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Evaluation of auditory working memory in Bharatanatyam dancers

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A B S T R A C T

Background: Neuroplasticity is a phenomenon exhibited by our nervous system as an indicator of overall development and in response to training, injury/loss of particular function, treatment/drugs and as a result of stimulation from the surrounding environment.
Objective: The aim of the current study was to assess the auditory working memory capacities in Bharatanatyam dancers.
Method: The participants comprised fifty-four females with normal hearing sensitivity who belonged to two groups. Group-I consisted of 27 individuals who underwent formal training in Bharatanatyam for a minimum period of three years. Group-II consisted of the age-matched control group, consisting of 27 individuals who were non-dancers. The auditory working memory tasks included arranging the English digits presented binaurally in forward, backward, ascending, and descending spans. The maximum values (for the length of sequence arranged), midpoint values (average score), and response time for each task were noted down and compared among groups.
Results: The scores were compared using the Mann-Whitney *U* test, which revealed enhanced working memory exhibited by dancers for maximum values and midpoint scores for all three tasks except ascending span. It was also noted that the dancers exhibited a shorter response time compared to non-dancers for all the tasks except ascending span.
Conclusion: The current study highlights an enhanced auditory working memory capacity in Bharatanatyam dancers, which could be perceived as evidence of neuroplastic changes induced in the auditory and motor cortex as a consequence of extensive stimulation for auditory processing abilities and motor planning resulting from long-term dance training and regular practice.

1. Introduction

Neuroplasticity can be explained as a response of the nervous system towards extrinsic and intrinsic stimuli by rearranging its structure, functions, and inter-connections. It can be defined at many levels, extending from molecular to cellular level and to systems and behaviors. It can occur as a consequence of development, in response to a stimulating environment, learning, a disease, or as a result of treatment. Evidence of neural plasticity can be observed as an enhanced performance that is exhibited while carrying out a particular function or task. (Cohen et al., 1997). It has been extensively studied and explained in stroke patients, where the sensory and/or motor functions are lost initially due to the damage caused to their central nervous system, which gradually seems to recover or improve with time and therapeutic training (Nudo et al., 1996; Rathore et al., 2002; Weiller et al., 1993).

Similarly, activities involving physical training, musical training, or learning any skilled tasks that require mental and cognitive efforts have demonstrated neuroplasticity in children as well as in adults (Zhang et al., 2021; Vaquero et al., 2016; Roy et al., 2020). A study by Zhang et al. (2021) reported significant structural and functional changes in fMRIs of long-term athletes who were skilled ice-skaters compared to healthy non-athletes who belonged to a similar age group. This could be due to the long-term extensive motor training that involves rapid and precise motor planning (Chang et al., 2011). Similarly, Roy et al. (2020) reported improved auditory attention and working memory in children who

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underwent abacus training. A study done by Vaquero et al. (2016) revealed a positive effect of age of onset of musical training in pianists. Imaging studies were conducted in pianists and age-matched non-musicians, that revealed an increased volume of grey matter indicating complex effects of plasticity resulting from musical training. Apart from this, those musicians who had begun musical training during their early stages of life and used to undergo regular practices had a reduced volume of grey matter in the right putamen and better performance on playing the piano (especially in the left hand). These evidences are suggestive of significant neuroplasticity occurring as a consequence of musical training, arithmetic calculations, and long-term skilled motor activities.

Bharatanatyam is a synchronized kinesthetic art that originated in the Tamil Nadu state of South India during the 4th century. This ancient dance form uses orchestrated body movements in synchronization with Carnatic music. Apart from coordinated and stylized movements, it utilizes schematized body motion, music, and paralinguistic features like gestures and facial expressions to present stories or events from Hindu epics (The Editors of Encyclopedia Britannica, 2018; Banerjee, 2013). Many studies have attempted to study neuroplasticity and the therapeutic effects of Bharatanatyam. A study by Parab et al. (2019) reported that Bharatanatyam-based dance therapy improved lower limb muscle strength, cardio-respiratory fitness, and balance in adolescents and children with Down Syndrome. Swathi and Sathish (2013) evaluated Cervical Vestibular Evoked Myogenic Potential (C-VEMP) in dancers. They observed an early latency and higher amplitude of P13 and N23 peaks in the CVEMP waveform than those in the control group of age-matched females who had no dance training history. However, contradicting findings were reported by Sinha et al. (2013), which showed no significant difference from those of non-dancers in either amplitude or latency of P13–N23 complex and N10–P14 complex of cervical VEMP and Ocular VEMP, respectively.

