Original article

Nuclear Medicine Communications

Cerebral blood flow changes during chanting meditation

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Purpose **To examine changes in brain physiology during a chanting meditation practice using cerebral blood flow single-photon emission computed tomography.**

Methods **Single-photon emission computed tomography scans were acquired in 11 healthy individuals during either a resting state or meditation practice randomly performed on two separate days. Statistical parametric mapping analyses were conducted to identify significant changes in regional cerebral blood flow (rCBF) between the two conditions.**

Results **When the meditation state was compared with the baseline condition, significant rCBF increases were observed in the right temporal lobe and posterior cingulate gyrus, and significant rCBF decreases were observed in the left parietotemporal and occipital gyri.**

Conclusion **The results offer evidence that this form of meditation practice is associated with changes in brain function in a way that is consistent with earlier studies of related types of meditation as well as with the positive clinical outcomes anecdotally reported by its users.** ***Nucl Med Commun*** **00:000–000 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

Nuclear Medicine Communications 2009, **00**:000–000

Keywords: cerebral blood flow, meditation, single-photon emission computed tomography

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Received 19 May 2009 **Revised** 12 June 2009
Accepted 15 June 2009

Introduction

Meditation is a 5000-year-old method of healing whose benefits have been evaluated by research over the past three decades. Starting with the work by Wallace and Jevning's 'Transcendental Meditation' study, continuing with Kabat-Zinn's 'Mindfulness Meditation' and the 'Relaxation Response' of Benson and others, meditation has been associated with a variety of health factors [1–8]. Meditation practices are extremely diverse, but are among the most popular practices associated with complementary and alternative medicine techniques [9].

Common elements of meditation are a quiet environment, a tool such as a repetitive sound or breath, and internal focus. When meeting these conditions while passively ignoring everyday thoughts, a particular set of integrated physiological effects ensues, including a wakeful state, decreases in certain physiological markers, and changes in electroencephalographic patterns [10–13].

Newberg and Iverson [14] distinguish between guided and volitional meditation. In guided meditation, the practitioner is cued by a leader to direct attention on an object of focus, such as a sound or mantra. In contrast, volitional meditation requires internally directed focus. Recent imaging studies have begun to delineate the neurological underpinnings of these different modalities. Using single-photon emission computed tomography (SPECT), Newberg *et al.* [15] studied Tibetan Buddhists in a volitional meditation and found activations in areas associated with concentration: bilaterally across the frontal lobes and prefrontal cortex (PFC). Similarly, using functional magnetic resonance imaging on another type of volitional meditation (Kundalini), Lazar *et al.* [16] found PFC and pregenual cingulate activations, and Herzog *et al.* [17] found frontal lobe activations in Yogic meditators using positron emission tomography (PET). In contrast with these results, Lou *et al.* [18] studied guided Tantric Yoga using PET and found PFC deactivations during meditation.

Other differences were noted as well. Herzog *et al.* [17] and Newberg *et al.* [15] found bilateral parietal lobe deactivations, to which they attribute the sense of timelessness and lack of self–other differentiation reported by meditators. In contrast, Lazar *et al.* [16] and Lou *et al.* [18] found parietal lobe activations. The implication is that different modalities affect brain function in different ways.

This study reports on a retrospective analysis of experience of healthy controls in the practice of Kirtan Kriya (KK), a guided meditation technique deriving from Kundalini Yoga, as developed by Yogi Bhajan [19]. KK induces a

0143-3636 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins DOI: 10.1097/MNM.0b013e32832fa26c

meditative state using a specific breathing pattern, upright sitting posture, word set, sequence of finger tip movements, and focus of concentration. SPECT was used to evaluate the baseline and meditation states for several reasons. First, it would be possible to study this form of meditation while maintaining an environment conducive to the meditation, which requires sitting up. Functional magnetic resonance imaging has the drawback that it is very loud and claustrophobic, making it a less-than-suitable environment for meditating. A problem with ^{18}F-fluorodeoxyglucose-PET imaging is that the uptake occurs over approximately 20–30 min, which would average not only the meditation, but also the baseline state together in a single image. The SPECT tracer uptake occurs within 1–2 min, which allows capture of a 'peak' meditation state. In SPECT imaging, the 6-h half-life of the radiopharmaceutical means that the image can be 'acquired' through intravenous injection on individuals performing almost any activity in virtually any setting.

