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Original Research

Raga-music intervention in verbal autistic children: a randomized controlled pilot study

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Abstract

Autism spectrum disorder is a multifactorial neurodevelopmental disorder with increasing prevalence worldwide. Given the heterogeneity of autism, it is highly unlikely to have a single effective therapy for autism. Adversities associated with current pharma-therapies in treating autism have prompted the emergence of alternative therapies including variety of behavioral and music interventions. Autistic children, who tend to show a strong preference for music, makes music therapy a promising intervention for autism. Music interventions have shown improved mental and physical health across multiple domains including autism. Previous clinical trials of music therapy versus traditional therapy for autistic children have shown encouraging but mixed results. In that regard, Indian classical music is postulated to exert enhanced benefits due to its melodic uniqueness. Current randomized controlled pilot study tested the hypothesis if Indian classical music-Raga co-treatment will enhance the benefits of conventional standard care in 5–12 years old verbal autistic children. Participants were randomly assigned either to comprehensive standard care (Std) consisting of Applied Behavior Analysis (ABA) combined with occupational Sensory Integration Therapy (SIT), and Raga-Music therapy added to the Std care. The comparative effectiveness of Raga-Music therapy add-on over 8-weeks of treatment duration was evaluated by primary and secondary outcome measures. The primary outcome measure included the Autism Treatment Evaluation Checklist (ATEC) assessment that examined the progression of autism, while the secondary outcome measures included sensory processing assessment using Sensory Profile 2 (SP2) followed by Canadian Occupational Performance Measure (COPM) with client satisfaction scoring, before and after the treatment. Raga-Music co-treatment was found to accentuate the benefits of Std treatment in reducing the progression of autism along with improvement in sensory profile of verbal autistic children. Current study supports the notion that Raga-Music is an effective adjuvant for early intervention autism healthcare program while warranting further investigation.

Keywords: Autism Spectrum Disorder; Music Therapy; Indian Classical Music; Raga, Emotional Upliftment, Sensory Profile, ABA, SP2, ATEC, COPM

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Graphical Abstract

Introduction

Autism spectrum disorder (ASD) or autism is a heterogeneous neurodevelopmental disorder encompassing a group of neurobehavioral conditions including autism, Asperger's disorder and pervasive developmental disorder, afflicting 1 in 31 children in United States and 1 in 100 children worldwide [1–4]. Currently, there is no cure for ASD [5]. Ongoing pharmacological treatments of ASD include the use of psychostimulants, atypical antipsychotics, anti-depressants and α-2 adrenergic receptor agonists, which provide only partial symptomatic relief and are associated with adverse side effects [6–10]. In that regard, non-pharmacological treatments with none/least adversities [11], such as cognitive behavioral therapy (CBT) [12], applied behavioral therapy (ABA) [13], social behavioral therapy (SBT) [14], and creative art [15–17] including music therapy (MT) [18–21] are increasingly being considered as effective alternatives for treating autism.

The "spectrum" of autism embraces both challenges and strengths [22]. The challenges of ASD are characterized by persistent deficits in two core areas of functioning i.e. social communication and interaction and restricted/repetitive patterns of behavior [23–25], along with other co-psychomorbid conditions such as anxiety, depression, attention deficit, epilepsy, etc. [26,27]. Despite difficulties in such psychobehavioral domains, autistic children exhibit strong visual/auditory learning and remarkable ability to excel in math, art, craft, and music [28–30]. There is a growing recognition in using music as a potential therapeutic intervention to improve psychological, motor and behavioral dysfunctions in people with neurological disorders including ASD [20,31–35]. Regardless of an inability to interpret other people's nonverbal, facial, and bodily expressions of emotion(s), a strong preference for music is observed in autism [36–38], suggesting that music can be exploited as an effective alternative for treating ASD [39].

Early evidence suggests remarkable improvements following music exposure across many clinical domains of ASD, along with structural and functional corrections in the key brain-areas [33,40,41]. One study showed statistically significant improvement in emotional responses of autistic children to musical stimuli [42]. Another report showed that compared to non-music controls, 8–12 weeks of music intervention improved parent-reported social communication and restored brain activity, as indicated by functional MRI after music intervention [41,43]. The social skills were significantly improved after improvisational music therapy in autistic children [44,45]. One study showed that listening to both "Happy" and "Sad" music activated cortical and subcortical brain regions involved in emotional processing and reward brain network, although "Happy" music effects were more pronounced than that of "Sad" music [46]. Effectiveness of music therapy may be attributed to its distinct ability to modify structural and functional brain connectivity via neuroplastic and neurophysiological mechanisms [47–49]. Moreover, the potential of music in reducing stress hormones while simultaneously elevating hormones involved in emotional/reward/cognitive processing and neuroplasticity, makes music, an effective therapeutic choice [50–54]. Music affects functional brain connectivity and therefore is effective in treating neurological disorders [55–58] including ASD [28,41,59]. Music has a unique ability to target ASD-specific core disabilities aimed at restructuring auditory-motor-cognitive connectivity leading to enhanced social communication, emotional and motor functions [37,41,42,60]. In that regard, Indian Classical Music (Raga) may exert added advantage due to its structural uniqueness, defined rhythmicity and melodic framework of Raga, known to induce specific emotions/moods in a circadian-specific manner [61–64]. Studies have shown the ability of specific Ragas to elicit specific "Rasa" (emotion) aligning with corresponding brain physiology [65–69]. However, there are sparse reports showing Raga effects in autism [41,70].

This randomized controlled study explored the effects of Raga in treating autistic children. Current pilot study evaluated therapeutic feasibility of Indian Classical Music-Raga intervention (https://youtu.be/viL-8iubNpE; Owner, Mahesh Kale; One of the Authors), edited to remove extra-music components defined as "MUSIC", in the verbal group autistic children between 5–12 years of age [71,72],

at the Early Intervention Child Development Center, RUGRATS Cocoon, Ahmedabad, Gujarat, India. Since this is a preliminary pilot study aimed at assessing only the feasibility of MUSIC, and not a true 3-arm randomized controlled trial (RCT), it has not been registered in a clinical trials registry (ClinicalTrials.gov or CTRI). The primary objective of our study was to determine the comparative effectiveness of MUSIC intervention in attenuating autism-progression in autistic children, as evaluated by the standardized Autism Treatment Evaluation Checklist (ATEC) assessment [73,74]. In addition, since the abnormal sensory processing constitutes a characteristic feature of ASD [75–78], the secondary objective of our study was to examine the changes in sensory processing patterns in autistic children, before and after MUSIC intervention, using Winnie Dunn's standardized sensory profile 2 (SP2) [79–82], followed by Canadian Occupational Performance Measure (COPM), reflecting patients' occupational functional improvement index and client satisfaction [83,84].

Methods

Participants

A total of 75 participants (5–12 years of age) were recruited who met the eligibility (inclusion criteria) after diagnosed for the presence of ASD using CARS2-ST scale [85,86] and randomly assigned to experimental groups (**Figures 1** and **2**). There was no attrition from the recruited participants.

