed, prior to the BM program and also post the training program. The studies were administered directly by the lead researchers who were blind to the control and intervention group list. Pre-intervention EEG readings were carried out in December 2018, and the Post-intervention EEG studies were carried out with both the control and intervention groups in March 2019. The pre-processing of the entire dataset was done using MATLAB® (MathWorks®, Natick, MA, United States) with EEGLab Toolbox (Delorme A 2004), and the pre-processing protocol was adopted from the HAPPE pipeline (Gabard-Durnam LJ 2018) with minor changes. The only difference with the HAPPE pipeline was that if there was any noise while collecting the data, rather than interpolating the signal or dropping out the channels, the entire dataset was discarded. We filter the data with a high pass filter from 1 Hz, which removes the non-stationary signal drift across the recordings. As mentioned in (Maess et al. 2016), under noisy conditions, as in our case of measurements obtained from experiments outside an electromagnetically shielded lab, the usage of a high-pass filter is the better option than detrending or baseline correction. Any noise or artefacts in the channels were checked for by using wavelet-enhanced ICA (wICA), as mentioned in (Gabard-Durnam LJ 2018).

Results

Participants Profile

The distribution of intervention and control cases in the three different study locations and the sociodemographic profile of the sample is as given in Table 1.

Table 1
Sociodemographic Profile of the Study Samples

	Intervention (%)	Controls (%)	Total
Distribution of the study participants			
Mahabubnagar	62 (75.6)	36 (73.5)	98 (74.8)
Gangtok	16 (19.5)	13 (26.5)	29 (22)
Bengaluru	04 (4.9)	00 (0)	04 (3.1)
Gender			
Male	30 (36.6)	07 (14.9)	37 (28.2)
Female	52 (63.4)	42 (85.7)	94 (71.8)
Schooling details			
Preschool (Playschool/LKG UKG)	01 (1.2)	00 (0)	01 (0.8)
Primary Education (1st to 5th grade)	01 (1.2)	13 (26.5)	14 (10.7)
Middle school/Upper Primary school (6th to 8th grade)	43 (52.4)	25 (51.0)	68 (51.9)
Secondary School (9th to 10th grade)	37 (45.1)	11 (22.4)	48 (36.6)
Residence			
Rural	63 (76.8)	36 (73.5)	99 (75.6)
Urban	19 (23.2)	13 (26.5)	32 (24.4)
Child lives with			
With parents	49 (59.8)	13 (26.5)	62 (47.3)
With grandparents	04 (4.9)	00 (0)	04 (3.1)
With relatives	01 (1.2)	00 (0)	01 (0.8)
With caregivers (Hostel)	28 (34.1)	36 (73.5)	64 (48.9)
Total	**82 (100)**	**49 (100)**	**131 (100)**

The age of the children, who participated in the study, ranged between 10 and 15 years, with the mean age of children being 13.08 years. About 71.75% of children were female, 75.6% were residing in rural areas. 47.32% of children were residing with their parents (59.75% of intervention and 26.53% of controls); 48.85% of children were residing in hostels (34.14% of intervention and 73.46 % of controls). 51.91% of children were in upper primary school; 36.64% were in secondary school; 10.69% of children were studying in primary school.

Parent/ Caregiver Interview Results

The statistical analysis of the interview results of the parents and caregivers are listed in Table 2 for both the groups and also the significance values.

Table 2
Summary of Parental Reports - Comparison of Intervention and Controls (Pre and Post)

		Intervention			Controls		
	Feedback	Pre-test N (%)	Post-test N (%)	Sig.	Pre-test N (%)	Post-test N (%)	Sig
Focus	Good	34 (41.5)	50 (61.0)	**0.043**	19(38.8)	27(55.1)	0.228
	Average	34 (41.5)	22 (26.8)		21(42.9)	17(34.7)	
	Poor	14 (17.1)	10 (12.2)		9(18.4)	5(10.2)	
	Total	82	82		49	49	
Observation	Good	41 (50.6)	46 (605)	0.279	20(41.7)	24(51.1	0.643
	Average	31 (38.3)	20 (20.6)		20(41.7)	17(36.2)	
	Poor	9 (11.1)	10 (13.2)		8(06.7)	6(12.8)	
	Total	81	76		48	47	
Memory	Good	38 (46.3)	50 (60.5)	0.168	19(38.8)	24(51.1)	0.351
	Average	28 (34.1)	21 (25.6)		22(44.9)	19(40.4)	
	Poor	16 (19.5)	11 (13.4)		8(16.3)	04(8.5)	
	Total	82	82		49	47	
Self-confidence	Good	33 (40.2)	49 (59.8)	0.43	23(46.9)	28(58.3)	0.265
	Average	38 (46.3)	25 (30.5)		22(44.9)	14(29.2)	
	Poor	11 (13.4)	8 (9.8)		4.(8.2)	6(12.5)	
	Total	82	82		49	44	
Participation in actives	Often	35 (43.2)	48 (59.3)	0.120	19. (38.8)	24(50.0)	0.404

		Intervention			Controls		
	Some time	28 (34.6)	21 (25.9)		21(42.9)	19(39.6)	
	Rarely	18 (22.2)	12 (14.8)		9(18.4)	5(10.4)	
	Total	81	81		49	48	
Empathy	Frequently	36 (44.4)	54 (66.7)	**0.014**	18(37.5)	27(56.3)	0.131
	Moderately	23 (28.4)	16 (19.8)		18(37.5)	15(31.3)	
	Rarely	22 (27.2)	11(13.6)		12(25.0)	6(12.5)	
	Total	81	81		48	48	
Understanding others	Good	34 (41.5)	41(52.6)	0.110	16(34.8)	13(27.7)	0.066
	Average	30 (36.6)	29(37.2)		16(34.8)	27(57.4)	
	Poor	18 (22.0)	8(10.3)		14(30.4)	7(14.9)	
	Total	82	78		46	47	
Intuition	Good	29 (35.8)	47 (57.3	**0.019**	15(30.6)	18(37.5)	0.614
	Average	34 (42)	25 (30.5)		26(53.1)	25(52.1)	
	Poor	18 (22.2)	10 (12.2		8(16.3)	5(10.4)	
	Total	71	82		49	48	
Comprehension	Good	30 (37.0)	42 (52.5)	**0.020**	16(34)	21(42.9)	0.589
	Average	30 (37.0)	30 (37.5)		26(55.3)	22(44.9)	
	Poor	21 (25.9)	8 (10.0)		5(10.6)	6(12.2)	
	Total	81	80		47	49	
Abstract Concept Understanding	Good	31(39.2)	55(67.1)	**0.002**	17(34.7)	23(46.9)	0.082
	Average	29(36.2)	17(20.7)		20(40.8)	22(44.9)	

		Intervention		Controls	
	Poor	19(24.1)	10(12.2)	12(24.5)	4(8.2)
	Total	79	89	49	49

Among the intervention group, statistically significant improvements were seen in child's focus (P < 0.05), empathy (P < 0.05), intuition (P < 0.05), comprehension (P < 0.05) and child's abstract concept understanding (P < 0.01).

