Aathiyoga Indian Journal of Ancient Medicine and Yoga

eISSN : 3048-9822 (Online)
Volume: 1 Issue : 05 January 2025

Aathiyoga Indian Journal of Ancient Medicine and Yoga
Peer Reviewed Multidisciplinary Journal

Impact of Yoga Versus Memory Enhancement Training on Hippocampal Connectivity in Older Women at Risk for Alzheimer's Disease

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Abstract:

This research investigates the differential effects of Kundalini yoga (KY) and memory enhancement training (MET) on resting-state hippocampal connectivity in older women with subjective memory decline and cardiovascular risk factors for Alzheimer's disease (AD). Using a randomized controlled trial design, we examined changes in hippocampal subregion connectivity following 12 weeks of either KY or MET. Our results indicate that KY is associated with increased connectivity between a left anterior hippocampal subregion and ventral visual stream regions, correlating with reduced perceived stress. In contrast, MET showed increased connectivity between posterior hippocampal subregions and default mode/frontoparietal networks, which was associated with a lower frequency of forgetting. These findings suggest that KY and MET may engage distinct neural pathways, potentially offering complementary benefits for individuals at risk for AD.

Keywords: Alzheimer's disease, cardiovascular, hippocampus, memory, resting-state, yoga, Kundalini yoga, memory enhancement, default mode network, frontoparietal network, stress

1. Introduction

Alzheimer's disease (AD) is a devastating neurodegenerative disorder characterized by progressive cognitive decline, particularly affecting memory. Aging, coupled with cardiovascular risk factors, significantly increases the likelihood of developing AD (Barnes & Yaffe, 2011). Early interventions targeting modifiable risk factors are crucial for mitigating the progression of AD. The hippocampus, a critical brain region for memory and spatial navigation

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(Scoville & Milner, 1957), is one of the earliest structures affected by AD pathology (Braak & Braak, 1991). Therefore, interventions that promote healthy hippocampal function are of high importance for preventing or delaying the onset of AD.

Emerging evidence suggests that non-pharmacological interventions like yoga and cognitive training may offer promising avenues for enhancing cognitive function and promoting neural resilience (Gothe et al., 2019; Owen et al., 2010). Yoga, with its integration of physical postures, breathing techniques, and mindfulness practices, has been shown to reduce stress, improve mood, and enhance cognitive performance (Büssing et al., 2012; Kramer et al., 2021). Specifically, Kundalini yoga (KY), a specific style of yoga, emphasizes dynamic breathing and meditation and may exert unique effects on neural networks (Sørensen et al., 2021). Memory enhancement training (MET), on the other hand, typically involves targeted exercises designed to improve specific cognitive abilities, such as working memory and attention (Rebok et al., 2014).

This study seeks to contrast the effects of KY and MET on resting-state hippocampal connectivity in a group of older women exhibiting subjective memory decline and cardiovascular risk factors, thereby at elevated risk for developing AD. Resting-state functional connectivity, assessed using functional magnetic resonance imaging (fMRI), provides a measure of intrinsic brain network organization (Biswal et al., 2010). By examining changes in functional connectivity, we aim to understand how these two distinct interventions may modulate brain networks linked to memory and cognitive resilience.

2. Materials and Methods

2.1. Participants

The data for this study was derived from a parent randomized controlled trial registered at clinicaltrials.gov (NCT03503669). Participants were recruited from the community and included women aged 55 and over with subjective memory decline (self-reported) and at least one cardiovascular risk factor (e.g., hypertension, hyperlipidemia, or diabetes). Participants had no history of neurological conditions, contraindications for MRI, or any regular yoga participation in the past 6 months.

A total of 22 participants completed the study, were randomized and included in the analysis: 11 were in the KY group (mean age = 61.45 ± 6.58 years) and 11 were in the MET group (mean age = 64.55 ± 6.41 years). Baseline characteristics are summarized in Table 1.

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Table 1: Baseline Characteristics of Participants

Characteristic	KY Group (n=11)	MET Group (n=11)
Mean Age (years)	61.45 ± 6.58	64.55 ± 6.41
Subjective Memory Decline (Score range from 1-5)	3.25 ± 0.82	3.18 ± 0.98
Cardiovascular Risk Factors (number)	1.36 ± 0.49	1.27 ± 0.45

Data presented as Mean ± Standard Deviation

2.2. Interventions

Participants were randomly assigned to either a 12-week KY or MET program.

- **Kundalini Yoga (KY):** The KY intervention consisted of 60-minute classes, twice weekly, led by a certified instructor. Each class involved a blend of breathing exercises (pranayama), dynamic movement, postures (asanas), meditation, and relaxation. The specific KY sequences were designed to promote overall well-being and cognitive function.
- **Memory Enhancement Training (MET):** The MET program comprised 60-minute sessions, twice weekly, focused on targeted cognitive exercises to improve memory, attention, and problem-solving abilities. The tasks included visual memory, verbal memory, and working memory exercises with progressive levels of difficulty.

2.3. Resting-State fMRI Acquisition and Analysis

Resting-state fMRI data were collected using a 3T Siemens scanner before and after the 12-week intervention period. During these scans, participants were instructed to fixate on a crosshair and remain still. Imaging parameters included a TR of 2 seconds, TE of 30ms, and 3.5 mm isotropic voxels. The raw fMRI data were preprocessed using standard procedures within SPM12, including slice timing correction, realignment, coregistration, normalization, and smoothing (8mm FWHM Gaussian kernel).