Another study by Joseph et al. (2019), reported an enhanced functioning of the efferent auditory pathway in Bharatanatyam dancers who had increased contralateral suppression of otoacoustic emissions compared to the non-dancers. Apart from motor training, they are simultaneously getting musical training (The Editors of Encyclopedia Britannica, 2018), which would potentially trigger the plasticity of their auditory nervous system. Undergoing intense auditory and motor training for a long-term duration could enhance the rate of processing of auditory stimuli as well as motor commands in sequence with continuously changing rhythm. To perform this art, they need to achieve a very short response time to auditory stimuli and sharp motor planning.

An individual's ability to process, analyze, store, and recall auditory information is termed as auditory working memory (Baddeley and Logie, 1992). It has got a crucial role in clinical as well as research in the field of Audiology. Most of the test items in the Central Auditory Processing test battery utilize the individual's working memory capacities to obtain responses (Nagaraj and Magimairaj, 2020). Similarly, several daily activities like comprehension of a spoken message or performing mental arithmetic rely on working memory. Very limited studies have tried exploring the auditory abilities and working memory in dancers. Hence, there is a need to explore auditory perceptual and memory skills in this population. The current paper aims to study whether there is any difference in auditory working memory capacity for Ascending, Descending, Forward and Backward spans of digits in normal-hearing individuals with and without Bharatanatyam training. These tests are performed to assess the auditory memory and sequencing skills of an individual. The subject must maintain the auditory signals heard in their short-term memory and arrange them in a specific sequence according to each task. The secondary objective of the paper is to compare the response times obtained for the four tasks mentioned above among dancers and non-dancers.

2. Methods

2.1. Selection of participants

Fifty-four female subjects aged between 18 and 26 years and with normal hearing sensitivity were included in the study. The participants were categorized into two groups. Group-I consisted of individuals who had undergone formal training in Bharatanatyam for a minimum of three years or more. Group-II consisted of individuals who belonged to a similar age group and had no history of any form of dance training. The experimental group consisted of 27 individuals who had a minimum training experience of 3 years or more as well as those who currently have regular training and practice. The 27 individuals in the control group had not undergone any formal training in any dance forms and have not been a participant in any cultural events or stage programs. By conducting a structured interview, it was confirmed that all the participants had similar formal educational backgrounds and the participants in the control group had no training in vocal/instrumental music, athletics, sports, or physical training activities. The mean age of participants in group-I was 20.85 (age range = 18–24 years), and in group-II was 21.67 (age range = 18–26 years). The ages of the participants of both the groups were compared using a Mann-Whitney *U* test to confirm the age-matching between the groups ($U = 283.0$, $p > 0.05$).

2.2. Procedure

The hearing sensitivity of all the subjects was within ≤15 dB HL at frequencies 250, 500, 1000, 2000, 4000, and 8000Hz for air conduction (AC), and frequencies 250, 500, 1000, 2000, and 4000Hz for bone conduction (BC). The hearing thresholds for air conduction and bone conduction were obtained using TDH-50P supra-aural headphones (Telephonics, Farmingdale, NY, USA) and B71 bone vibrator (Radioear, KIMMETRICS, Smithsburg, MD, USA), respectively. The modified procedure by Hughson and Westlake was used to obtain the hearing thresholds (Carhart and Jerger, 1959). The pure tone audiometry was carried out using Inventis Piano, a two-channel diagnostic audiometer (Inventis, 35127 Padova, ITALY). To rule out middle ear infections, all the participants were subjected to Immittance audiometry. The tympanometric evaluation was carried out using a 226-Hz probe tone end acoustically evoked stapedial reflex (ASR) thresholds were measured at 500, 1000, 2000, and 4000 Hz. A bilateral A-type tympanogram was obtained for all participants, suggestive of a normal conductive pathway. Similarly, bilateral ipsilateral and contralateral ASR thresholds were obtained within normal sensation levels, suggestive of a functionally intact auditory pathway up to the level of the lower brainstem on both sides for all subjects. The immittance evaluations were performed using GSI- Tympstar Middle ear Analyzer (Grason Stadler Inc.-GSI-61; Milford, NH, USA). Speech identification scores were tested using Phonemically Balanced words in Kannada developed by Yathiraj and Vijayalakshmi (2005) at All India Institute of Speech and Hearing (AIISH) Mysore.