As meditation studies have previously shown increased activity in the frontal cortices, we anticipated finding KK meditation to increase regional cerebral blood flow (rCBF) in the attentional centers of the PFC (i.e. the dorsal–lateral PFC) and decreases in those areas associated with spatial–temporal processing [particularly Brodmann area (BA) 7 of the parietal lobes]. Similarly, because of research on temporal lobe seizures and spirituality [20], and because of the reported transcendent experience of KK, we anticipate focal activations in the temporal lobes.

Additional hypotheses are based on what we have observed clinically using KK. First, we have noted improvements in stroke patients with both sensory and expressive aphasia; thus we anticipate finding meditative increases in both the posterior part of the left superior temporal gyrus (BA 22, associated with language comprehension) and Broca's Area (BA 44, associated with language expression). Second, we have noted improvements in patients with memory problems who use KK. At least two imaging studies have found hypoperfusion in the posterior cingulate gyrus to be a first indicator of Alzheimer's disease [21,22], and it is also widely known that the hippocampus degenerates in Alzheimer's disease. Given that Lou *et al.* [18] found hippocampal activations using guided meditation, we anticipated activations in both the posterior cingulate gyrus and the hippocampus.

Methods

Participants

The meditation individuals participated as part of a clinical program for evaluating healthy individuals and individuals with a variety of psychological problems. Six male and five female adults (mean age = 35.4 years, SD = 13.5) had their scans evaluated retrospectively. Ten of the participants had no history of psychiatric illness, and one had a history of mild depression. A historical review by one of the clinicians revealed that none of the participants suffered from neurological or medical disorders, except one male who had a motorcycle accident 20 years earlier, which included a brief loss of consciousness without subsequent behavioral changes. Six of the participants were right-handed, four were left-handed, and one was ambidextrous. All the 11 participants had some earlier experience with meditation, and 10 of the 11 considered themselves 'expert' meditators. Within 2 weeks before scanning, none of the participants had taken any psychoactive or psychotropic drugs.

Meditation technique

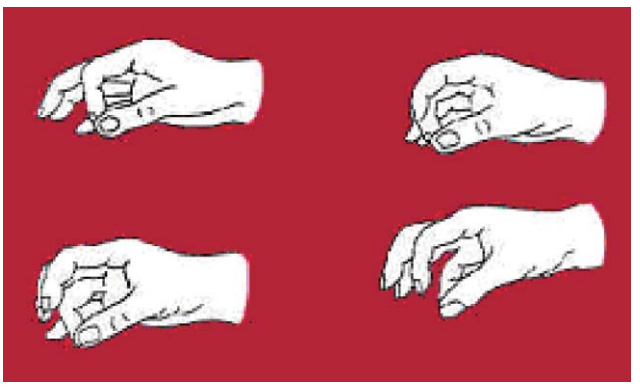
During the practice of KK, the breath is allowed to come naturally. The posture is one of simply sitting comfortably on the floor or in a chair. The sounds utilized are known as the five primal sounds: Sa, Ta, Na, Ma with Ahh, the end of each sound, considered to be the fifth sound. Figure 1 illustrates the finger movements that are performed with each sound.

As shown in Fig. 1, the meditation involves touching the thumbs to the first finger while chanting, 'Sa', the second while chanting, 'Ta' the third while chanting 'Na', and the fourth while chanting, 'Ma'.