The hippocampus was parcellated using the Cole-Anticevic (CAC) atlas, which contains functionally relevant subregions of the hippocampus (Cole et al., 2020). Time series were extracted from each hippocampal subregion from each participant. Functional connectivity was calculated using Pearson correlation coefficients between all pairs of subregions. Connectivity changes were

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computed by subtracting pre-intervention connectivity from post-intervention connectivity. Partial least squares (PLS) analysis was employed to investigate group differences in connectivity changes between KY and MET, while controlling for age.

2.4. Questionnaires

Participants completed questionnaires to assess perceived stress and frequency of forgetting at baseline and post-intervention. We used the Perceived Stress Scale (PSS) to measure stress levels and a tailored questionnaire to measure frequency of forgetting, which has been shown to correlate with perceived memory decline (Bialystok et al., 2010).

2.5 Statistical Analysis Statistical analyses were performed using SPSS. Group differences in baseline characteristics were assessed using independent t-tests. Correlations between hippocampal connectivity changes, and changes in perceived stress and frequency of forgetting were examined using Pearson's correlations. Statistical significance was set at $p<0.05$ (two tailed).

3. Results

3.1. Hippocampal Connectivity Changes

The PLS analysis revealed statistically significant group differences in hippocampal connectivity changes ($p < 0.001$). For the KY group, we observed a greater increase in connectivity between the left anterior hippocampal subregion (assigned to the default mode network, DMN) and regions predominantly localized to the ventral visual stream compared to the MET group. Conversely, the MET group exhibited a greater increase in connectivity between several posterior hippocampal subregions (associated with sensory networks in the CAC atlas) and regions primarily within the DMN and frontoparietal network (FPN) compared to the KY group. These connectivity differences are detailed in Table 2.

Table 2: Differential Hippocampal Connectivity Changes

Subregion	Group	Increased Connectivity With	Network Association
Left Anterior Hippocampus	KY	Ventral Visual Stream Regions	DMN
Posterior Hippocampus Subregions	MET	DMN and Frontoparietal Network Regions	Sensory-Based

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3.2. Correlations with Perceived Stress and Forgetting

Changes in connectivity between the left anterior hippocampal subregion and ventral visual regions in the KY group were negatively correlated with changes in perceived stress ($r=-0.55$, $p<0.05$). This suggests that increased connectivity with the visual stream is associated with lower stress levels. In contrast, connectivity changes in posterior hippocampal subregions to DMN and FPN regions in the MET group were negatively correlated with changes in reported frequency of forgetting ($r = -0.61$, $p<0.05$), indicating increased connectivity was associated with fewer reported memory lapses.

4. Discussion

This study provides compelling evidence that KY and MET interventions lead to differential changes in hippocampal functional connectivity. Our findings suggest that KY may primarily target stress-related hippocampal function through its connection to visual processing regions while MET may be more effective in targeting sensory-integration and executive control related to memory formation and recall reliability.

The increased connectivity observed between the left anterior hippocampal subregion and ventral visual stream regions in the KY group is noteworthy. The DMN, which includes the anterior hippocampus, is often implicated in self-referential processing and internally directed thought. Chronic stress can disrupt DMN function and impact hippocampal integrity (Lupien et al., 2018). It is possible that KY's combination of breathing, movement, and mindfulness practices promote a more integrated interaction between the hippocampus and visual systems, which might facilitate processing of emotional content. This increased coupling was found to be linked to decreased self-reported stress levels, supporting the notion that KY can positively modulate stress-related neural pathways.

In contrast, the increased connectivity between posterior hippocampal subregions and the DMN and FPN in the MET group suggests a different mechanism of action. Posterior hippocampus, especially subregions linked to sensory experiences, are heavily involved in memory encoding and the formation of new associations with experiences, and are known to be disrupted in age-related cognitive decline. The fact that this increase was observed to be associated with decreased reported memory lapses is consistent with these regions having a key role in memory reliability. This effect suggests that cognitive exercises may improve the ability to access the memory network and improve the brain's ability to correctly recall learned information.

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4.1. Limitations Several limitations of this study should be noted. The sample size, although appropriate for the type of analysis, is relatively small, which limits our ability to generalize. Secondly, we only used a single time point for post-intervention imaging. A longitudinal design with multiple follow-up points would be valuable to investigate the long-term effects and stability of these connectivity changes. Finally, our analysis did not control for all lifestyle factors (e.g. diet, sleep, substance use), that may exert influence on brain connectivity changes.

5. Conclusion

This study demonstrates that KY and MET, while both potentially beneficial for cognitive health, engage distinct neural mechanisms and may offer complementary benefits for older women at risk for AD. KY appears to modulate stress-related hippocampal connectivity, whereas MET may enhance sensory integration and attentional pathways relevant to memory. These findings suggest that tailored interventions that meet the specific needs of individuals may be the most effective method for promoting healthy brain function into old age. Future research should aim to directly compare these two interventions in larger, more diverse populations, and explore the optimal combinations of these (and other) interventions to elicit the best cognitive gains.

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