Immediate Effects of Yoga Breathing with Intermittent Breath Holding on Response Inhibition among Healthy Volunteers

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Abstract

Background: There is very little evidence available on the effects of yoga-based breathing practices on response inhibition. The current study used stop-signal paradigm to assess the effects of yoga breathing with intermittent breath holding (YBH) on response inhibition among healthy volunteers. **Materials and Methods:** Thirty-six healthy volunteers (17 males + 19 females), with mean age of 20.31 ± 3.48 years from a university, were recruited in a within-subject repeated measures (RM) design. The recordings for stop signal task were performed on three different days for baseline, post-YBH, and post yogic breath awareness (YBA) sessions. Stop-signal reaction time (SSRT), mean reaction time to go stimuli (go RT), and the probability of responding on-stop signal trials (p [r/s]) were analyzed for 36 volunteers using RM analysis of variance. **Results:** SSRT reduced significantly in both YBH (218.33 ± 38.38) and YBA (213.15 ± 37.29) groups when compared to baseline (231.98 ± 29.54). No significant changes were observed in go RT and p (r/s). Further, the changes in SSRT were not significantly different among YBH and YBA groups. **Conclusion:** Both YBH and YBA groups were found to enhance response inhibition in the stop-signal paradigm. YBH could be further evaluated in clinical settings for conditions where response inhibition is altered.

Keywords: *Breath awareness, breath holding, cognition, pranayama, stop-signal task, yoga, Kumbhaka*

Introduction

Yoga is an ancient traditional Indian practice that has become popular in the recent years, due to its plausible effects on health. The original form of yoga consists of a system of ethical, psychological, and physical practices. Though it has an ancient origin, it transcends cultures and languages.[1] In the recent years, there has been a growing interest in the scientific community about the effects of yoga in health and disease. One of the key physiological domains, which seems to be influenced by yoga practices, is human cognition. There is a growing interest in understanding the effects of yoga practices in neurocognitive, psychology, and psychiatric settings.[2] Several studies indicate the beneficial effects of yoga practices on the cognitive abilities.[3-6]

Pranayama or the yoga breathing practices find a special emphasis in the yogic tradition. A verse in *Hatha Yoga Pradipika,* a traditional text on yoga, describes "When breath moves, the mind moves. When breath is without movement, the mind also settles down. Thus, a yogi attains steadiness by retaining the breath."[7] The yogic texts describe four phases of breathing, namely, inhalation (*puraka*), internal retention of breath (*antarkumbhaka*), exhalation (*recaka*), and external retention of breath (*bahyakumbhaka*), which are practiced in varying proportions. Although the practice of breath holding and its benefits is emphasized in the ancient texts of yoga,[7-9] not much is known about the effects of yoga breathing with intermittent breath holding (YBH). The limited existing evidence suggests beneficial effects of YBH on autonomic activities,[10] baroreflex sensitivity,[11] and metabolic functions.[12]

However, there are no studies evaluating the effects of YBH on cognition. The earlier studies on other yoga breathing techniques show positive influence on cognitive tasks involving visual and auditory reaction times (RTs),[13,14] attention,[15] spatial memory,[16] working memory,[17]

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and response inhibition.[18] Considering the importance in the traditional texts for the practice of breath retention and positive influence of yoga breathing techniques on the cognitive abilities, we hypothesized that YBH may positively influence human cognition.

Response inhibition is one of the most important aspects of cognition. It is defined as the ability to inhibit unwanted responses according to change in the environment.[19] It is affected in various conditions such as schizophrenia[20] and attention-deficit hyperactivity disorder (ADHD).[21] The stop-signal task (SST) has proved to be a useful tool for the study of response inhibition in cognitive psychology, cognitive neuroscience, and psychopathology.[22] In SST, individuals act upon a go RT task. On a random selection of the trials (stop-signal trials), a stop signal is presented, instructing them to withhold their go responses.[19] The ability to stop the ongoing motor responses in a split second is a vital element of response control and flexibility that relies on frontal–subcortical network.[23] Further, stop-signal paradigm allows a sensitive estimate of inhibitory control known as the stop-signal RT (SSRT), which reflects the time taken to internally suppress a response.[22] Studies have demonstrated that the medications for the treatment of ADHD enhanced SSRT in healthy volunteers.[24,25] Recently, SST paradigm has also been used to demonstrate an enhanced response inhibition using a specific type of yoga breathing on response inhibition.[18] Hence, the present study was designed to evaluate whether the practice of YBH could enhance the ability of response inhibition through enhanced ability to inhibit unwanted responses as assessed using the stop-signal paradigm.