Diagnosis of Autism Spectrum Disorder-Childhood Autism Rating Scale

The childhood autism rating scale (CARS) is the most widely accepted diagnostic tool for diagnosing autism, originally developed by Schopler *et al.* [87,88], and later refined as CARS2, second edition with two versions i.e. standard version (CARS2-ST) and high function version (CARS2-HF) [89]. CARS2-ST, although similar to the original version, includes some modification(s) designed for children below 6 years of age, and a high function version (CARS2-HF) for older children [90–92]. The diagnostic validity of CARS2-ST is high across Diagnostic and Statistical Manual of Mental Disorders (DSM)-IV/V criteria for diagnosing autism [90,93].

The CARS2-ST consists of 15-item questionnaire and is evaluated by a clinical expert based on personal interviews with the primary caregiver and direct observation of children [86]. Each question is rated on a scale of 1 (Normal at the corresponding age) to 4 (Severely abnormal at the corresponding age). Individual item scores are added to obtain an aggregate score ranging between 15–60 for each subject [85,86,92]. CARS2-ST score <30 indicates non-autism-Normal, the score >30 between 30–36 indicates mild-moderate ASD, and the score >36 indicates severe ASD [86,92,94–96]. The CARS2-ST assessment was conducted by a licensed and trained clinical professional and confirmed by the occupational therapist having many years of experience in treating autistic children at the Early Intervention Child Development Center, RUGRATS Cocoon, Ahmedabad, Gujarat, India. All data were accurately recorded including age, demographics, date of test administration, CARS2-ST scores, and used for diagnosis of ASD.

Inclusion / Exclusion Criteria

Inclusion Criteria

- Age between 5–12 years
- ASD score < 30 on CARS2-ST scale, as Typically Developing (TD) normal control subjects
- ASD score > 30 on CARS2-ST scale, as ASD experimental subjects
- Reasonable sitting tolerance (evaluated at initial assessment)
- Basic verbal skills, able to speak for needs

Exclusion Criteria

- Younger than 5 Years and Older than 12 years of Age
- Not able to speak
- Very low sitting tolerance
- Severe sensory seeking behavior
- Not willing to participate in the study

Figure 1. Distribution of participants.

Recruitment and Randomization

Based on the inclusion and exclusion criteria, eligible subjects between 5–12 years of age were recruited in the study and distributed among experimental groups (**Figures 1** and **2**). Eligible children with CARS2-ST score <30 were identified as non-autistic who served as typically developing (TD) normal controls (Group 1). Since this is only a pilot feasibility study to see if Raga may have any effect at all, TD group has been included as a non-randomized observational reference group. Eligible children with CARS2-ST score >30 were identified as ASD. The ASD subjects were randomized as follows. The randomization and recruitment was conducted by a healthcare professional at the Early Intervention Child Development Center, RUGRATS Cocoon, Ahmedabad, Gujarat, India. The enrollment was conducted by creating an unpredictable random list of participants to be assigned to different groups using a "Coin-Toss" simple randomization, while hiding the sequence of assignment from the enrolling participants. As mentioned earlier, a non-randomized TD group was included as an observational reference group (Group 1). Thus, the participants were randomly assigned to two experimental groups (1:1) based on the treatment regimen. ASD children to be treated only with standard therapy (Std) (Group 2), and ASD children to be treated with Std plus MUSIC co-treatment (Group 3) (**Figures 1** and **2**).

Group 1 (TD): Typically developing (TD) Non-ASD normal children, <30 CARS2-ST, (N=25)

Group 2 (ASD-Std): ASD children, CARS2-ST >30, treated with standard (Std) intervention only (N=25)

Group 3 (ASD-Std+MUSIC): ASD children, CARS2-ST >30, treated with Std plus MUSIC intervention (N=25)

Standard intervention (Std) consisted of Applied behavioral Analysis (ABA) combined with occupational Sensory Integration Therapy (SIT). MUSIC intervention consisted of Raga rendition (https://youtu.be/viL-8iubNpE (Owner, Mahesh Kale, One of the Authors), edited to remove extra-music components (MUSIC).

Although it appears unusual, in fact, there was no attrition from the recruited subjects for a short duration of 8 weeks.

Figure 2. CONSORT 2010 flow diagram.

All assessments were conducted at the pre- and post-treatment time-points. The TD controls, although not treated, underwent ATEC evaluation at the matching pre- and post-assessment time-points parallel to the experimental groups.

Sample Size Justification

The sample size of N=25 per group was determined as recommended by the National Center for Complementary and Integrative Health (NCCIH), National Institute of Health (NIH), suggesting the sample size of N=25 per group to be practical for establishing feasibility rather than the consideration of statistical power [www.nccih.nih.gov]. Supporting reports confirmed that for the qualitative work (such as the current study) involving behavioral, emotional and psycho-social assessments, the sample size less than N=30 is adequate to establish the feasibility [97–100]. A power analysis for sample-size estimation indicated that a range of 15–22 participants would be sufficient to detect a meaningful treatment outcome while testing feasibility [101]. A study aimed at evaluating feasibility and acceptability of music therapy used the sample size ranging between N=19–23 [98]. Another study that examined comparative effectiveness of music therapy involving pre- and post-test measurements used the sample size of N=20 [99]. With the recommended minimum sample size of N=12 to be used for the pilot trials as a rule of thumb [102], a sample size range of N=20–25 may be adequate to obtain meaningful group differences [103]. Since the main goal of current pilot study is to establish the platform for predicting meaningful outcomes after MUSIC therapy, and to establish the feasibility for larger studies, a sample size of N=25 per group was deemed adequate without requiring a need for large sample size [98–100,104]. Thus, a sample size of N=25 per group used in the current feasibility pilot study is well-justified to determine comparative effectiveness of MUSIC therapy.

Ethical Aspects

This randomized feasibility pilot study was conducted in accordance with the approval (HSN/SAC Code: 998346; Date of Approval: January 12, 2024) granted by CONSCIENCE Independent Ethics Committee (CIEC), Ahmedabad, Gujarat, India. CIEC operates in compliance with the Indian Council of Medical Research (ICMR) Guidelines for Biomedical Research on Human Subjects, and WMA Declaration of Helsinki, Brazil, Oct 2013, 21 CFR Part 56 and 21 CFR Part 50, in governance with Good Clinical Practice. This approved feasibility pilot study protocol has been registered at the Data Governance and Compliance Infrastructure (DGCI) (ECR/233/Indt/GJ/2015/RR21); Department of Health and Human Services (DHHS) (IORG0008391); and Office of Human Research Protections (OHRP) (IRB00010059).

The process of obtaining informed consent was conducted in accordance with the requirements of CIEC Ethics Committee guidelines. The signed "Informed Consent" from each child/parent was registered before recruiting patients in the study. Participants were educated about the study set-up (Purpose, Procedure/Methods, Duration of the Project, Non-invasive risk-free nature of MUSIC intervention). They were assured that the session(s) will cease immediately if their child becomes distressed or uncomfortable for any reason. Participants were guaranteed that they have freedom to withdraw from the study at any time without the loss of benefits they are entitled to.