Psychometric Test Results

Table 3
Statistical Significance Test for comparing mean values of Psychometric test results between Intervention and Control

	Intervention (n = 82)			**Control (n = 49)**		
	Base line	**End line**	**Sig. (P < 0.01)**	**Base line**	**End line**	**Sig. (P < 0.01)**
Raven's SPM	30.69	31.95	0.48	23.43	27.78	0.028
MMSE	25.17	27.89	**0.000**	26.39	28.16	0.019
Memory Recall (Nonverbal)	84.89	116.31	**0.000**	87.18	109.10	**0.000**
Susan Harter's Test	53.80	56.67	0.50	50.20	50.51	0.94

Study of psychometric test results shows that statistically significant improvements were seen in tests of MMSE (P < 0.01), and Memory profile (P < 0.01) for the intervention group. However, statistically significant improvements were also seen in the control group for Memory Profile (P < 0.01) (Table 3).

EEG Test Results

In Fig. 4, we show the power spectral density (PSD) plot of the signal collected from two electrodes located in the pre-frontal lobe (locations AF7 in purple and AF8 in green) for a child who underwent the BM program. This participant, a twelve-year-old female child, was randomly chosen from among all the children who had participated in the program. We do not normalize the power spectrum by spectral flattening or baseline normalization as we would like to compare the rate of the '1/f' drop for control and intervention.

Unsupervised Learning Results

In this section, we learn and draw insights from the entire data by adopting some recent trends in unsupervised learning approaches. One such approach is the dimensionality reduction algorithm such as Principal Component Analysis (PCA). However, the data comprised of a mixture of both qualitative and quantitative variables.

In Fig. 5 (below), we show the scatter plot of the components after Factor analysis (Escofier Brigitte & Pagès Jérôme (2008)) of the data which is a mixture of quantitative and qualitative. FAMD was chosen to include also the categorical variables along with the continuous variables. The columns that specified the location of the training program was removed prior to factorization, and only used for visualization and color labelling.

Discussion

In recent years, literature shows a growing interest among researchers in studies related to early childhood development and the role of brain and cognition enhancement during the formative years of childhood. The objective of this article is aimed at exploring the hypothesis that multi-modal cognitive training can influence the inherent traits and bring a change in a child's external behavior. It is one of the first of its kind that used a controlled before and after study design to assess effectiveness of MCT among children under general settings, and evaluate their implications. The tests that are canvassed in this study were chosen to cover most of the spheres of cognitive abilities, because of its reliability and the validity tested in the previous research conducted (Madhavi and Jayanna, 2019).

The parent and caregiver interviews in our study reported improvements in cognitive traits such as the child’s focus, empathy, memory, intuition, comprehension and understanding of abstract concepts, and improvements in behavior traits such as self-confidence, empathy, and participation. These findings are comparable to the results of the study conducted recently in (Madhavi & Jayanna, 2019), who also reported within the educational settings.

The Psychometric Test results revealed statistically significant improvements in the MMSE ($P < 0.01$) for the intervention group. However, for both the control and the intervention group, statistically significant improvements were seen for Memory ($P < 0.01$). It had been reported (Nezla *et al.*, 2017.) that self-worth and self-competence in different settings like scholastics, social acceptance, athletic competence, physical appearance, and behavioral conduct improved with multimodal brain training programs. From our results, it could not be concluded if the BM program brought any significant difference in Memory, Raven’s SPM or Susan Harter’s Test to the intervention as against control participants. A similar conclusion can be drawn from the Violin Plots in Fig. 3, where we see significant improvements in MMSE but not the other tests.

One possible explanation in the case of Susan Harter’s test is that it was observed that children had in general very low self-esteem scores. New findings on this subject believes that self-esteem is relatively stable trait and it is similar to some basic personality characteristics. Another reason for the difference could be attributed to the lower number of samples of Control than Intervention participants, and hence seeming to appear from a different statistical distribution. This might also be explained by a new theory

(Jaeggi, S. M., 2020) that was put forth suggesting that the outcomes may be averaged across all individuals who received the intervention, and benefit experienced by a few might be averaged out. Another possibility is that the program does not improve fluid intelligence due to the shorter time span between training intervals (< 7days) (Wang, Z. et al. 2014). The SPM results might be pointing out to the fact that while some abilities are enhanced after the training program, a few others might have impaired or diminished (Colzato, L. S. et al. 2020).

Figure 4a is the PSD calculated on the baseline EEG signals for the control, and Fig. 4b was the PSD calculated from the processed EEG signal for the intervention after the eight weeks training program. It was reported that in the waking state with eyes closed, the frequency band below 20Hz scales as 1/f, and with possible peak around 20Hz, while in the slow-wave sleep state, the '1/f' scaling is not visible (Bedard et al. 2006). We observed a similar trend as well, except this difference was observed between the control and the intervention group. In the control group, the '1/f' scaling is visible (see Fig. 4a red line for local slope) but in the case of the intervention, the drop is much steeper than for the control (see Fig. 4b orange line for local slope). Our test results of EEG on a selected sub-sample of children, showed that the spectral signatures of the EEG in the intervention group were quite similar to those with spectra from EEG recorded during a relaxed or slow sleep state. We observed that, in general, the spectrum for the intervention group exhibited a drop in the higher frequencies, especially above 12 Hz (see Fig. 4b) frequencies. This raises the interesting reflection if the intervention program might have led to transfer effect on other skills like relaxation and a permanent change in their inner traits in comparison to the control group. It is known that Power-Law scaling governs the brain's surface electric potentials (Miller et al. 2009, Bedard et al. 2006) and is also an intrinsic property of complex dynamic systems (Marković, D. and Gros, C. 2014, Meisel, C., Bailey, K., Achermann, P. *et al.*, 2017).

During FAMD, for visualization, we can see in Fig. 5, that the ellipses separate the two data coming from the two locations Mahabubnagar and Gangtok very distinctly. The location clustering could be an indicator to a hidden latent variable-the effect of the training facilitator (here teachers) on the training program. When we removed the influence of the locations in the analysis, for the data from the Gangtok site, there is a clear grouping happening between the Intervention and the Control groups (see Fig. 6) after the Factor Analysis. However, for the Mahabubnagar location (see Fig. 7), the distinction between the Control and intervention data is not distinct. This could be explained by the fact that the control group children from the Mahabubnagar program were living in hostels and the program leaked through the intervention group.

Limitations of the study

The study has a few limitations. Identification and recruitment of children who are naturally seeking admission into the Brighter Minds program was a challenge in study sites outside of Mahabubnagar. Fewer children were enrolling into the program in the learning centers on these sites. Even though we had identified and recruited 186 participants (93 intervention and 93 controls) in the baseline study, only 131 participants (82 intervention and 49 control cases) were available for end line assessment. The remaining cases (about 30%) were lost from the sample due to exposure of controls to intervention programs and drop out because of illness. This 30% loss was much higher than our anticipated loss of 10%. Many children, from the schools in Mahabubnagar district, were residing in hostels, and there are chances of exposure of the control participants to the intervention (see Fig. 7 and Fig. 8). It is also likely that some of the facilitating teachers from these rural schools do understand the importance of proving an environment that can improve the children's confidence and self-esteem. The logistical complexity of conducting the controlled studies in community settings such as children's hostels will need to be taken into account in future studies. This also violated our initial assumption that the biological and social conditions during the study will not change or influence the study. It was also not possible to evaluate clearly what cognitive skill was impaired after the training program.