Auditory working memory was evaluated using Smriti Shravan software, a customized tool for assessing auditory and visual working memory (Kumar and Sandeep, 2013). The stimuli consisted of a cluster of digits from the auditory module of the software that was presented binaurally to the subject. For the Forward Span task, the subject has to arrange the digits in the forward order in which the stimuli were presented. Similarly, for Backward, Ascending, and Descending spans, the subject was asked to arrange the digits in the reverse, ascending, and descending orders, respectively. Each trial consisted of digits that were presented continuously with a 1-s interval in between each digit. Upon completion of one whole trial, the subject was given 5 seconds to type down the digits heard in a particular sequence as per the instructions given for each task. Every task had a trial for familiarization before the actual testing.

The instructions for each test were displayed on the computer screen before the beginning of the test. If required, further instructions were provided orally by the examiner to the subjects. The number of digits presented in the initial trial was set to 3 for all subjects. The number of digits in each stimulus trial was dependent on the subject's response. With each correct response, the number of digits presented in the subsequent trial increased by one, and with an incorrect response, the number of digits was reduced by one in the subsequent trial. The digits one to nine were used in the stimulus trials, except seven which had a comparatively longer duration. The stimulus was delivered via a laptop computer calibrated with TDH-50P headphones (Telephonics, Farmingdale, NY, USA). The intensity of stimulus presentation was at 40 dB SL (ref. speech recognition threshold) for all subjects and the tests were carried out in a quiet and distraction-free environment. The scores obtained for each task were calculated by the software. The three parameters measured were: (1) maximum value, which was the maximum length of sequence answered correctly by an individual for a particular task, (2) mid-point, which was the average score obtained for each task, and (3) response time (in milliseconds), which showed the time taken by the individual to type down the digits in a specific order, as mentioned for a particular task. The scores of the three parameters mentioned above were obtained for ascending, descending, forward and backward spans and compared between the groups using appropriate statistical measures.

Ethical considerations: The objectives and procedures were explained to the participants before initiating the study and informed consent was obtained from all the participants. All the procedures followed were non-invasive and adhering to the "Ethics approval committee of the Institute and compiled with the Declaration of Helsinki."

Statistical Analyses: The statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS) software version 21.0 (Frey, 2017). Descriptive statistical analysis was performed to obtain the mean, median, standard deviation, and interquartile range of maximum values, midpoints, and reaction times for forward, backward, ascending, and descending spans. The Shapiro Wilk's test for normality was used to check whether the data were normally distributed. Since the data were not normally distributed ($p < 0.05$), a non-parametric Mann-Whitney *U* test was performed to evaluate the differences in scores obtained by dancers and non-dancers. This was performed for maximum values, midpoints, and reaction times of all four subtests.

3. Results

The dancers exhibited better performance than non-dancers for forward, backward, and descending spans. The maximum values, midpoints, and response times for the respective tests showed the same trend. The median, upper limit, and lower limit for maximum values, midpoints, and response times obtained by both groups for each task have been depicted in Fig. 1.

The results of descriptive statistics for maximum values, midpoints, and response times have been depicted in Tables 1–3, respectively.