Study Design

This feasibility pilot study design was aimed at testing whether the MUSIC co-treatment will enhance the benefits of standard therapy and possibly delay/attenuate the progression of ASD in autistic children. The study was conducted in verbal group children between 5–12 years of age [71,72], recruited after confirmed diagnosis of ASD or absence of ASD, as determined by CARS2-ST assessment [85,86]. The established CARS2-ST scale defines the score >30 as normal, the scores >30 (30–36) as mild-moderate ASD, and the scores >36 as severe ASD [86,92,94,95].

As mentioned earlier, Children with CARS2-ST scores <30 were classified as typically developing (TD) non-ASD normal controls while the children with the CARS2-ST scores >30 were classified as ASD experimental subjects. The non-ASD TD controls did not receive any treatment while the ASD experimental subjects received standard treatment with or without MUSIC co-treatment. The ASD experimental group was divided into two treatment groups with 1:1 allocation ratio, including an experimental group treated with only standard (No MUSIC) (Std) intervention, and another experimental group treated with Std intervention combined with MUSIC intervention including a 15-min daily session of MUSIC therapy for 8 weeks. The primary outcome included ATEC assessment to monitor the progression of autism [73,74], while the secondary outcome assessments included SP2 [80–82] and COPM [83,84] to evaluate changes in the sensory processing and occupational performance, before and after the interventions. All evaluations were performed at the treatment-start base level (Pre-test) and at the treatment-end (Post-test) time points. ATEC evaluation was performed in all three groups, while SP2 and COPM assessments were conducted only in experimental groups (**Figure 3**).

Figure 3. Treatment regimen and outcome evaluation timeline.

Interventions

This study included 2 types of interventions:

[1] Standard intervention (Std)

[2] Indian Classical Music-Raga (https://youtu.be/viL-8iubNpE) intervention edited to remove extra-music components (MUSIC)

Standard Intervention

Standard intervention (Std) consisted of a comprehensive treatment plan including Applied behavioral Analysis (ABA) [13,105] combined with occupational Sensory Integration Therapy (SIT) [106,107], addressing behavioral and sensory processing aspects [107,108] in treating verbal group autistic children. All interventions were delivered as "one-on-one" basis (**Figure 4**). Session compliance of all participants was confirmed.

Initial Assessment

The initial assessment of participants randomized to the stated intervention(s) was carried out over an in-person introductory session of ~1h duration at the study site (Early Intervention Child Development Center, RUGRATS Cocoon, Ahmedabad, Gujarat, India), starting with a greeting-exchanges and welcoming. The comprehensive highlights of the project, including the purpose of the project, how the project to be conducted, what kind of treatments to be given (Std and MUSIC), duration of treatments, etc. all details were given to the participants. Then the designated healthcare professional discussed individualized occupational/behavioral treatment plan depending upon the weaknesses/strengths identified for each patient. Parents were assured about their child's safety, comfort and freedom to withdraw from the study at any time for any reason. Following the introductory session, the signed "Informed Consent" was obtained from each child's parent, after their agreement for participating in the project.

Treatment Plan, Implementation/Modification, and Data Collection

Applied Behavior Analysis (ABA) Therapy (1h/Day, 5 Days/Week, 8 Weeks): Based on the initial assessment, the therapist created a personalized ABA therapy-plan that aligned with the learner's unique needs, by setting the goals to eliminate disruptive social behavior, such as throwing tantrums or inflicting self-injury, to encourage better, healthier social interactions.

The goals were modified depending on the age, ability, and skills of patients:

- Learning abilities
- Social skills
- Self-care capabilities (e.g. bathing or brushing)
- Motor skills
- Communication skills

The parents/caregivers played a major role in ensuring the success of ABA therapy by actively enforcing desired behavior. The therapist trained the parents/caregivers on how to respond to both desired and unacceptable social behavior. The therapist constantly evaluated the patient's response and made changes as needed to ensure better outcomes.

Techniques Used in Implementing and Modifying ABA:

» Positive Reinforcement: This involved rewarding desired social behavior with favorite food right after a child exhibited the right behavior. This was to establish a positive correlation between the act and the reward, making them more likely to remember and repeat good behavior in the future.

» Negative Reinforcement: This was not intended to be confused with punishing for displaying inappropriate behavior. Instead, negative reinforcement involved taking away an object or activity after the instance involving undesired social behavior. Examples included if a child kicked his/her peer in class, the child was engaged with his/her favorite activity and keep away from repeating bad behavior.

» Visual Cues: Both verbal prompts and visual gestures were effective at reinforcing the desired social behavior as long as they weren't accusatory or intimidating. Example included directing the child to wash hands before meals or place his/her belongings neatly in a designated spot and repeating the directions frequently till they no longer need a cue/prompt.

» Verbal Cues: The therapist may teach the child to spell out certain words by singing and then use the same vocabulary to create entire sentences and stories.

» Analysis of Tasks: The instructor assigned tasks and observed the way they were completed to better analyze the child's abilities to create future tasks in line with their skills.

Figure 4. Standard intervention flow chart.

Sensory Integration Therapy (SIT) (45 min/Day, 5 Days/Week, 8 Weeks): This therapy was aimed at providing controlled sensory experiences to help children better process and regulate their sensory input, involving a variety of play-based activities, deep pressure input, vestibular stimulation, and brushing protocols, all designed to address specific sensory processing needs.

Techniques Used in Implementing and Modifying SIT:

» Play-Based Activities: Play as medium to engage children in activities that stimulated different sensory systems.

» Vestibular stimulation: Activities like swinging, spinning, and balancing, which stimulated the vestibular system, responsible for balance and spatial awareness.

» Deep pressure Input: Squeezing stress balls, using weighted blankets, applying gentle pressure can provide calming and grounding sensory experiences, improving body awareness and reducing anxiety.

» Tactile Play: Engaging with different textures, materials, to develop a more refined understanding of tactile sensations.

» Brushing Protocol: This technique involved using a soft brush to apply deep pressure to the skin, which can help regulate sensory input and improve tactile awareness.

» Proprioceptive Input: Activities like pushing, pulling, and engaging in resistive exercises can help improve body awareness and coordination by stimulating proprioceptors, located in muscles and joints.

» Visual and Auditory Stimuli: Activities like visual tracking exercises, using colorful lights, or playing with music can help improve visual processing, attention, and auditory processing skills.

» Oral Motor Activities: Chewing, blowing bubbles, and other oral motor activities can help improve oral sensory processing and support speech and feeding skills.

» Environmental Modifications: Adjustments to the environment, such as reducing noise levels, minimizing visual clutter, or providing sensory breaks, creating a more supportive and less overwhelming environment.

ABA therapy was conducted 1 h/day, combined with occupational Sensory Integration Therapy (SIT) 45 min/day.