For the EEG analysis, in order to simplify the recordings for children, we restricted the number of electrode sensors to 5 and were dry electrodes. Dry electrodes can bring in additional noise due to a temporary loss in contact with the skin. This was partly mitigated by using gel but we lost the signal from the dry electrodes and had to redo the experiments. As the number of electrodes are only a few, the recordings might not be precise for source localization using methods such as ICA. The recordings are done in a relatively noise-free room, but it is not shielded completely from outside noise. Advanced EEG analysis in a laboratory-controlled settings and functional MRI in future studies have potential to shed light on trait changes in the children that undergo cognitive and behavioural changes as a result of cognitive training.

Conclusions

Brighter Minds' multimodal cognitive training program has a positive effect on self–worth and self-competence as well as cognitive skills such as comprehension, observation, intuition, and focus. Ability of children for abstract thinking, verbal and spatial abilities, and mathematical reasoning when improved, will in turn benefit achievements and comprehensive abilities of children. The program duration and feasibility to implement in diverse settings including the schools, shows that the benefits of this program potentially outweigh the efforts. Early childhood education requires a paradigm shift as emphasized by India National Education Policy (2020) to advance human potential and development, and the present study provides new evidence and direction in this regard.

Declarations

Acknowledgments

The authors would like to thank all the parents and schoolteachers who provided their consent and helped in participation of children in the evaluation exercises. The authors would like to thank the Research team at Institute of Health Management Research, Bengaluru (IIHMR-B), Dr. S R Chandrasekhar Institute of Speech and Hearing, Center for Integrative Health and Wellbeing (CIHW) for supporting intervention and evaluation exercises of this research project, and Ashish Sinha (BITS Pilani, Goa) for the help with the EEG data processing.

Funding

The infrastructure and logistics required for the study was funded by Cognitive Skills Pvt Ltd. The donor did not have any role in the study design, study implementation, or data collection and analysis. All the authors involved in this study received funding from independent sources.

Competing interests

PP and KJ are unpaid research advisors at Brighter Minds. There are no other competing interests to declare for all other authors.

Authors’ contributions

MR: Study designing, Methodology, Validation, Investigation, Report Writing

AJ: Planning of psychometric tests, execution of psychometric tests, report writing

PP: EEG Study Design, EEG Data Acquisition, EEG Formal Analysis, Statistical Analysis, Investigation, Curation, Data Visualization, Report Writing

GCK: Statistical analysis, Report writing

UM: Field planning, monitoring and supervision of data collection activities **KJ:** Report Review, Funding acquisition, Project conceptualization, Supervision

Ethics Approval

Institutional ethics committee of IIHMR University reviewed the proposal, research tools, and consent forms and provided ethical approval. Before reaching any intervention, it was ensured that all approvals from the authorities were in place. All ethical procedures were followed in guidance from the Institutional Ethical Review Board (IERB) of IIHMR University, Jaipur, India.

Consent to participate

Written informed consent, in local language was obtained from parents/caregivers. They were explained about the purpose of the study and that the confidential information collected will be masked.

Data availability

The datasets generated during and/or analysed during the current study are available from the Mendeley repository here: https://data.mendeley.com/datasets/szf5gz82jp/1

References

[1] Bandla, S., Mandadi, G. D., & Bhogaraju, A. (2017). Specific Learning Disabilities and Psychiatric Comorbidities in School Children in South India. *Indian journal of psychological medicine*, *39*(1), 76–82. https://doi.org/10.4103/0253-7176.198950

[2] Benning T. Limitations of the biopsychosocial model in psychiatry. Adv Med Educ Pract. 2015;6:347-352

[3] Bedard, Claude & Kroeger, Helmut & Destexhe, Alain. (2006). Does the 1/f Frequency Scaling of Brain Signals Reflect Self-Organized Critical States?. Physical Review Letters. 97. 10.1103/PhysRevLett.97.118102.

[4] Bolton D., Gillett G. (2019) The Biopsychosocial Model 40 Years On. In: The Biopsychosocial Model of Health and Disease. Palgrave Pivot, Cham. https://doi.org/10.1007/978-3-030-11899-0_1

[5] Bongarala, Madhavi & Jayanna, Krishnamurthy. (2019). Parents' Perspective on Effects and Benefits of "Brighter Minds" Cognitive Training Program: Results from an Online Survey in India. Creative Education. 10. 224-235. (ISSN 2151-4755)

[6] Bostrom, N., Sandberg, A. Cognitive Enhancement: Methods, Ethics, Regulatory Challenges. *Sci Eng Ethics* **15,** 311–341 (2009). https://doi.org/10.1007/s11948-009-9142-5

[7] Chevalier, N., Sheffield, T. D., Nelson, J. M., Clark, C. A. C., Wiebe, S. A., & Espy, K. A. (2012). *Underpinnings of the costs of flexibility in preschool children: The roles of working memory and inhibition*. Developmental Neuropsychology, 37, 99–118. doi:10.1080/ 87565641.2011.632458

[8] Colzato, L. S., Hommel, B., & Beste, C. (2020). *The Downsides of Cognitive Enhancement.* The Neuroscientist: a review journal bringing neurobiology, neurology and psychiatry, 1073858420945971. Advance online publication. https://doi.org/10.1177/1073858420945971

[9]Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. Journal of Neuroscience Methods, 134(1), 9-21. Retrieved from https://escholarship.org/uc/item/52k1t4sz

[10] Douglas, V.I., Parry, P., Marton, P., Garcon, C. Assessment of a cognitive training program for hyperactive children. J Abnorm Child Psychol 4, 389–410 (1976). https://doi.org/10.1007/BF00922535

[11] Duric, N. S., Assmus, J., Gundersen, D., Duric Golos, A., & Elgen, I. B. (2017). Multimodal treatment in children and adolescents with attention-deficit/hyperactivity disorder: a 6-month follow-up. *Nordic journal of psychiatry*, *71*(5), 386-394.

[12] Engel G. L. (1977). The need for a new medical model: a challenge for biomedicine. Science (New York, N.Y.), 196(4286), 129–136. https://doi.org/10.1126/science.847460

[13] Escofier Brigitte & Pagès Jérôme (2008). Analyses factorielles simples et multiples. Dunod. Paris. 318 p. p. 27 et seq.

[14] Frances Buttelmann and Julia Karbach, Development and Plasticity of Cognitive Flexibility in Early and Middle Childhood Front Psychol. 2017; 8: 1040.