Image acquisition

Each participant was scanned while resting with eyes closed (*t1*) and while in the meditative state (*t2*), so that any change in rCBF from *t1* to *t2* could be calculated. Participants sat on a sheepskin rug with closed eyes and chanted 'Sa, Ta, Na, Ma', while touching fingers two to five to the thumb with each sound. The meditation was done for 12 min (2 min singing out loud, 2 min whispering the sounds, 4 min saying the sounds silently to

Fig. 1



Kirtan Kriya finger tip movements.

themselves, 2 min whispering them again, and finally 2 min out loud). The chanting was guided by a previously recorded CD, which helped the participants keep time.

For the two conditions to be as similar as possible, we imposed four constraints. First, the participants continued meditating for an additional 2 min, but without chanting or finger touching, increasing the experimental manipulation time to 14 min. This created a small window wherein the participants could remain in the meditative state, but without activating their brains' motor strips or auditory centers. Second, for the baseline studies, the participants kept their eyes closed during, and for 5 min after, the injection of the bolus. Third, for the meditation studies, the onset of the injection began at the onset of the silent meditation period, meaning that cerebral uptake of the tracing agent would begin after any motor or auditory activity dissipated, and that uptake would be completed within a comfortable time before the silent meditation period ended. Finally, on the first day, half (six) of the participants were scanned in the meditative state and half (five) at rest; on the second day this breakdown was reversed.

Brain images were captured using SPECT. For each scan, approximately 25 mCi of ^{99m}Tc exametazime was administered intravenously. The camera used to capture photon emission was a high-resolution Picker Prism 3000 triple-headed γ-camera (Picker Inc., Cleveland, Ohio, USA) with fan beam collimators. Data were acquired in 128 ×128 matrices, yielding 120 images per scan with each image separated by 3 degrees spanning 360 degrees, and attenuation correction was performed using general linear methods.

Statistical analysis

For each scan, the transaxial slices were three-dimensionally reconstructed into $2.17 \times 2.17 \times 6.4$ mm rectilinear regions called 'voxels'. We performed voxel-by-voxel *t*-tests comparing meditation with resting scans using Statistical Parametric Mapping '99 (SPM99) [23]. We set the cluster threshold at 8 voxels, meaning any significant clusters of fewer than 8 voxels would be excluded from our results. The significance threshold was set at a *P* value less than 0.005 (uncorrected for multiple comparisons). A threshold mask was used to ensure that no voxel counts from outside the brain were included in the analyses. The threshold for inclusion was set at 80% of the mean global value.

To ensure that the voxels from one brain scan were approximately lined up with the 21 others in our analyses, all scans were spatially preprocessed. Each meditation scan was first coregistered to its respective baseline scan (using SPM's realign function), which created a 12-parameter realignment matrix for each of the 11 meditation/baseline pairs. Each pair was then visually inspected for coregistration errors. All 22 scans from both conditions were then normalized to a single standardized anatomical space using sinc interpolation and a $9 \times 9 \times 9$ voxels kernel [24]. Finally, all images were smoothed to 7 mm^3 using a Gaussian kernel.

Results

Areas of meditative activation include two significant clusters (Table 1). The largest cluster comprises 411 voxels and has an uncorrected *P* value of 0.001 (corrected $P = 0.056$), within which two gray matter maxima are significant (Table 2): the postcentral gyrus of the left

Table 1 Summary of SPM results significant clusters of gray matter activations and deactivations during Kirtan Kriya meditation (*n*=11)

Brain region	Cluster size (in voxels)	Valence	Uncorrected *P* value*
Frontal left (BA 25)	191	Deactivation	0.020
Frontal right (BA 31)	350	Activation	0.003
Temporal right (BA 20)	228	Deactivation	0.012
Parieto-temporal left (BAs 41, 43)	411	Activation	0.001
Parietal left (BA 7)	571	Deactivation	0.001*
Occipital left (BA 19)	516	Deactivation	0.001**

BA, Brodmann area.
*Significant at P=0.012, Bonferoni's corrected for multiple comparisons.
**Significant at P=0.02, Bonferoni's corrected for multiple comparisons.