ABA and SIT Therapies together were targeted at:

- Developing behavioral skills while simultaneously decreasing the severity of autism
- Encouraging acceptable social behavior
- Increasing attention and concentration
- Reducing self-harming behavior or throwing tantrums
- Developing effective communication to better interact with peers and parents

The data were collected after primary and secondary outcome measurements including Autism Treatment Evaluation Checklist (ATEC), Winnie Dunn's Sensory Profile 2 (SP2) and Canadian Occupational Performance Measure (COPM) along with client satisfaction, before (Pre-) and after (Post-) the treatment(s).

MUSIC Intervention

MUSIC Therapy (15 min/Day, 5 Days/Week, 8 Weeks)

The MUSIC therapy was administered in the autistic children aged 5–12 years with one-on-one basis, at the Early Intervention Child Development Center, RUGRATS Cocoon, Ahmedabad, Gujarat, India, as outlined (**Figure 5**). Session compliance of all participants was confirmed.

Experimental Set-Up

The experimental set up consisted of a ~300 sq ft. isolated room within the facility, specifically dedicated to conduct MUSIC therapy, with the least sound disturbance, environmental controls of temperature and humidity, and optimum ambience. This room was large enough to house a dedicated computer-desk with comfortable chair set up, equipped with a large-screen computer monitor and a well-tested audio-visual system for an optimum display of MUSIC video, with ample walk-around free space. The room also contained sitting arrangements for the healthcare professional(s) conducting the MUSIC sessions.

Mock Trial

A mock trial session was conducted prior to administering experimental sessions to ensure proper functioning of all technical devices to allow necessary adjustments such as computer-screen brightness, sharpness, audio-speakers, adjusting chair-computer height/distance, room environment and overall comfort adjustments, optimally ready to conduct experimental sessions.

Figure 5. MUSIC intervention flow chart.

Experimental Trials

Each experimental session of 15 min duration was conducted by the licensed, well-trained and experienced professional using one on one settings. Each subject was stationed at designated computer-desk spot. Occasionally, the child was allowed to freely choose whether to stay on the carpeted floor or switch between chair and floor. The child was encouraged to communicate in one's comfortable way including gestures, speech, hand-waving, using individual comfort level. Needed adjustments were made accordingly All sessions were conducted in the same identical settings.

- Each 15 min Session; One Session/Day; Mon-Fri; 5 Sessions/Week, for 8 Weeks (Total 40 Sessions)
- Sat-Sun Week-end was used as a "wash-out" period, and for making up "Missed" Session in order to run parallel with the group.

Data Collection

The data were collected after primary and secondary outcome measurements including Autism Treatment Evaluation Checklist (ATEC), Winnie Dunn's Sensory Profile 2 (SP2) and Canadian Occupational Performance Measure (COPM) along with client satisfaction, before (Pre-) and after (Post-) the treatment(s). In addition to parent/care-giver reporting, the data for all participants was randomly re-assessed once/week by the healthcare professional in-charge at the facility.

Treatment fidelity

At every ABA-SIT and MUSIC session(s), the healthcare professional(s) confirmed session compliance, and documented clinical notes including significant events, notable child behavior, confirmed appropriate administration of interventions including session-duration, child's attention and/or intermittent participation such as singalong/gestures/hand-waving. All therapy and parent counselling sessions were videotaped to be re-assessed by independent raters and licensed occupational therapist, if needed, for additional confirmation.

Outcome Measures

As mentioned earlier, the primary outcome measure included ATEC assessment [73,74], while the secondary outcome measures included SP2 [80–82], and COPM-satisfaction [83,84] evaluations. All evaluations were performed at the treatment-start (Baseline/Pre-test) and at the treatment-end (Post-test) time-points. TD control group did not differ significantly between pre- and post-time points. TD controls, although untreated, were matched with the Pre- and Post-time points of experimental groups for ATEC assessments. ATEC evaluation was performed in all the groups, including non-ASD control group that did not receive any treatment, while SP2 and COPM-satisfaction evaluations were conducted in experimental Groups, Group-2 that received only Std intervention and Group 3 that received Std plus MUSIC Co-treatment.

Primary Outcome Measure: Autism Treatment Evaluation Checklist (ATEC) Assessment

The Autism Treatment Evaluation Checklist (ATEC) was originally developed by Rimland and Edelson to measure the severity of autism symptoms and to monitor or track changes over the duration of study/observation [109]. The primary use of ATEC evaluation is to measure changes in an individual's autism symptoms after interventions [74]. Researchers have used ATEC to measure the effectiveness of new treatments by measuring severity index of ASD in response to treatment after comparing the baseline ATEC scores with the post-treatment ATEC scores [19,101,110]. ATEC is a one-page form designed to be completed by parents, teachers, or caretakers [73,74]. It consists of a total of 77 questionnaire items distributed in 4 subclasses representing 4 diagnostic domains: (i) Speech/Language/Communication (14 items); (ii) Sociability (20 items); (iii) Sensory/Cognitive Awareness (18 items); and (iv) Health/Physical/Behavior (25 items) [20,74]. Lower ATEC scores indicate lower ASD severity and efficient functioning while higher ATEC scores indicate greater ASD severity and abnormal functioning [111].

Secondary Outcome Measure: Winnie Dunn Sensory Profile-2 (SP2) Assessment

The Sensory Profile™ 2 (SP2) [112,113] is a standardized instrument to assess children's sensory processing patterns which assesses the child's response to sensory events throughout daily living situations. The SP2 has been widely used in many autism studies [75,79,106,114–116], and its reliability and validity has been very well established [82,117–119].

This instrument is based on Dunn's four quadrant Sensory Processing Model (1997) [120] which theorizes the relationship between: (a) the functioning of a person's nervous system (neurological construct), and (b) self-regulatory strategies (behavioral construct). The interaction of these neurological and behavioral constructs creates 4 basic patterns of sensory processing: (i) Seeking, (ii) Avoiding, (iii) Sensitivity, and (iv) Registration. These four quadrants of sensory responses are analyzed by SP2 in 9 sensory processing diagnostic domains: Auditory, Visual, Touch, Movement, Body Position, Oral, Conductual, Socio-emotional, and Attentional response(s) [121]. It comprises of 86 items which are scored on a 6-point scale (0–5): Not applicable (0), Seldom or Never (1), Occasionally (2), Half of the times (3), Frequently (4), and Always or Almost Always (5). First, the raw scores are recorded for all 9 areas (Auditory, Visual, Touch, Movement, Body Position, Oral, Conductual, Socio-emotional, Attentional responses). These raw scores are then entered into the "Quadrant Grid", appropriately distributed within the 4 basic sensory processing patterns (Seeking, Avoiding, Sensitivity, Registration), and total quadrant raw scores are obtained for each of the 4 sensory processing areas. These total quadrant raw scores are entered into the "Summary Score Sheet" to interpret the data according to the Quadrant Definitions. The Sensory Profile 2 (SP2) scores are interpreted by comparing a child's raw scores to a standard reference, which then categorizes their responses as "More than Others," "Less than Others," or "Just like the Majority of Others". It helps clinicians and researchers to understand a child's sensory processing patterns and how these patterns impact their daily activities and behavior. In general, lower the score, better the performance.