[15] Gabard-Durnam LJ, Mendez Leal AS, Wilkinson CL, Levin AR. The Harvard Automated Processing Pipeline for Electroencephalography (HAPPE): Standardized Processing Software for Developmental and High-Artifact Data. *Front Neurosci*. 2018;12:97. Published 2018 Feb 27. doi:10.3389/fnins.2018.0009

[16] Gates, N. J., & Sachdev, P. (2014). Is cognitive training an effective treatment for preclinical and early Alzheimer's disease?. *Journal of Alzheimer's disease : JAD*, *42 Suppl 4*, S551–S559. https://doi.org/10.3233/JAD-141302

[17] Gerrard P, Malcolm R (June 2007). *"Mechanisms of modafinil: A review of current research"*. Neuropsychiatr Dis Treat. **3**: 349–64

[18] George L. Engel, The Clinical Application of the Biopsychosocial Model, The Journal of Medicine and Philosophy: A Forum for Bioethics and Philosophy of Medicine, Volume 6, Issue 2, January 1981, Pages 101–124, https://doi.org/10.1093/jmp/6.2.101

[19] Ghaemi, S. (2009). The rise and fall of the biopsychosocial model. British Journal of Psychiatry, 195(1), 3-4. doi:10.1192/bjp.bp.109.063859

[20] Grinker RR Sr. A Struggle for Eclecticism. Am J Psychiatry. 1964. 121:451-457. doi:10.1176/ajp.121.5.451

[21] Gray, J. A. (1987a). Perspectives on anxiety and impulsivity: A com-mentary. Journal of Research in Personality, 21, 493-509

[22] Harter, S (2012) Self Perception Profile for Children: Manual and Questionnaires University of Denver

[23] Hirisave Uma, Oommen Anna, Kapur Malvika (2011) Psychological assessment of children in clinical setting, NIMHANS , publication 48, 197-264

[24] Jacobson, E. (1987). Progressive Relaxation. The American Journal of Psychology, 100(3/4), 522-537. doi:10.2307/1422693

[25] Jaeggi, S. M., Pahor, A., Seitz, A. R. "*Does 'Brain Training' Actually Work?,*" Scientific American, Sep. 2020.

[26] Johnston MV, Brain plasticity in paediatric neurology. Eur J Paediatr Neurol. 2003;7(3):105-13.

[27] Jedlicka, P. (2017). Revisiting the quantum brain hypothesis: toward quantum (neuro) biology?. *Frontiers in molecular neuroscience*, *10*, 366.

[28] Kadis D, Iida K, Kerr E, Logan W, McAndrews M, Ochi A, et al Intrahemispheric reorganization of language in children with medically intractable epilepsy of the left hemisphere. J Int Neuropsychol Soc 2007; 13: 505–16.

[29] Karch, D., Albers, L., Renner, G., Lichtenauer, N., & von Kries, R. (2013). The efficacy of cognitive training programs in children and adolescents: a meta-analysis. *Deutsches Ärzteblatt International*, *110*(39), 643.

[30] Karunamuni N., Imayama I., Goonetilleke D., (2020). Pathways to well-being: Untangling the causal relationships among biopsychosocial variables. Social Science & Medicine, 112846, https://doi.org/10.1016/j.socscimed.2020.112846.

[31] Krigolson OE, Williams CC, Norton A, Hassall CD, Colino FL. Choosing MUSE: Validation of a Low-Cost, Portable EEG System for ERP Research. *Front Neurosci*. 2017;11:109. Published 2017 Mar 10. doi:10.3389/fnins.2017.00109

[32] Madhavi Bongarala, Shashi Kumar, Ronald Ross, R. Manjunatha, N. S. Nagaraja & Krishnamurthy Jayanna; Impact of a Neuro-Cognitive Intervention on Students' Cognitive Functions: Assessments in a Government School Setting in South India. Journal of Educational and Developmental Psychology; Vol. 9, No. 2; 2019 (ISSN 1927-0526)

[33] Maess, Burkhard et al. "High-pass filters and baseline correction in M/EEG analysis-continued discussion." Journal of Neuroscience Methods 266 (2016): 171-172.

[34] Marković, D. and Gros, C., "Power laws and self-organized criticality in theory and nature", *Physics Reports*, vol. 536, no. 2, pp. 41–74, 2014. doi:10.1016/j.physrep.2013.11.002.

[35] McLaren, N. (1998). A Critical Review of the Biopsychosocial Model. Australian & New Zealand Journal of Psychiatry, 32(1), 86–92. https://doi.org/10.3109/00048679809062712

[36] McMorris, T., & Hale, B. J. (2015). Is there an acute exercise-induced physiological/biochemical threshold which triggers increased speed of cognitive functioning? A meta-analytic investigation. *Journal of Sport and Health Science*, *4*(1), 4-13.

[37] Meisel, C., Bailey, K., Achermann, P. *et al.* Decline of long-range temporal correlations in the human brain during sustained wakefulness. *Sci Rep* **7,** 11825 (2017). https://doi.org/10.1038/s41598-017-12140-w

[38] Miller K J, Sorensen L B, Ojemann J G, den Nijs M (2009) Power-Law Scaling in the Brain Surface Electric Potential. PLoS Comput Biol 5(12): e1000609. https://doi.org/10.1371/journal.pcbi.1000609

[39] Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proc. Natl. Acad. Sci. U.S.A.* 108, 2693–2698. doi: 10.1073/pnas.1010076108

[40] Mosch S, Max J, Tranel D. A matched lesion analysis of childhood versus adult-onset brain injury due to unilateral stroke. Cog Behav Neurol 2005; 18: 5–17.

[41] Nagaraja Nanjegowda Siddaramappa, Meghna Manocha (2019). An integrated system and intervention method for activating and developing whole brain cognition functions (U.S. Patent App. US20190325767A1). U.S. Patent and Trademark Office.

[42] Rabipour, Sheida & Raz, Amir. (2012). Training the brain: Fact and fad in cognitive and behavioral remediation. Brain and cognition. 79. 159-79. 10.1016/j.bandc.2012.02.006.

[43] Raven J., Raven, J. C., & Court, J. H. (1984c). Manual for Raven's Progressive Matrices and Vocabulary Scales. Section 3, The Standard Progressive Matrices. H K Lewis & Co. Ltd.London, ISBN 07186 04717

[44] Rogge, AK., Röder, B., Zech, A. *et al.* Balance training improves memory and spatial cognition in healthy adults. Sci Rep 7, 5661 (2017). https://doi.org/10.1038/s41598-017-06071-9

[45] Rueda, Maria & Rothbart, Mary & Mccandliss, Bruce & Saccomanno, Lisa & Posner, Michael. (2005). Training, maturation and genetic influences on the development of executive attention. Proceedings of the National Academy of Sciences of the United States of America, 102, 14931-14936. 10.1073/pnas.0506897102.

[46] Rosenzweig M. R., Bennett E. L., (1996). Psychobiology of plasticity: effects of training and experience on brain and behaviour. Behavioural Brain Research, 78(1), 57-65. https://doi.org/10.1016/0166-4328(95)00216-2

[47] Rothbart, M., Ahadi, S., & Hershey, K. (1994). Temperament and Social Behavior in Childhood. Merrill-Palmer Quarterly, 40(1), 21-39. Retrieved August 21, 2020, from http://www.jstor.org/stable/23087906

[48] Rovner BW, Folstein MF. Mini-mental state exam in clinical practice. *Hosp Pract.*1987; 22(1A):99, 103, 106, 110.

[49] Scarpa, A., & Raine, A. (2000). Violence associated with anger and impulsivity. In J. Borod, (Ed.), The neuropsychology of emotion (pp. 320–339). NY: Oxford University Press.