Table 2 Summary of SPM results significant voxel-level gray matter activations and deactivations during Kirtan Kriya meditation (*n*=11)

Brain region	*x, y, z* Talairach coordinates	*t*-value*
Activations		
Parietal lobe		
Left postcentral gyrus (BA 43)	−48, −14, 14	4.71
Right inferior lobule (BA 40)	68, −28, 24	3.46
Temporal lobe		
Left superior gyrus (BA 41)	−52, −20, 8	4.33
Right superior gyrus (BA 42)	62, −28, 14	4.23
Frontal lobe		
Right paracentral lobule (BA 31)	8, −12, 44	3.51
Left precentral gyrus (BA 6)	−38, −10, 44	3.92
Deactivations		
Parietal lobe		
Left superior lobule (BA 7)	−34, −54, 54	7.50
Left superior lobule (BA 7)	−36, −64, 48	4.14
Right precuneus (BA 19)	30, −74, 40	4.49
Right cuneus (BA 19)	30, −82, 32	4.08
Right inferior lobule (BA 40)	−48, −38, 54	4.78
Temporal lobe		
Left inferior gyrus (BA 20)	−56, −8, −20	3.61
Left fusiform gyrus (BA 37)	−28, −42, −12	3.31
Right fusiform gyrus (BA 20)	34, −38, −18	7.06
Right fusiform gyrus (BA 20)	48, −22, −24	4.62
Frontal lobe		
Left medial frontal gyrus (BA 25)	−12, 30, 18	4.05
Left superior gyrus (BA 8)	−18, 34, 54	8.01
Right superior gyrus (BA 8)	24, 36, 46	3.55
Orbital gyrus (BA 11)	−6, 50, −20	4.24
Occipital lobe		
Left middle gyrus (BA 19)	−44, −82, 12	4.18
Limbic system		
Left lentiform nucleus (putamen)	−20, 4, 0	3.69

BA, Brodmann area.
*Significant at P<0.001, uncorrected for multiple comparisons.

parietal lobe and the superior gyrus of the left temporal lobe. The second cluster comprises 350 voxels and has an uncorrected P value of 0.003 (corrected $P = 0.106$), within which one gray matter maximum is significant: the paracentral lobule of the right frontal lobe.

In addition, there are three gray matter maxima that reach voxel-level significance: the superior temporal gyrus of the right temporal lobe, the inferior lobule of the right parietal lobe, and the precentral gyrus of the left frontal lobe.

The arrow in each Fig. 2 image points to the Talairach coordinates $x = 60$, $y = -2$, $z = 16$, the maximum within a white matter cluster of 1978 voxels ($t = 9.45$, uncorrected $P < 0.001$) associated with BA 4, corresponding to the precentral gyrus or primary motor area.

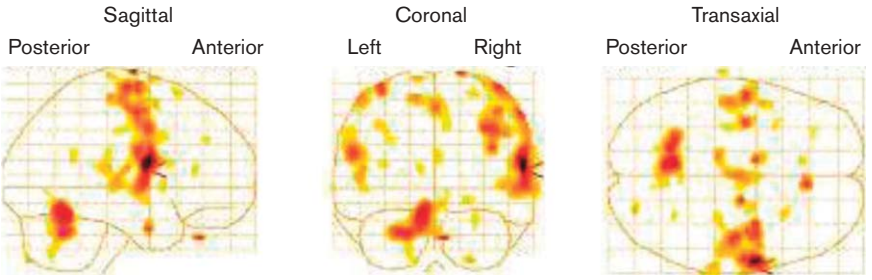
Deactivations during meditation include two clusters that are statistically significant after correcting for multiple comparisons (Table 1). The first cluster comprises 571 voxels and was significant at $P = 0.012$ (uncorrected $P < 0.001$). Within it were two significant gray matter minima (Table 2), both in the superior lobule of the left parietal lobe. The second cluster comprised 516 voxels and was significant at $P = 0.02$ (uncorrected $P < 0.001$). Within it was one significant gray matter minimum in the middle gyrus of the left occipital lobe.