Canadian Occupational Performance Measure (COPM) and Client Satisfaction Evaluation

Canadian Occupational performance Measure (COPM) is a client-centered outcome measure to assess an individual's perception of their occupational performance in the areas such as selfcare, productivity and leisure activities [122]. It is an evidence-based

outcome measure to capture client's satisfaction about the treatment success level [81,84]. It is a useful tool for identifying occupational functional improvement and tracking progress [123], assessed within five problems in the activities of daily life with a proven reliability and validity [124]. The five occupational performance activities selected within the appropriate COPM domain(s): (a) Personal Care-(Bathing, Dressing, Personal Hygiene); (b) Productivity (Writing); (c) Leisure Activity (Reading, Drawing, Swimming, Tavel, Socialization), were evaluated by a trained healthcare professional on a 10-point scale ranging from 1 to 10. The COPM uses a 10-point scale for both performance and parent satisfaction, where 1 indicates "not able to do it at all" and 10 indicates "able to do it extremely well" or "extremely satisfied" [81,83]. Scoring for all items under Performance and Satisfaction categories was recorded and the aggregate score for each category was entered on the score sheet. A higher score generally indicates better occupational performance and client satisfaction indicating betterment [125].

Data Analysis

The raw data from all participant-records were first entered into the excel spreadsheets and cross-checked independently by two healthcare professionals for accuracy. Data were subjected to statistical analysis using GraphPad Prism Program (Version 8.0.2, Boston, MA, USA). GraphPad Prism software is designed for analyzing all data at 95% confidence interval.

- Data were first analyzed for descriptive column statistics to obtain respective group means with standard error of means (SEM) at 95% confidence interval.
- Data were analyzed by parametric Paired t-test (that assumes normal distribution), to compare the measurements from the same individual/group at two different time-points, such as pre- and post-test time-points, with an intervention administered between two time-points [126–129].
- Data were analyzed by non-parametric Wilcoxon signed-rank test (that does not assume normal distribution) to compare two related samples or repeated measurements on the same subjects, as an alternative to the Paired t-test when the data do not meet the assumptions of normality, assessing whether the median differences between paired observations are significant [128,130,131].
- The use of both parametric Paired t-test and non-parametric Wilcoxon signed-rank test, was to rule out the concerns about normal distribution-related outcome variability and sample size of <100 [132–135].
- The data were analyzed by Analysis of Covariance (ANCOVA) that combines the Analysis of Variance (ANOVA) and Regression to compare the means of a dependent variables (Post-test) across independent variables (Pre-test) for comparing Std treatment vs Std+MUSIC treatment.
- The data were also analyzed using Bonferroni post hoc test for multiple comparisons to determine which specific group comparison is driving the effect.
- A value of $p<0.05$ was considered statistically significant.

Results

Primary Outcomes

MUSIC Co-Treatment Maximally Attenuated Autism Advancement in Verbal Autistic Children

ATEC measurements were performed to assess the advancement and severity of autism [110,111].

All 3 groups were subjected to ATEC assessments before (Baseline/Pre-) and after (Post-) the intervention(s).

Data for all three groups were analyzed and plotted representing:

a. Individual ATEC score(s) derived from a total of all four diagnostic domains (**Figure 6**)

b. Data representing group means for each diagnostic domain(s) of ATEC evaluation (**Figure 7**)

c. ANCOVA Analysis comparing ATEC Domains of Std vs Std+MUSIC groups (**Figure 8**)

d. Bonferroni Multiple Group Comparison (**Table 1**).

(a) Individual ATEC Index with Reference to CARS2-ST: Individual aggregate ATEC scores derived from 4 diagnostic domains for all groups, plotted with reference to respective CARS2-ST scores, showed remarkable differences (**Figure 6**). As expected, typically developing (TD) untreated controls, in absence of ASD with <30 CARS2-ST scores (Open black triangles), did not exhibit autism or its progression. The pre- and post-ATEC index in TD controls did not show significant difference between pre-(Open bold red triangles) and post-(Filled bold red triangles) time points (**Figure 6**).

On the other hand, ASD subjects with >30 CARS2-ST scores (Open black squares) that received only Std treatment, showed moderately improved ATEC outcome as indicated by reduced post-treatment ATEC values (Filled green squares) than the pre-treatment ATEC values (Open green squares) (**Figure 6**). Such an improvement was found to be enhanced in ASD subjects with >30 CARS2-ST scores after MUSIC co-treatment (Open black circles), showing remarkably reduced ATEC index indicating maximum improvement (Filled blue circles) compared to the pre-treatment ATEC values (Open blue circles) after MUSIC-co-treated ASD group **Figure 6**).

(b) Data Representing Group Means for each Diagnostic Domain(s) of ATEC Evaluation: Following the comparison of individual aggregate ATEC data, detailed analysis of each of the ATEC-diagnostic domains i.e. Speech/Language/Communication (Communication), Sociability, Sensory/Cognitive Awareness (Sensory/Cognitive), Health/Physical/Behavior (Health/Behavior) was conducted in all groups (**Figure 7**). Overall observations showed non-significant changes in all ATEC-diagnostic domains in untreated TD group (**Figure 7**, red bars). ASD group with Std treatment showed ~4% moderate improvement in only 2 diagnostic domains i.e. Communication and Sensory/Cognitive categories, with the overall improvement of ~8% (**Figure 7**, green bars). While ASD group that received Std plus MUSIC treatment showed improvement in all diagnostic domains ranging between ~11–15%, with maximum improvement of ~15% (*p/**p=0.0001) (**Figure 7**, blue bars). These observation indicate that MUSIC co-treatment enhanced the benefits of Std treatment in reducing the progression of autism in verbal autistic children.

Figure 6. Individual ATEC index with reference to CARS2-ST in control and experimental groups.

Figure 7. ATEC diagnostic domains in control and experimental groups.

(c) ANCOVA Comparing ATEC-Domains of Std vs Std+MUSIC Groups: Following is the comparison of individual aggregate ATEC data analysis of covariance (ANCOVA) for each of the ATEC-diagnostic domains conducted at the 95% confidence interval, where Std and Std+MUSIC post-test mean values as dependent variables were compared with the independent pre-test covariates.