[50] Shaw, C., Lanius, R., & Doel, K.V. (1994). The origin of synaptic neuroplasticity: crucial molecules or a dynamical cascade? *Brain Research Reviews, 19*, 241-263.

[51] Sohlberg, M. M., & Mateer, C. A. (1987). Effectiveness of an attention-training program. Journal of clinical and experimental neuropsychology, 9(2), 117–130. https://doi.org/10.1080/01688638708405352

[52] Stephen P Hinshaw, Attention Deficits and Hyperactivity in Children Vol 29 New Delhi

[53] Stiles J Neural plasticity and cognitive development, Dev Neuropsychol. 2000;18(2):237-72.)

[54] Taupin P. Adult neurogenesis and neuroplasticity. Restorat Neurol Neurosci 2006; 24: 9–15.

[55] Titz, C., and Karbach, J. Working memory and executive functions: effects of training on academic achievement. *Psychol. Res 2014.* 78, 852–868. doi: 10.1007/s00426-013-0537-1

[56] Teicher MH, Andersen SL, Polcari A, Anderson CM, Navalta CP, Kim DM. The neurobiological consequences of early stress and childhood maltreatment. Neurosci Biobehav Rev. 2003;27(1-2):33-44. doi:10.1016/s0149-7634(03)00007-1

[57] Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: the role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science*, *4*(1), 47-55.

[58] Van der Donk, M. L. A. (2016). *Cognitive training for children with ADHD: Individual differences in training and transfer gains*. Doctoral dissertation). Retrieved from: http://hdl. handle. net/11245/1.534724.

[59] Wakeman, D. G., & Henson, R. N. (2015). A multi-subject, multi-modal human neuroimaging dataset. *Scientific data*, *2*, 150001.

[60] Yeniad, N., Malda, M., Mesman, J., van Ijzendoorn, M. H., and Pieper. Shifting ability predicts math and reading performance in children: a meta-analytical study. *Learn. Individ. Differ 2013,* 23, 1–9. doi: 10.1016/j.lindif.2012.10.00

[61] Wang, Z., Zhou, R., Shah, R. (2014) Spaced cognitive training promotes training transfer, Front. Hum. Neurosci, 8, 217. doi: 10.3389/fnhum.2014.00217

[62] Zaccaro A, Piarulli A, Laurino M, Garbella E, Menicucci D, Neri B and Gemignani A (2018) How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing. Front. Hum. Neurosci. 12:353. doi: 10.3389/fnhum.2018.00353

[63] Zwilling, C. E., Daugherty, A. M., Hillman, C. H., Kramer, A. F., Cohen, N. J., & Barbey, A. K. (2019). Enhanced decision-making through multimodal training. *NPJ science of learning*, *4*(1), 1-10.

Figures

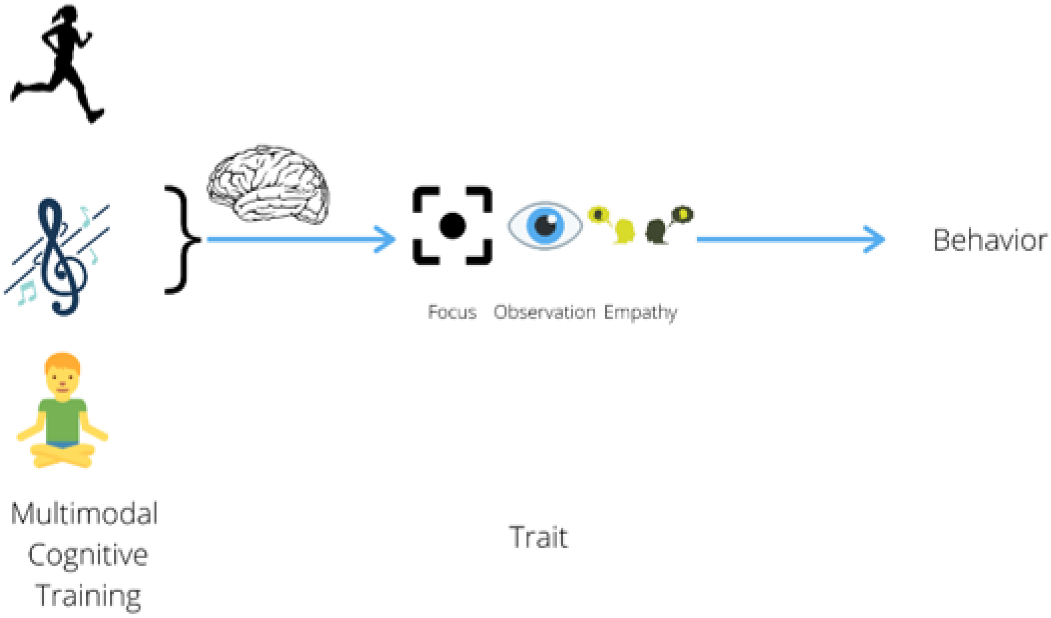

Figure 1

Multimodal Cognitive Training can influence traits such as focus, observation and empathy, and have transfer effects on behavior.