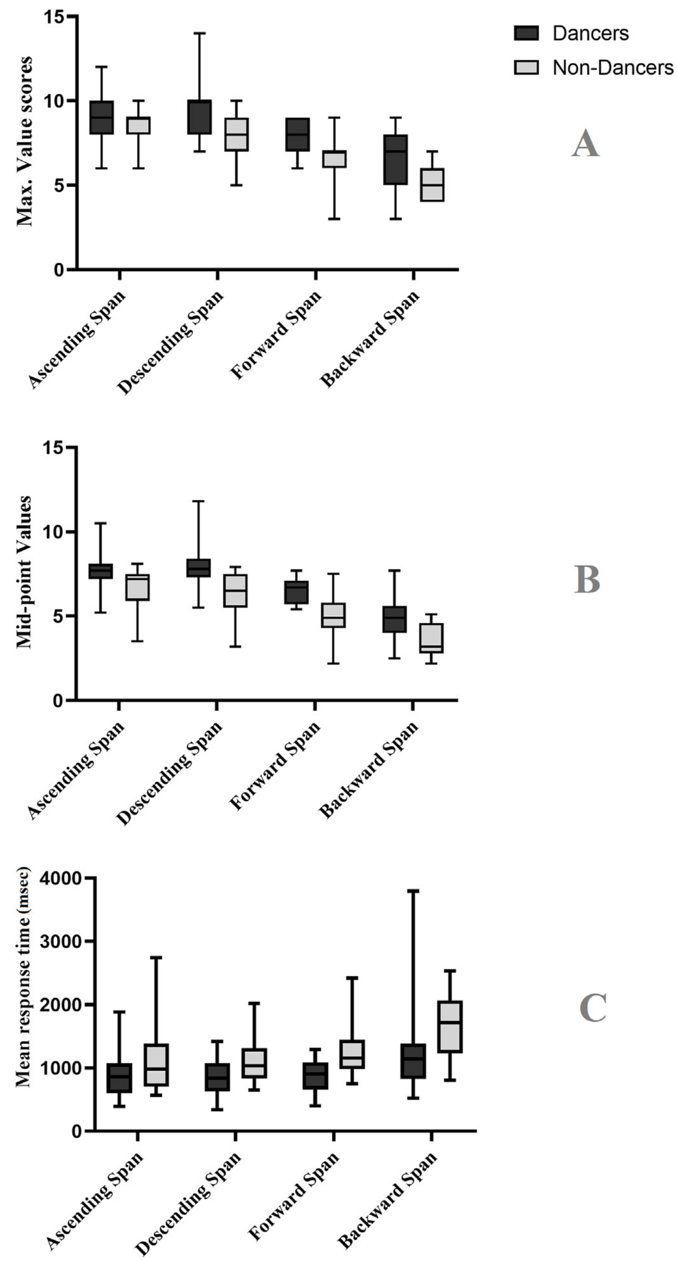

Fig. 1. Fig. 1 shows box and whisker plots depicting median scores, 25th and 75th percentile quartiles and maximum and minimum scores for maximum values (A), midpoints (B) and mean response time (C) obtained by dancers and non-dancers for each subtest.

Table 1
Table 1 depicts the results of descriptive statistics of maximum values obtained by each group for each task.

Maximum value		Mean	Std. Dev	Median	Inter-quartile range
Dancers	A. S	9.07	1.33	9.00	2.00
	D. S	9.56	1.48	10.00	2.00
	F. S	7.85	0.91	8.00	2.00
	B. S	6.48	1.42	7.00	3.00
Don-dancers	A. S	8.30	1.17	9.00	1.00
	D. S	7.96	1.51	8.00	2.00
	F. S	6.41	1.34	7.00	1.00
	B. S	5.19	1.11	5.00	2.00

(Abbreviations: A.S- Ascending Span, D.S-Descending Span, F.S-Forward Span, B.S-Backward Span).

Table 2
Table 2 depicts the results of descriptive statistics of midpoint values obtained by each group for each task.

Mid-point		Mean	Std. Dev	Median	Inter-quartile range
Dancers	A. S	7.59	1.06	7.70	0.90
	D. S	7.81	1.21	7.80	1.10
	F. S	6.48	0.73	6.70	1.40
	B. S	4.85	1.26	4.90	1.60
Don-dancers	A. S	6.70	1.20	7.20	1.60
	D. S	6.28	1.30	6.50	2.00
	F. S	4.95	1.17	4.90	1.50
	B. S	3.57	0.96	3.20	1.80

(Abbreviations: A.S- Ascending Span, D.S-Descending Span, F.S-Forward Span, B.S-Backward Span).