The results showed group-specific effects in all diagnostic domain of ATEC assessment after ANCOVA comparison of both experimental groups (Std treatment, Std+MUSIC treatment) (**Figure 8**). R^2 values in this scatterplot indicated the proportion of variance in the dependent variables (Post-test measures) relative to Pre-test independent covariates (**Figure 8**). An observed R^2 value (R^2 = 0.7363) in Std group indicated ~70% change in Std dependable variable group (Std) (**Figure 8**, Red Symbols), while an observed R^2 value (R^2 = 0.9801 in Std+MUSIC group indicated >90% change in Std+MUSIC dependable variable group (Std+MUSIC) (**Figure 8**, Blue Symbols). The results indicate that despite moderately high R^2 value after Std treatment (R^2 = 0.7363), it did not reach statistical significance (p=0.1419) (**Figure 8**). On the other hand, the R^2 value after Std+MUSIC treatment (R^2 = 0.9801) was found to be highly significant (p=0.0100) (**Figure 8**). Overall, these results suggest that the MUSIC add-on to Std treatment may be more advantageous in reducing the progression of autism.

(d) Bonferroni Multiple Comparison of ATEC Data between Std and Std+MUSIC Groups: The Bonferroni multiple comparison test was conducted to determine which treatment-means are significantly different from each other. Although Bonferroni correction helps reduce Type I errors (false positives), it can increase the likelihood of Type II errors (false negatives), making it harder to find intergroup significance. To determine which means are significantly different, Bonferroni multiple comparison test was conducted using GraphPad Prism, comparing all pairs between Std treatment (Pre and Post) and Std+MUSIC treatment (Pre and Post) with the mean-difference adjusted at the 95% confidence interval (**Table 1**).

Figure 8. ANCOVA analysis of ATEC diagnostic domains in Std and Std+MUSIC experimental groups.

Table 1. Bonferroni multiple comparison of ATEC data between Std and Std+MUSIC groups.

Bonferroni's Multiple Comparison	Mean Difference	t Distribution	Significance (p<0.05)	Adjusted Difference Mean 95% CI
Std (Pre) vs Std (Post)	2.160	0.5275	Not Significant	-8.872 to 13.19
Std (Pre) vs Std+MUSIC (Pre)	-11.76	2.872	Not Significant	-22.79 to -0.7283
Std (Pre) vs Std+MUSIC (Post)	-2.840	0.6935	P=0.003	-13.87 to 8.192
Std (Post) vs Std+MUSIC (Pre)	-13.92	3.399	P=0.002	-24.95 to -2.888
Std (Post) vs Std+MUSIC (Post)	-5.000	1.221	Not Significant	-16.03 to 6.032
Std+MUSIC (Pre) vs Std+MUSIC (Post)	8.920	2.178	P=0.0001	-2.112 to 19.95

The results showed that the comparison between the Std (Pre) group vs Std (Post) or Std+MUSIC (Post) groups were non-significant. Similarly, the comparison between Std (Post) vs Std+MUSIC (Post) also was non-significant. On the other hand, the comparisons between Std (Pre) vs Std+MUSIC (Post) (p=0.003), Std (Post) vs Std+MUSIC (Pre) (p=0.002) were observed to be moderately significant, while the comparison between Std+MUSIC (Pre) vs Std+MUSIC (Post) reached the highest significance (p=0.0001). These results strengthen ANCOVA findings showing the additive effectiveness of MUSIC co-treatment in reducing autism advancement.

Secondary Outcomes

Based on the fact that abnormal sensory processing and atypical hypersensitivity to sensory input constitute a cardinal feature of ASD [79,115,136], sensory profile assessment was performed as a secondary outcome measure in the current study. Secondly, sensory challenges in ASD are known to impair perceptual and cognitive skills [83,137], and interfere with the occupational performance including activities of daily living [138]. Therefore, occupational performance using COPM and client satisfaction were included in addition to SP2 assessment as a client-centered outcome measure, to verify the effects of intervention [83].

MUSIC Co-Treatment Significantly Restored Sensory Profile to Normalcy in Verbal Autistic Children

Sensory profile-2 (SP2) assessment was conducted in experimental groups with or without MUSIC intervention.

ASD children typically score very high in almost all sensory profile diagnostic domains than TD children [79,136], and therefore lower sensory scoring is interpreted as interventional effectiveness towards normalcy [136]. Consistent with this, current observations show higher SP2 diagnostic domain scores before the treatment (Pre-test) than the SP2 diagnostic scores after the treatment (Post-test) (**Figure 9**). Results show that MUSIC co-treatment exhibited significant improvement in all diagnostic domains of SP2 (**Figure 9**). Attention, Conduct and Auditory domains were improved by <10%, while all other domains showed highly significant improvements ranging between >10%-20% (**Figure 9**).

Although Std treatment-effects were not found to reach the significant level, there was an observed trend towards marginal improvement in all SP2 diagnostic domains (**Table 2**).

As observed in **Figure 10**, all diagnostic domains of SP2 evaluation showed group-specific effects after ANCOVA analysis both in Std treatment group and in Std+MUSIC treatment group. The scatterplot showed R^2 values indicating the proportion of variance in all dependent variables (Post-test measures) relative to Pre-test covariates (**Figure 10**). An observed R^2 value (R^2 = 0.9456) in Std group indicated >90% of change in the Std treatment dependable variable (**Figure 10**, Red Symbols), while an observed R^2 value (R^2 = 0.9970) in Std+MUSIC group indicated almost 100% of the change in this dependable variable group (Std+MUSIC) (**Figure 10**, Blue Symbols). The results show that both Std treatment and Std+MUSIC treatment have exerted highly significant effects (P=0.0001), with slightly higher improvement-edge after MUSIC co-treatment (**Figure 10**). These results support added advantage of MUSIC co-treatment in improving sensory profile in verbal autistic children.

As observed for ATEC data analysis, SP2 data also showed non-significant differences between Std (Pre) group vs Std (Post) or Std+MUSIC (Post) groups were (**Table 3**). Similarly, the comparison between Std (Post) vs Std+MUSIC (Pre) also was non-significant. On the other hand, the comparison between the Std (Pre) vs Std+MUSIC (Post) (p=0.002), and Std (Post) vs Std+MUSIC (Post) (p=0.005) were observed to be moderately significant, while the comparison between Std+MUSIC (Pre) vs Std+MUSIC (Post) was highly significant (p=0.0001) (**Table 3**). These results emphasize previous observations indicating enhanced effectiveness of MUSIC co-treatment in improving sensory profile in verbal autistic children.

MUSIC Co-Treatment Efficiently Improved COPM-Satisfaction in Verbal Autistic Children

Effect of Std and Std plus MUSIC Co-Treatment on COPM Satisfaction

Children suffering from ASD are known to express serious problems with sensory processing which affects their occupational performance in selfcare and productivity [83,137,138]. COPM is conventionally used to assess occupational performance of ASD and to see the effectiveness of therapeutic intervention [81,84,123]. COPM has two main scoring categories i.e. Performance and Satisfaction. A score between 1 (Not able to do at all) and 10 (able to do extremely well) [124] within the COPM domain(s). For both categories, a lower score indicates low performance and satisfaction while higher scores indicate occupational functional improvements and the impact of autism treatment success level and satisfaction [125]. Results show that although both Std and Std plus MUSIC interventions improved all categories of COPM assessment i.e. Performance and Satisfaction, more pronounced results were evident with MUSIC co-treatment.