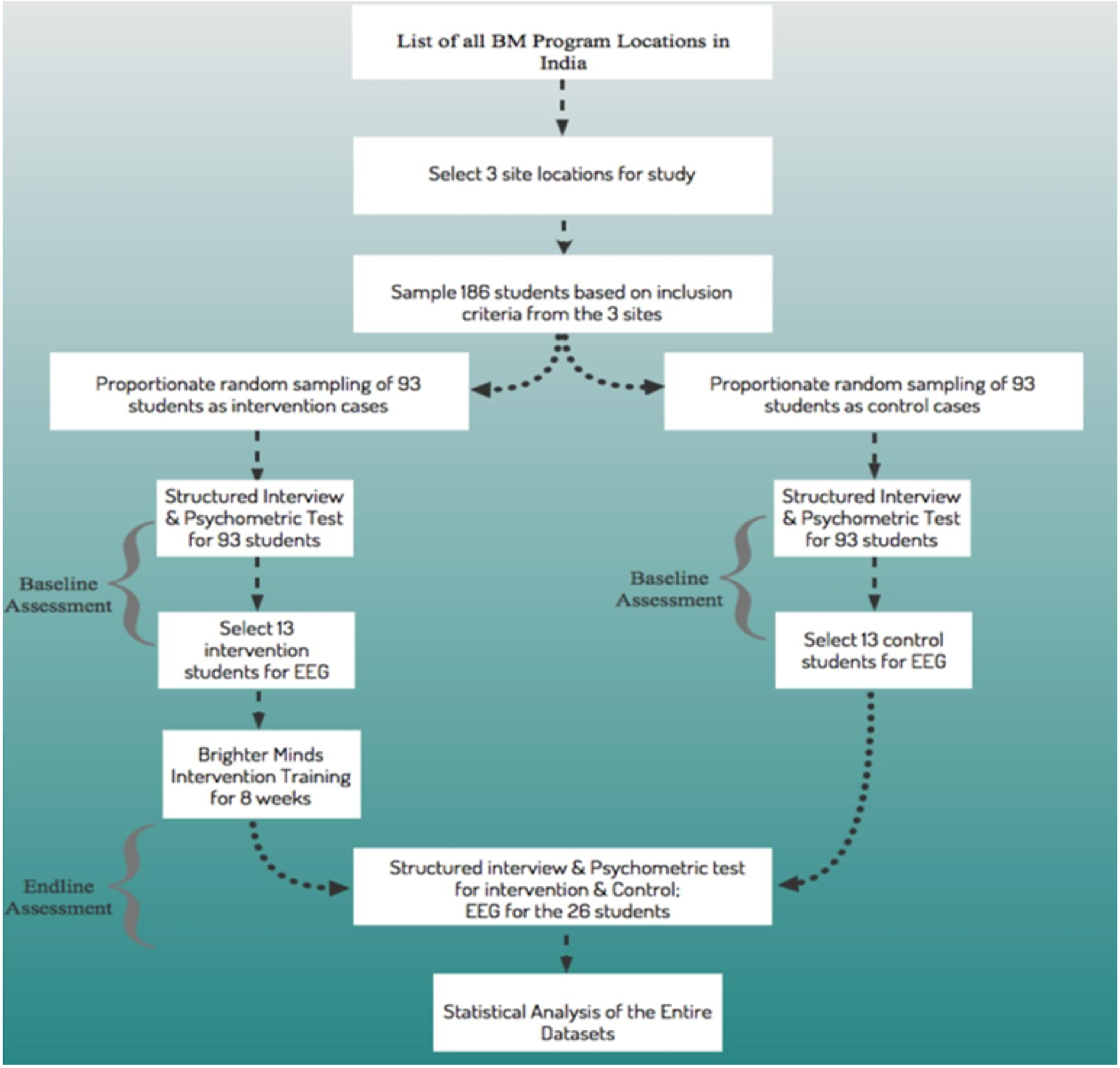

Figure 2

Sampling Frame and Workflow

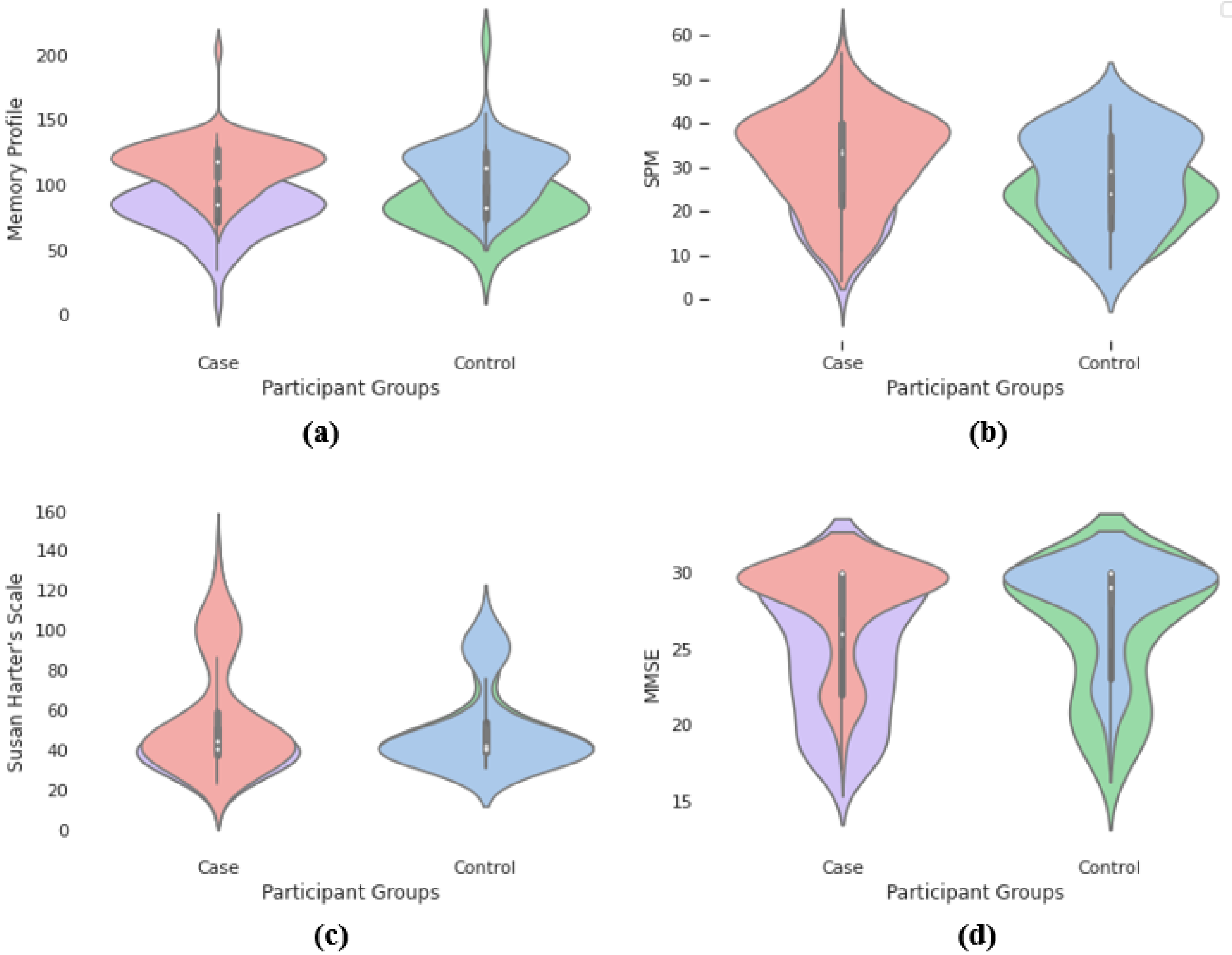

Figure 3

Violin Plots for the two participant groups, Control and Intervention (Case) for the Psychometric Tests of (a) Memory Recall (b) SPM, (c) Susan Harter's (d) MMSE. Violet and Green represent Pre-CT, and Red and Blue represent Post-CT. Error bars indicate 95% confidence interval.