Table 4
Table 4 shows the results of the Mann-Whitney *U* test indicating the difference between scores obtained by dancers and non-dancers for each subtest. Bonferroni corrected α-value = 0.0125.

	Maximum value		Mid-point		Response time	
	Z	*p*	Z	*p*	Z	*p*
A. S	−2.24	>0.0125	−2.8	<0.0125*	−2.31	>0.0125
D. S	−3.37	<0.005**	−4.06	<0.005**	−2.67	<0.0125*
F. S	−4.03	<0.005**	−4.49	<0.005**	−3.3	<0.005**
B. S	−3.39	<0.005**	−3.65	<0.005**	−3.31	<0.005**

*-the significant difference is present. (p < 0.0125), **- (p < 0.005), (Abbreviations: A.S- Ascending Span, D.S-Descending Span, F.S-Forward Span, B.S- Backward Span).

Inferential statistics were performed using the Mann-Whitney *U* test as the data showed non-normal distribution in the Shapiro-Wilk's test for normality ($p < 0.05$). As there were multiple variables for comparison, the 'α' value was adjusted using Bonferroni correction. The dancers showed statistically significant higher scores than non-dancers ($p < 0.0125$) for the forward, backward and descending spans, and the response time taken by the dancers for the same was of shorter durations than taken by non-dancers ($p < 0.0125$). However, the maximum value and mean response time obtained for ascending span did not show any statistically significant difference between the groups ($p > 0.0125$). The results of the Mann-Whitney *U* test are shown in Table 4.

4. Discussion

Apart from being just an art form, dance training has proven to be effective in maintaining an individual's physical and mental well-being (Rajeev, 2014). It improves the overall physical fitness and positively impacts vital functions like lung capacity, blood circulation, aerobic capacity, the flexibility of limbs, neck, and trunk, and helps to maintain overall skeletal and muscular tone (Chatterjee, 2013). There have been reports of dancers' enhanced abilities to encode and memorize dance movements and spatial locations compared to those who were non-dancers. Smyth and Pendleton (1994) studied memory of encoding movement in professional Ballet dancers in which 18 nonsense movements were demonstrated to two groups of subjects, one consisting of dancers and the other of non-dancers. It was found that dancers exhibited shorter learning times and lesser fading of movements and articulatory sequences over time compared to non-dancers.

The current study aimed to explore the effects of neuroplasticity induced by dance training on cognitive grounds of individuals who had undergone formal Bharatanatyam dance training. The dancers exhibited an overall better performance in different tasks that assessed the auditory working memory. During training as well as performing, they are simultaneously synchronizing information via motoric, visual, and auditory modalities, which is exhibited through rhythmic movements of the body parts and facial expressions that keep changing in fractions of seconds (The Editors of Encyclopedia Britannica, 2018). Undergoing several years of training would trigger the neuroplasticity changes and be reflected as an overall betterment of dance performance due to long-term practice.

The results of our study revealed that dancers exhibited an extended memory span and sequencing skills in arranging the digits in forward, backward, and descending orders. However, deviant results showing no significant difference in scores was noted for the task of arranging the digits in ascending span where both the groups showed similar maximum values and response times. At the same time, the midpoint scores of ascending span task showed better performance by dancers. One possible explanation for this discrepancy could be the difficulty of the task. Compared to the other three tasks, the subjects took shorter time intervals to arrange the digits in ascending span irrespective of the group to which they belonged. On enquiring the subjects also reported the relative easiness that they felt in completing the task. Apart from this, the dancers exhibited comparatively shorter response times for all other three tests. This could be correlated with faster auditory and cognitive processing that takes place in dancers.

Several authors have studied the neurological basis of auditory working memory.