Effect of Std and Std plus MUSIC Co-Treatment on COPM Performance

ASD subjects treated only with Std treatment showed non-significant improvement in selfcare, productivity and one of the leisure activity (Reading) diagnostic domains of COPM, while rest of the two leisure categories (Sports, Socialization) were non-significantly improved (**Table 4**). Nonetheless, there was an overall significant improvement in COPM after Std treatment (**Table 4**). Compared to Std treatment (**Table 4**), when ASD subjects were treated with MUSIC co-treatment, there was significant improvement in all diagnostic domains of COPM (**Table 5**).

Effect of Std and Std plus MUSIC Co-Treatment on Satisfaction

Satisfaction index in ASD subjects that received Std treatment showed significant improvements for selfcare area, whereas there were moderate improvements observed for Sports and Reading Leisure activity domains. While Writing and Socialization categories did not exhibit significant improvements, there was a significantly higher level of satisfaction when aggregate rank was considered (**Table 6**).

The MUSIC co-treatment along with the Std treatment resulted in significantly enhanced Satisfaction levels in all diagnostic domains, along with overall highly significant improvement in aggregate score (**Table 7**).

In Summary, significant differences were observed for ATEC assessment both after Std treatment and after MUSIC co-treatment,

Figure 9. SP2 Diagnostic domains in experimental groups.

Figure 10. ANCOVA analysis of SP2 diagnostic domains in Std and Std+MUSIC experimental groups.

Table 2. Non-significantly improved sensory profile 2 in ASD subjects after Std treatment.

Sensory Profile 2 Diagnostic Domains	Pre-SP2 (Mean ± SEM) (N=25)	Post-SP2 (Mean ± SEM) (N=25)	% Change	Parametric Paired t-Test (*p Value)	Non-Parametric Wilcoxon Signed Rank Test (**p Value)
Seeking	45.16±0.82	44.2±0.82	↓ 2.13%	0.975 (NS)	1.0 (NS)
Avoiding	46.2±0.48	45.2±0.92	↓ 2.16%	0.657 (NS)	0.625 (NS)
Sensitivity	43.2±0.50	42.98±0.72	↓ 0.62%	0.467 (NS)	0.365 (NS)
Registration	48.92±1.1	47.34±1.1	↓ 3.23%	0.245 (NS)	0.217 (NS)
Auditory	23.62±0.64	23.2±0.65	↓ 1.78%	0.0542 (NS)	0.0589 (NS)
Visual	19.5±0.47	18.5±0.43	↓ 4.13%	0.795 (NS)	0.821 (NS)
Touch	20.1±1.15	19.5±1.1	↓ 2.98%	0.541 (NS)	0.455 (NS)
Movement	22.52±0.51	21.88±0.58	↓ 2.84%	0.196 (NS)	0.167 (NS)
Body Position	19.1±0.58	18.92±0.63	↓ 0.94%	0.449 (NS)	0.561 (NS)
Oral	26.1±0.46	26.1± 0.58	↓ 0.00%	0.455 (NS)	0.609 (NS)
Conduct	22.54±0.56	22.14±0.56	↓ 1.77%	0.837 (NS)	0.866 (NS)
Socio-Emotional	30.32±1.56	29.89±1.6	↓ 1.42%	0.271 (NS)	0.286 (NS)
Attention	27.44±0.26	26.52±0.41	↓ 3.35%	0.811 (NS)	1.0 (NS)
Aggregate Rank	30.16±1.43	29.74±1.14	↓ 1.39%	0.171 (NS)	0.094 (NS)

[1] Sensory Profile 2 (SP2), [2] Autism Spectrum Disorder (ASD), [3] Not Significant (NS).

Table 3. Bonferroni multiple comparison of SP2 data between Std and Std+MUSIC groups.

Bonferroni's Multiple Comparison	Mean Difference	T Distribution	Significance (p<0.05)	Adjusted Difference Mean 95% CI
Std (Pre) vs Std (Post)	0.7136	1.206	Not Significant	-0.9314 to 2.359
Std (Pre) vs Std+MUSIC (Pre)	-0.4071	0.6880	Not Significant	-2.052 to 1.238
Std (Pre) vs Std+MUSIC (Post)	3.779	6.385	P= 0.002	2.134 to 5.424
Std (Post) vs Std+MUSIC (Pre)	-1.121	1.894	Not Significant	-2.766 to 0.5243
Std (Post) vs Std+MUSIC (Post)	3.065	5.179	P=0.005	1.420 to 4.710
Std+MUSIC (Pre) vs Std+MUSIC (Post)	4.186	7.073	P=0.0001	2.541 to 5.831

Table 4. COPM[1] performance after Std treatment in verbal autistic children.

COPM[1] Diagnostic Domains	Pre-COPM[1] (Mean ± SEM[2]) (N=25)	Post-COPM[1] (Mean ± SEM[2]) (N=25)	% Improvement	Parametric Paired t-Test (*p Value)	Non-Parametric Wilcoxon Signed Rank t-Test (**p Value)
Selfcare (Bathing, Dressing)	3.03±0.38	4.34±0.43	↑ 43.4 %	0.0001	0.0001
Productivity (Writing)	2.8±0.33	3.67±0.35	↑ 31 %	0.0035	0.0051
Leisure (Reading/Crafts)	3.28±0.35	4.06±0.39	↑ 20.7 %	0.0101	0.0053
Leisure (Sports/Travel)	2.85±0.32	3.0±0.32	↑ 5.5 %	0.4725 (NS)[3]	0.3410 (NS)[3]
Leisure (Socialization)	3.06±0.38	3.22±0.43	↑ 5.3 %	0.4205 (NS)[3]	0.3997 (NS)[3]
Aggregate Rank	**15.1±1.27**	**18.18±1.29**	**↑ 21.2 %**	**0.0001**	**0.0001**

[1] Canadian Occupational Performance (COPM), [2] Standard Error of mean (SEM), [3] Not Significant (NS)

Table 5. COPM[1] performance after MUSIC co-treatment in verbal autistic children.

COPM[1] Diagnostic Domains	Pre-COPM[1] (Mean ± SEM[2]) (N=25)	Post-COPM[1] (Mean ± SEM[2]) (N=25)	% Improvement	Parametric Paired t-Test (*p Value)	Non-Parametric Wilcoxon Signed Rank t-Test (**p Value)
Selfcare (Bathing, Dressing)	2.72±0.29	4.36±0.28	↑ 60.29 %	0.0001	0.0001
Productivity (Writing)	1.44±0.13	2.52±0.14	↑ 75.23 %	0.0001	0.0001
Leisure (Reading/Crafts)	1.8±0.19	2.76±0.29	↑ 53.33 %	0.0001	0.0001
Leisure (Sports/Travel)	1.48±0.12	2.2±0.14	↑ 48.64 %	0.0001	0.0007
Leisure (Socialization)	1.52±0.14	1.92±0.36	↑ 26.32 %	0.0093	0.0192
Aggregate Rank	**8.88±0.56**	**13.76±0.62**	**↑ 54.95 %**	**0.0001**	**0.0001**

[1] Canadian Occupational Performance (COPM), [2] Standard Error of mean (SEM)

Table 6. Satisfaction index after Std treatment in verbal autistic children.