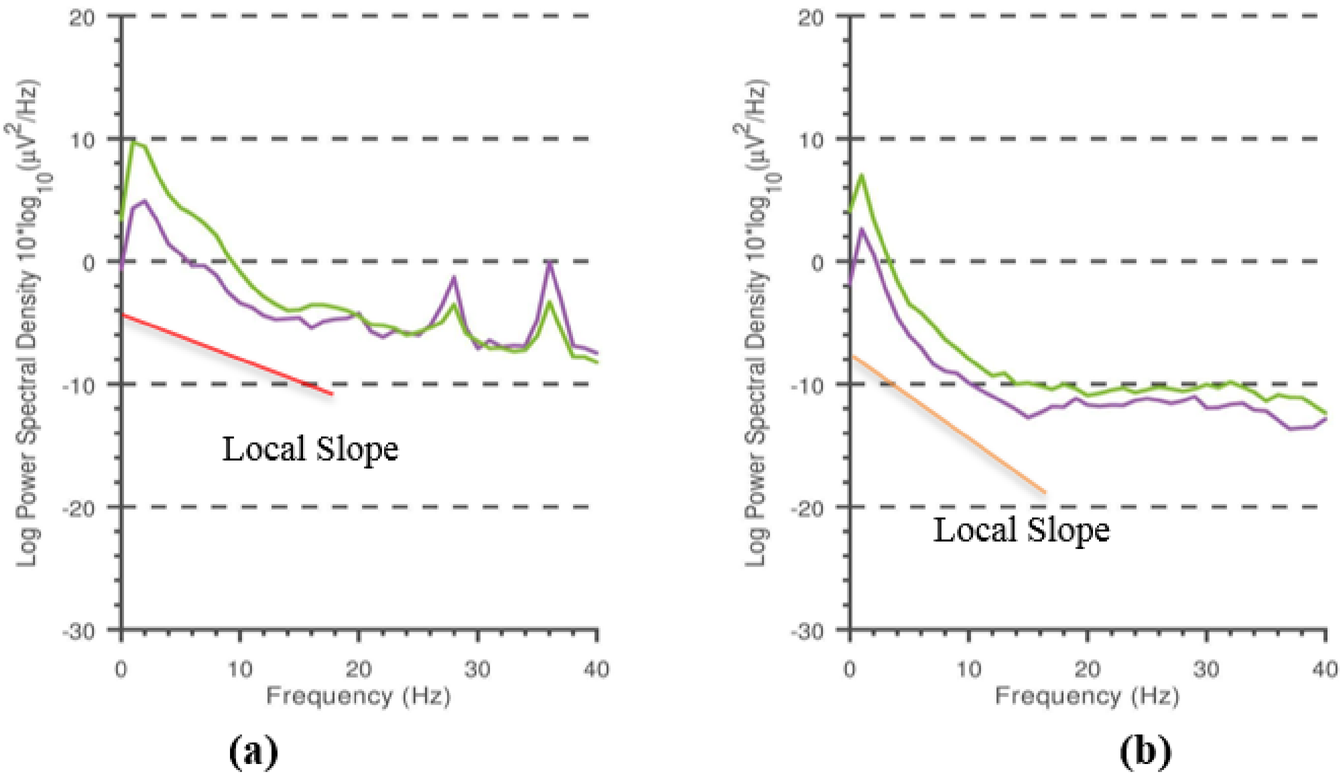

Figure 4

The Power Spectral Density (PSD) calculated on the AF7 (purple color) and AF8 (green color) EEG signals subject (a) Control; and (b) Intervention. Red and Orange lines indicate the local slopes for the PSD below 20Hz for the Control and Intervention respectively.

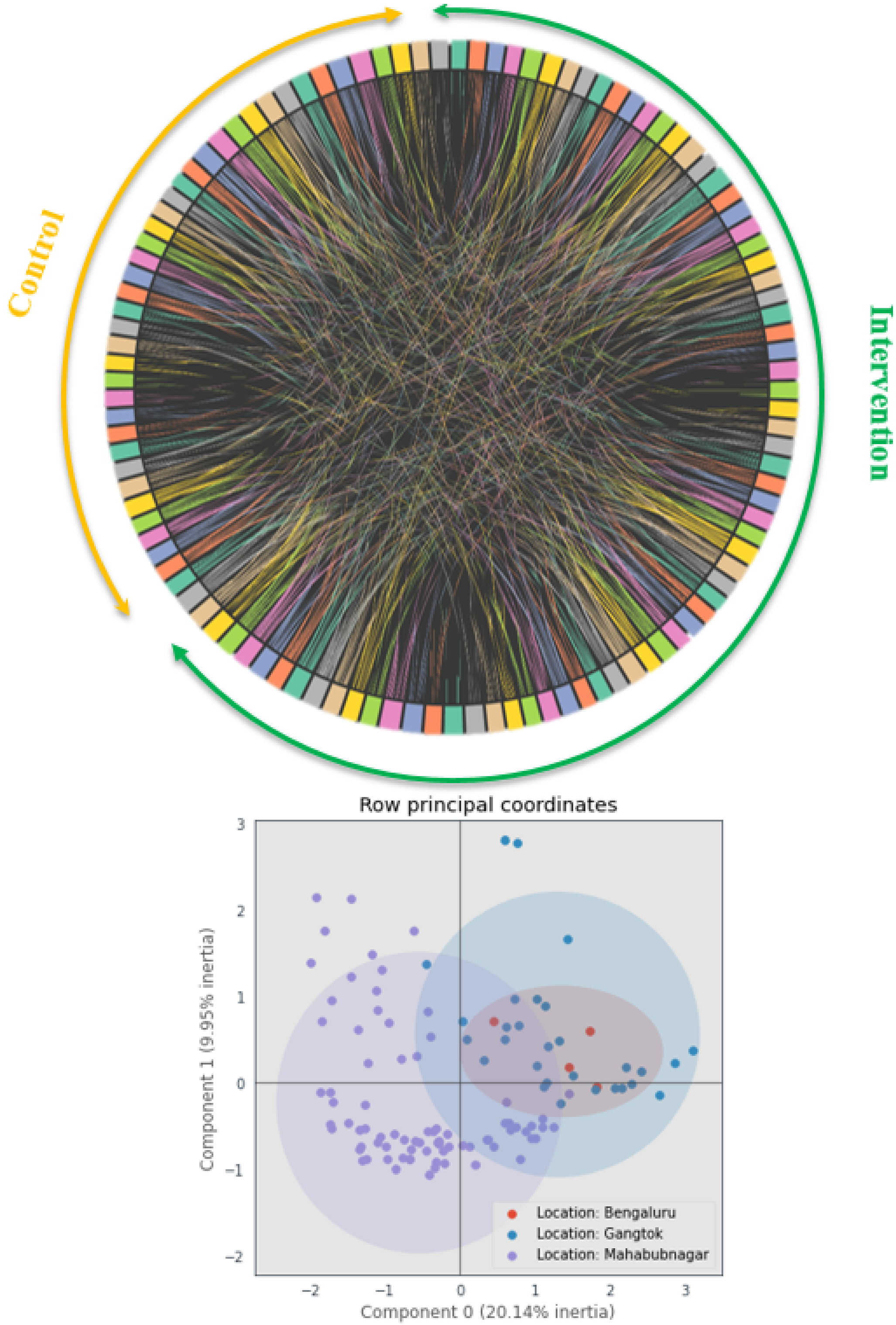

Figure 5

(above) Chord Diagram of the entire dataset with Control and Intervention Grouping based on the Dice Distance; (below) Scatter Plot after Factor Analysis on the Mixed Data (Categorical and Continuous) and colors representing the location of the training program (Bengaluru, Gangtok, Mahabubnagar).