Two clusters of deactivation were significant before correcting for multiple comparisons. The first and largest of these comprised 228 voxels (uncorrected $P = 0.012$) and contained two significant gray matter voxel-level minima in the right temporal lobe. The second comprised 191 voxels (uncorrected $P = 0.02$) and had one significant gray matter minimum in the left medial frontal gyrus.

Two additional clusters of deactivation are of interest. The first comprised 162 voxels and had an uncorrected P value of 0.03. Its largest minimum has Talairach coordinates $x = 26$, $y = -16$, $z = -22$ ($t = 5.44$), which is a white matter coordinate in the right parahippocampal gyrus, but is 1 mm off the z-axis from parahippocampal gray matter located in BA 23. The second is a cluster of 123 voxels (uncorrected $P = 0.054$) containing two gray matter minima in the right parietal lobe, both in BA 19 Fig. 3.

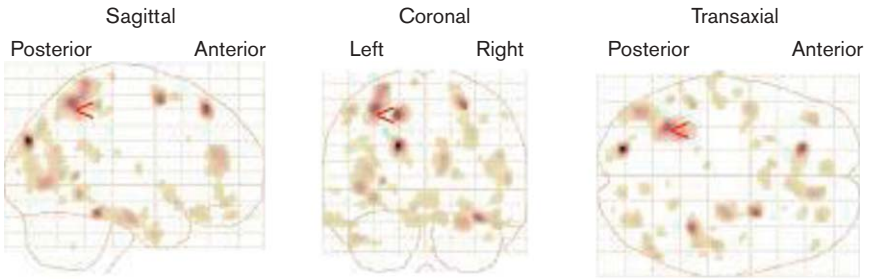
Seven additional gray matter deactivations reach voxel-level significance: the superior gyri of both the left and right frontal lobes, the inferior and fusiform gyri of the

Fig. 2



Glass brain activations rendered by SPM99. The arrow in each image points to Talairach coordinates $x = 60$, $y = -2$, $z = 16$, a 1978 voxel cluster located in the right primary motor strip.

Fig. 3



Glass brain deactivations rendered by SPM99. The arrow in each image points to Talairach coordinates $x = -34$, $y = -54$, $z = 54$, a 571 voxel cluster in the left superior parietal lobule.

left temporal lobe, the lentiform nucleus of the left putamen, the orbital gyrus of the right PFC, and the inferior lobule of the right parietal lobe.

Discussion

We had developed hypotheses based on the results of both prior meditation studies and our observed clinical results. Prior research had found deactivations in the parietal lobes [15] and, consistent with this, we found a large cluster of deactivation in the left posterior parietal lobe (BA 7), a region known to control spatial orientation. Deactivations in this area are consistent with KK meditators reporting a sense of transcendence or detachment. Although our participants also reported an increased sense of focus and capacity for concentration, we found no dorso-lateral PFC activation that met cluster-level or voxel-level significance. This result, along with the finding by Lou *et al.* [18] of PFC deactivations during guided meditation, suggests that it is the willful act of focusing – and not necessarily the mere act of meditating – that activates attentional networks.

On the basis of the improvements that we have observed clinically in patients with memory problems such as mild cognitive impairment and Alzheimer's disease, we anticipated activations in the posterior cingulate and hippocampal regions. In support of this, we found a significant cluster of activation in the posterior cingulate gyrus (BA 31), an area noted by Bonte *et al.* [21] and others to be among the first to deteriorate in Alzheimer's patients. Our observed positive clinical response using KK in patients with memory loss may be a function of KK's ability to activate this area. However, contrary to Lou *et al.* [18], we found no significant hippocampal increases. This may be the result of the difficulty in measuring CBF changes in this structure using SPECT imaging because of its limited spatial resolution. It is also possible that the lack of an increase in hippocampal CBF during KK meditation is a real finding that helps distinguish one meditation from another. KK may not activate the hippocampus as much as other structures that are also associated with memory and emotional regulation, such as the frontal lobes and cingulate gyrus.