Materials and Methods

Participants

A total of seventy volunteers, who were undergoing various long-term courses in yoga at a residential Yoga University, Bengaluru, India, were screened, out of which 42 volunteers were selected for the study. The experience of practicing yoga ranged from 6 months to 5 years. The screening for the recruitment, performed by a trained physician, ruled out the use of medication, smoking, alcohol consumption, stress-related as well as psychological or cardiorespiratory ailments. Six volunteers dropped out for various reasons during the 8-week training in yoga breathing. Finally, 36 volunteers (17 males + 19 females) were assessed for the current study. Participants' age ranged from 18 to 25 years with a mean age of 20.31 years (standard deviation [SD] = 3.48). All participants reported to have a normal or corrected vision and normal hearing. The assessment was performed for female participants during the ovulatory phase to minimize the effect of menstrual cycles on the performance in SST.[26] The study was approved by the Institutional Ethics Committee of the University. Participants were recruited after obtaining written informed consent.

Design

We executed a within-subjects repeated measures (RM) design wherein each participant was assessed in three conditions on three different days (baseline, YBH, and yoga breathing with breath awareness [YBA]). Random allocation was used to minimize the learning effect. The time of day was kept constant for all sessions for an individual (between 4 pm and 6 pm) since time of the day may influence the physiology of breath holding.[27] Each session lasted for approximately 40 min, other than baseline session in which participants visited laboratory only for the assessment duration of about 15 min. The SST was recorded after both the trial conditions (YBH and YBA). All participants underwent 8-week orientation in the breathing practice prior to the actual assessment. This orientation was administered to avoid the individual variations in the practice. Due to the residential nature of the university, all 36 volunteers who underwent the final assessment had more than 90% attendance for the training sessions.

Intervention

During both the experimental conditions, the participants were asked to sit erect, with closed eyes and focusing the awareness on breathing. The YBH session included the regulated yogic breathing for 20 min incorporating phases of inhalation (*puraka*), internal retention of breath (*antarkumbhaka*), exhalation (*recaka*), and external retention of breath (*bahyakumbhaka*) in a ratio of 1:1:1:1 for 6 s each. The schematic representation of the breathing practice is depicted in Figure 1. We chose the presented intervention from a classical training methodology of *pranayama* suggested in the text of yoga.[8] The intervals of 6 s were decided based on an earlier study.[10] The duration of 6 s was ensured through verbal cues in a prerecorded audio track. During the YBA session, the participants were seated erect, performing normal breathing with breath awareness for the same duration of 20 min in the same test environment, including the audible cues.

Assessment

We assessed the participants at baseline and following YBH and YBA sessions. On all the days of assessment, the

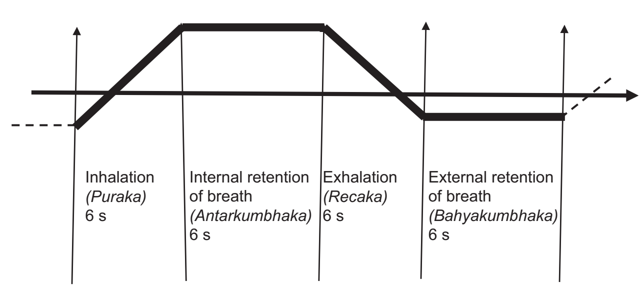

Figure 1: Schematic representation of one cycle of the practice of yoga breathing with intermittent breath holding

participants were asked to avoid consumption of caffeine, as it may alter the cognitive abilities. The SST paradigm developed by Verbruggen *et al*.[28] was presented using the INQUISIT Millisecond software package 4.0 (Millisecond Software, LLC, Seattle, USA) on an Dell desktop computer with a 21.5" color monitor. The configuration of the computers on which the task was presented was kept the same to maintain the uniform processing speed. All participants received a practice session prior to the experimental sessions to familiarize with the SST and procedures. The experiment was conducted individually in a room under normal fluorescent lighting in the research laboratory.