Satisfaction Diagnostic Domains	Pre-Satisfaction (Mean ± SEM[2]) (N=25)	Post-Satisfaction (Mean ± SEM[2]) (N=25)	% Improvement	Parametric Paired t-Test (*p Value)	Non-Parametric Wilcoxon Signed Rank t-Test (**p Value)
Selfcare (Bathing, Dressing)	2.64±0.31	3.58±0.43	↑ 35.6 %	0.0043	0.0036
Productivity (Writing)	2.16±0.29	2.53±0.32	↑ 7.3%	0.1132 (NS)[3]	0.1251 (NS)[3]
Leisure (Reading/Crafts)	2.56±0.2	3.33±0.34	↑ 29.94 %	0.021	0.0174
Leisure (Sports/Travel)	2.48±0.32	2.74±0.33	↑ 10.5 %	0.0396	0.0568 (NS)[3]
Leisure (Socialization)	2.46±0.29	2.52±0.35	↑ 3.7 %	0.6772 (NS)[3]	0.6658 (NS)[3]
Aggregate Rank	**12.4±1.17**	**14.44±1.19**	**↑ 16.45 %**	**0.0001**	**0.0001**

[1] Canadian Occupational Performance (COPM), [2] Standard Error of mean (SEM), [3] Not Significant (NS)

Table 7. Satisfaction index after MUSIC co-treatment in verbal autistic children.

Satisfaction Diagnostic Domains	Pre- Satisfaction[1] (Mean ± SEM[2]) (N=25)	Post-Satisfaction[1] (Mean ± SEM[2]) (N=25)	% Improvement	Parametric Paired t-Test (**p* Value)	Non-Parametric Wilcoxon Signed Rank t-Test (***p* Value)
Selfcare (Bathing, Dressing)	1.36±0.09	2.24±0.16	↑ 64.7 %	0.0001	0.0001
Productivity (Writing)	1.21±0.08	1.84±0.12	↑ 53.34%	0.0006	0.0020
Leisure (Reading/Crafts)	1.56±0.18	2.12±0.34	↑ 35.89 %	0.0198	0.0236
Leisure (Sports/Travel)	1.36±0.09	1.84±0.12	↑ 35.29 %	0.0152	0.0197
Leisure (Socialization)	1.4±0.22	1.8±0.29	↑ 28.57 %	0.0093	0.0083
Aggregate Rank	**6.84±0.44**	**9.84±0.44**	**↑ 43.86 %**	**0.0001**	**0.0001**

[1]Satisfaction, [2] Standard Error of mean (SEM)

with greater improvements observed in MUSIC co-treatment group. Regarding sensory profile, SP2 scores did not reach the significance although the trend was towards advancement after Std treatment but significantly improved after MUSIC co-treatment. Similar trend was observed for COPM-Satisfaction assessment showing overall greater impact of MUSIC co-treatment than Std treatment in verbal autistic children.

Discussion

This randomized controlled pilot trial tested the hypothesis if Indian classical music-Raga co-treatment will enhance the benefits of conventional standard care in 5–12 years old verbal autistic children. Music *per se*, has shown promising results in maintaining physical and mental well-being [139–141]. Especially in case of ASD, therapeutic use of music is even further magnified since preference for music constitutes one of the strengths of autism [38,39,142]. Moreover, music intervention primarily focuses on developing social, emotional and other sensory processing abilities, and impairments in these abilities are central to ASD [143]. One of the earliest study reported effects of music therapy on enhancing social skills in children with autism [101]. Sharda et al. have shown that 8–12 weeks of music exposure restored auditory-motor intrinsic connectivity and improved parent-reported outcomes in social communication [41]. Another study showed clinical improvement in Aberrant Behavior Checklist (ABC) and Clinical Global Impression (CGI) outcomes after music exposure in children with ASD [142]. A pilot study conducted by Feng *et al.* showed refinement of fine motor skills in autistic children after music therapy [144]. A recent randomized trial showed that music therapy improved engagement and intellectual disability in autistic children [60]. Currently, there are 26 clinical trials completed/ongoing involving the use of music intervention in treating ASD (Clinicaltrials.gov). Most of these are aimed at treating autism-progression and sensory processing abnormalities. Most clinical trials have not posted their results/outcomes, however, some of the findings do show reduced autism-advancement and improved sensory profiles (Clinicaltrials.gov).

To our knowledge, this is one of the pioneering studies in reporting effectiveness of Indian classical Raga (MUSIC) in alleviating autism-symptoms. Current findings are consistent with the previous reports of music benefits but show added advantage of Indian classical Raga. The enhanced potential of MUSIC that used Raga Yaman (https://youtu.be/viL-8iubNpE) may be attributed to the multifold mechanisms of Raga Yaman. The Predominance of Shuddha Swaras (pure notes) of Raga Yaman makes the Raga "Happy" and "Cheerful", and the presence of Tivra "Ma" intensifies the inherent emotions of accompanying Shuddha Swaras (pure notes), magnifying happiness/cheerfulness [61,66,145,146]. This effect may induce emotional processing and reward system [46] by elevating hormones involved in emotional/reward/cognitive processing and neuroplasticity while simultaneously reducing stress hormones [50–54], promoting functional brain connectivity leading to improvements in social communication, emotional and motor functions [37,41,42,60]. Thus, the intensified happy/cheerfulness elicited by Raga Yaman will stimulate joy, uplift emotions, remove "isolation", and promote sociability and communication in autistic kids. Moreover, the "Sampurna" Nature of Raga is considered to activate all energy centers (Chakras) [68,147,148], exposing individual to a full range of the frequency spectrum that can "open up" a person to wholeness [149]. Thus, Raga Yaman will help focus wandering attention and open up to wholeness in autistic children. Autism is a neurodevelopmental disorder. Swadhishthana Chakra governs creativity, pre- and post-natal development, emotions/mood, and anxiety [68,150]. Therefore, in addition to above-mentioned effects, Raga Yaman, can also boost self-esteem and control aggression in autistic kids. Currently observed "additive" effects of MUSIC due to its pleiotropy arising from the multifold mechanisms discussed above justify MUSIC as an effective adjuvant in treating ASD.

Conclusions

Current study suggests effectiveness of MUSIC intervention as an effective add-on in treating autism spectrum disorder. These findings warrant future research in testing Raga co-treatment for larger trials. We hope that autistic children and their families will be most impacted by the results of our study.

Author Contributions

All authors contributed equally.

Conflict of Interests

All authors declare no conflict of interests.

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Data Availability

The data are not publicly available due to privacy restrictions and ethical regulations. The data presented in the study can be made available upon request from the corresponding author only for scientific/academic purposes.

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