We found a large cluster of activation in the left frontal–temporal region spanning BAs 41 (Hechl's gyrus, the brain's primary auditory cortex) and 43, areas known to be associated with working memory and language. Although we had specifically anticipated meditative activations in BA 44 (the primary speech center), both BA 41 and 43 are linked with working memory and language processing [25,26]. Increased rCBF in BAs 41 and 43 may explain anecdotal clinical observations on the effect of KK meditation on patients with partial aphasia (from either brain injury or stroke) and other speech deficits.

We also found a large cluster of deactivation in the subgenual cingulate gyrus (BA 25), an area discovered to be atrophied in schizophrenic patients [27]. Mayberg, *et al.* [28] found this area to activate in individuals when experimenters induced sadness. Our finding of a large deactivation in this region might explain subjective reports of happiness and a sense of well-being.

In addition, we found a large deactivation in the left medial occipital lobe (BA 19), the brain's tertiary visual cortex. BA 19 is associated with working memory [29] and has been found to activate in individuals who performed mental manipulations of visualized concrete objects [30]. Deactivations here may be associated with the subjective experience of the mind becoming quieted during KK.

There was also a large deactivation in the inferior gyrus of the right temporal lobe (BA 20). This area is a visual association cortex implicated in assigning emotional valence to images [31], and also in abstract language processing, such as understanding a metaphor [32]. Focal temporal lobe seizures have also been associated with experiences of religious ecstasy [33]. As KK meditators frequently report having spiritual experiences, and because we would not expect meditation to result in diminutions in working memory, affective tagging, or language processing, we find this deactivation to be counter-intuitive. One possible explanation is that meditative deafferentation to these areas may result in a 'rebound effect' when individuals are not meditating, meaning that they have higher baseline function similar to a muscle once it has recovered from a workout. Of course, the notion of a rebound effect, while reasonable, is purely speculative. A test of this hypothesis would be a comparison of meditators' resting brain activity to an age-matched control group. It is a significant limitation of this study that no control group was used.

An additional limitation of this analysis was that we failed to control for handedness, which could have diminished our ability to observe more specific laterality changes as the KK meditation does involve a verbal component. If we assume the correlation between hand and brain dominance, the inclusion of these individuals may have introduced unnecessary variability in our data, but in such a case, it should have decreased our ability to find significant changes during meditation. However, we were able to find significant changes in CBF during KK meditation in spite of the individuals having variable handedness. Furthermore, all SPM analyses were rerun excluding those of the left-handed individuals, and while some voxel-level P values were different as a function of having fewer degrees of freedom, the pattern of activations and deactivations did not change. The implications are that KK meditation has the CBF effects

mentioned above regardless of handedness, but future studies are needed to confirm whether handedness has an effect on KK meditation.

Recent research by Davidson *et al.* [34], finds a correlation between Buddhist Compassionate Meditation and neuroplasticity, implying that meditation has the capacity for intentionally changing both the architecture and function of the human brain. In addition, because our findings are different from prior meditation studies, it is possible that different modes of meditation might ultimately be prescribed when clinical evidence suggests that certain functional brain regions are hypoactive or hyperactive. For meditation practices to become a medically validated means of treatment, however, more research is needed comparing different modalities with each other and contrasting them against normal control groups. As a preliminary step in this direction, we conclude that our findings provide preliminary evidence that KK meditation is associated with changes in the brain function, a result that holds significant potential in the clinical context.

Acknowledgements

Partial funding for SPECT scans was provided by the Alzheimer's Prevention Foundation International. Partial funding for SPECT scans and data analysis was provided by Amen Clinics Inc. Special thanks is owed to Jill Prunella, research associate, for her contribution toward the completion of this study.

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