An imaging study by Kumar et al. (2016) reported functional connectivity of the hippocampus and the left inferior frontal gyrus while performing the auditory memory task for pure tone stimuli. They observed sustained auditory cortex activity during the encoding, maintenance, and retrieval phases of the pure tone in short-term memory. The posterior portion of the hippocampus was activated during the maintenance phase. According to Jeneson and Squire (2012), hippocampal activation occurs when the stimuli activate the long-term memory for supporting the maintenance of the signals in the short-term memory. Furthermore, the activation of the left inferior frontal gyrus occurs due to subvocal, or covert articulatory rehearsals carried out by the subjects while performing the auditory working memory tasks. However, the role of motor areas in the mechanism of auditory working memory remains

Table 3
Table 3 depicts the results of descriptive statistics of mean response time taken by each group to complete each task.

Response time (in msec)		Mean	Std. Dev	Median	Inter-quartile range
Dancers	A. S	849	346	856	451
	D. S	856	289	840	425
	F. S	892	249	904	413
	B. S	1230	621	1142	548
Don-dancers	A. S	1164	593	979	658
	D. S	1117	337	1035	468
	F. S	1244	409	1155	449
	B. S	1622	466	1714	818

(Abbreviations: A.S- Ascending Span, D.S-Descending Span, F.S-Forward Span, B.S- Backward Span).

controversial (Liao et al., 2014).

Similarly, Albouy et al. (2013) studied the neurological basis of music perception, which revealed functional connectivity of Heschl's gyrus and the right inferior frontal gyrus. Hence, individuals who are getting continuous stimulation of these neural pathways as a part of dance training would undergo potential strengthening of these pathways over time. The subvocal rehearsal that happens while performing the auditory memory tasks is influenced by an individual's capacity to store auditory signals. This capacity will be comparatively higher for dancers, who are extensively trained to process, analyze, and store audio-visual signals and motoric commands and their recall at varying speeds based on beats and rhythms. Working memory has been reported to catalyze learning and academic outcomes (Smyth and Pendleton, 1994). Hence, providing children with formal training in games or activities that involve higher cognitive functions, vocal or instrumental music, dance, or athletics as a part of their extra-curricular activities, in the long run, would possibly enhance their cognitive processing and learning capacity.

5. Conclusions

The current study aimed to assess auditory working memory in Bharatanatyam dancers. Individuals who underwent formal training in Bharatanatyam were recruited and evaluated for auditory working memory for digits stimuli. In three of the four subtests, the dancers outperformed the non-dancers. Furthermore, a shorter response time was taken by the dancers in performing these tests. However, for the ascending span subtest, there was no significant difference observed between the dancers and non-dancers. The study highlights the neuroplastic changes induced as a result of dance training in the auditory cortex, hippocampus, and various parts of the frontal lobe, which are dominant for functions like auditory processing, motor planning, and sequencing. The results of the study suggest that individuals undergoing training in similar extra-curricular activities from childhood would have improved memory and learning capacities apart from mental and physical well-being.

5.1. Future directions

Since dancers are getting musical training as a supplement, there could be an enhanced auditory processing ability present in this population. Exploratory studies on psychoacoustic abilities like differential sensitivity and temporal processing tests could be performed. Apart from processing auditory signals, dance training is likely to induce neuroplastic changes in overall balance, equilibrium, and oculomotor systems. Hence, attempts to study postural and gaze stabilization abilities in dancers would help discover new possibilities and thereby add to the therapeutic value of dance training.

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Availability of data and material (data transparency)

No.

Code availability

Not applicable.

Authors' contributions

PP was involved in study design, stimulus preparation, data collection, analysis of the data, interpretation and writing the manuscript, AN was involved in study design, analysis of the data, interpretation and writing the manuscript, MJ was involved in study design, analysis of the data, interpretation and writing the manuscript, PP* was involved in study design, stimulus preparation, data collection, analysis of the data, interpretation and writing the manuscript.

Ethics approval

AIISH ethical committees approved the study method for bio-behavioral research.

Consent to participate

Written informed consent taken prior commencing the data collection.

Consent for publication

Yes, informed content was obtained from subjects for participating in the study.

Declaration of competing interest

Nil.

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