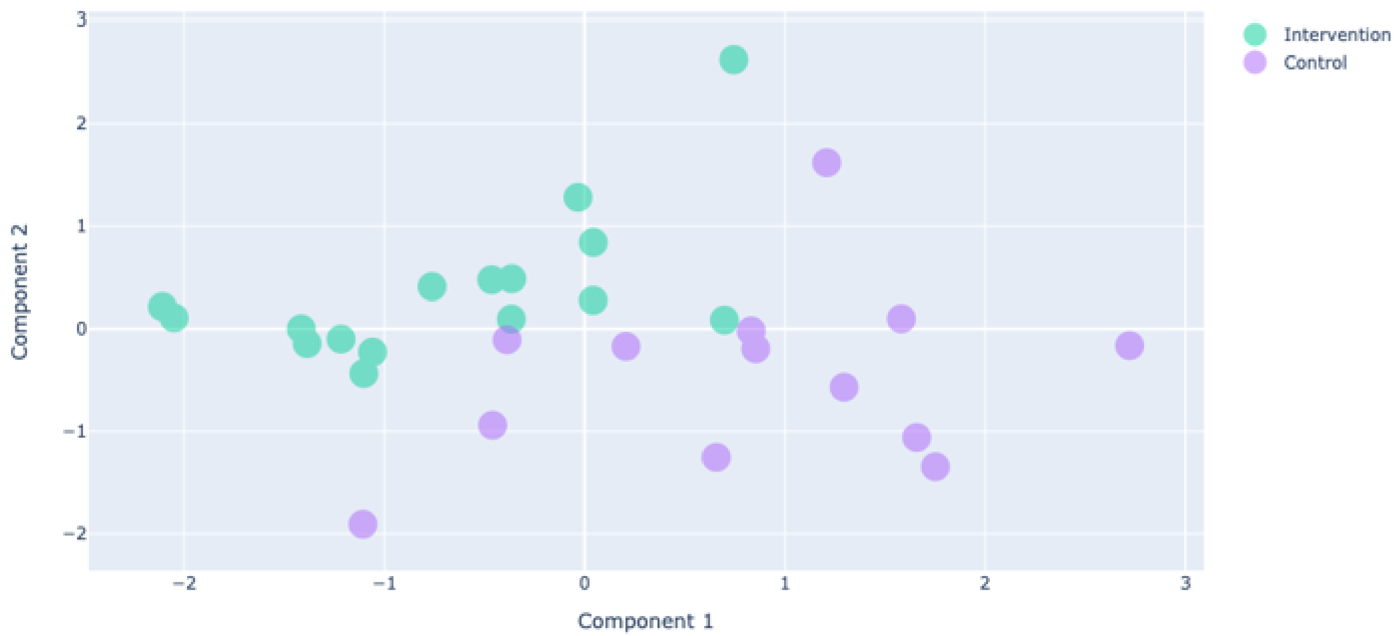

Figure 6

Scatter Plot after Factor Analysis on the Mixed Data (Categorical and Continuous) on location Gangtok. The purple color represents the Control group while the Cyan color represents the Intervention Group.

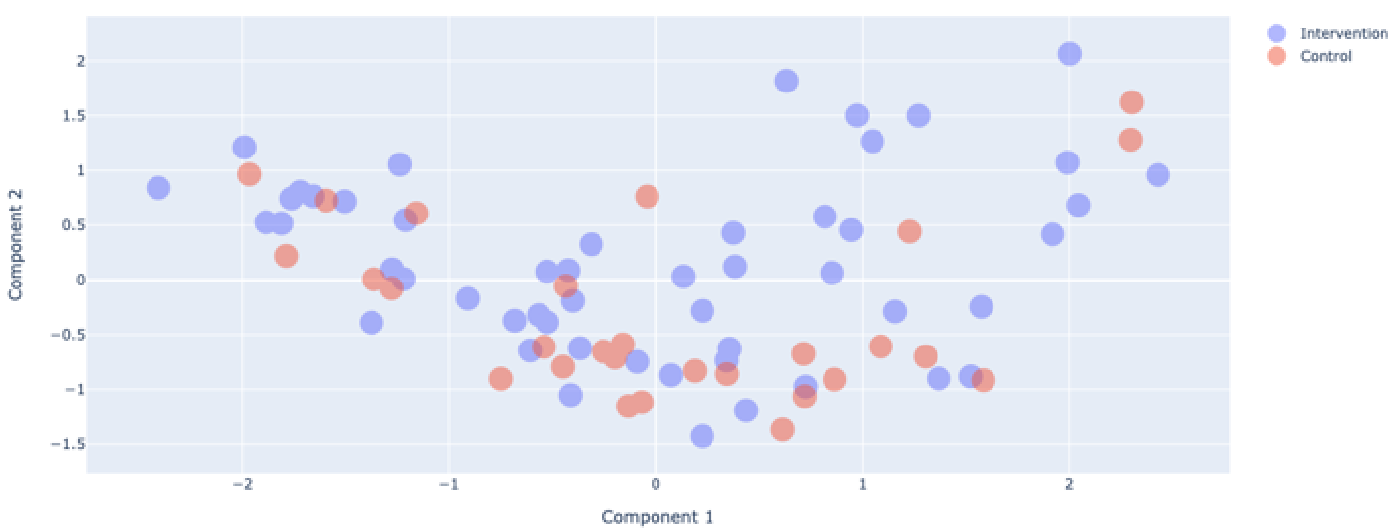

Figure 7

Scatter Plot after Factor Analysis on the Mixed Data (Categorical and Continuous) and on the dataset collected from the location Mahabubnagar. The purple color represents the Intervention group while the orange color represents the Intervention Group.

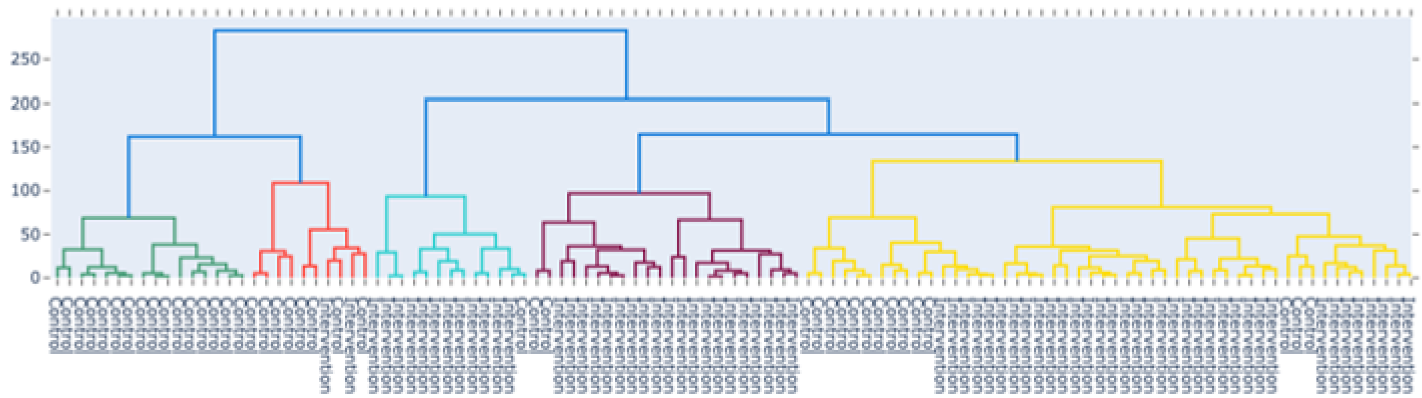

Figure 8

Unsupervised Clustering of the total dataset consisting of the categorical variables from the Psychomteric Tests and the Parent/Caregiver survey results, using dice metric. The Case and the Intervention clearly cluster as a separate group. The Case group form two major clusters based on the two locations: Mahabubnagar and Gangtok. It is likely that the anomalies in the Control appearing among the intervention group might be due to the exposure of the program to the control participants in hostels.