Stop-signal paradigm

The stop-signal paradigm is based on the horserace model where response execution races with the inhibitory process to determine whether a response is inhibited.[28,29] The primary task is to perform a two-choice task in which participants had to react as quickly and accurately as possible to discriminate between a left and a right arrow, presented at the center of the computer screen, in white, on a black background. The participant was supposed to respond with the alphabets "D" (for left arrow) and "K" (for right arrow) on a keyboard with the left and right index fingers, respectively. On no-signal trials (go task), only the primary task stimulus is presented. On stop-signal trials (stop task), an auditory "stop signal" beep is presented at a variable delay (stop-signal delay [SSD]) following the go stimulus. Participants were instructed to inhibit their responses on the trials with a stop-signal beep. Tasks were presented randomly: go task (75%) and stop task (25%). SSD is initially set at 250 ms and is adjusted continuously with dynamically tracking procedure, depending on the performance of the participant. Successful inhibitions resulted in an increase of the SSD by 50 ms, whereas failed inhibitions resulted in a reduction of the SSD by 50 ms. This procedure ensured that, on an average, each participant in each session had a probability of successful inhibition approaching 50%.[28] A schematic representation of the SST has been illustrated in Figure 2 based on the work of Logan *et al*.[19] A total of 392 trials were presented, divided over six blocks of 64 trials, lasting 3 min each. Participants waited for 10 s between blocks before they start the next block. The primary outcome measure was SSRT, an estimate of the participant's capacity for inhibiting the unwanted motor responses. SSRT was calculated by subtracting mean SSD from mean RT to go stimuli (go RT). Additional measures of interest are the probability of responding on stop-signal trials (p [r/s]) and go RT. Figure 3 illustrates the major outcomes of the stop-signal paradigm based on the computer program developed by Verbruggen *et al*.[28]

Data analysis

RM analysis of variance (RM-ANOVA) followed by *post hoc* Bonferroni adjustment was done to compare data recorded at baseline and following YBH and YBA sessions, using SPSS software Version 16.0 (SPSS INC., Chicago, USA). The alpha level was set at 0.05 to determine the significance in performance in SST in three states. Paired samples *t*-test was applied to the data while comparing the performance at the baseline to post-YBH and post-YBA, respectively.

Results

The group means and SDs for the conditions at baseline and following the YBH and YBA sessions are presented in Table 1. RM-ANOVA results have been described in Table 2 which showed a significant effect for SSRT F (2, 34) = 4.74, P = 0.015, partial η2 = 0.22, however the p (r/s) and go RT showed nonsignificant changes. Within-sessions analyses revealed significant reductions

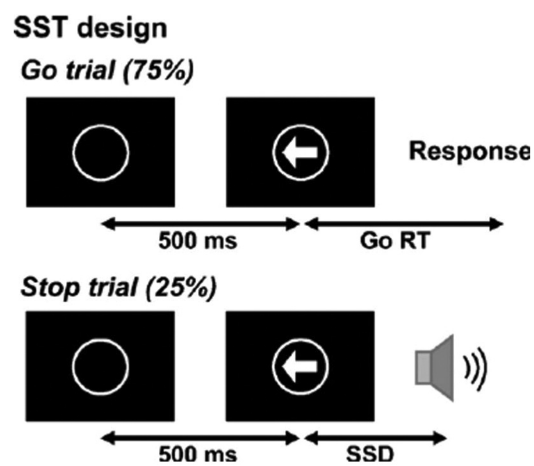

Figure 2: Schematic representation of the stop-signal paradigm. The stop-signal task consists of go and stop-signal trials. A circle is presented for 500 ms, followed by a presentation of an arrow pointing either left or right. Participants are instructed to respond as fast as possible by pressing a left or right button, depending on the direction of the arrow. In the stop trials, an auditory stop signal occurs after the presentation of the arrow, and on these trials, participants must try to withhold their responses. The latency to the sound (the stop signal delay) varies dynamically throughout the study to produce the stop-signal delay 50, where participants can inhibit approximately 50% of their responses. The stop-signal reaction time is calculated as the median go reaction time minus the stop-signal delay 50, according to the race model.[19] Image courtesy: Madsen *et al*., 2009[41]

Table 1: Group mean±standard deviation values for the stop-signal task

	Baseline	YBH	YBA
SSRT (ms)	231.98±29.54	218.33±38.38*	213.15±37.29*
p (r/s)	47.69±4.12	48.79±4.71	48.69±4.71
Go RT (ms)	565.05±138.03	591.74±174.45	604.08±166.50

*P<0.05. Paired samples *t*-test comparing the outcomes of the SST at baseline and following the sessions of YBH and YBA. YBH=Yoga breathing with intermittent breath hold, YBA=Yoga breathing with awareness, SSRT=Stop-signal reaction time, SST=Stop-signal task, p (r/s)=Probability of responding on stop-signal trials, RT=Reaction time

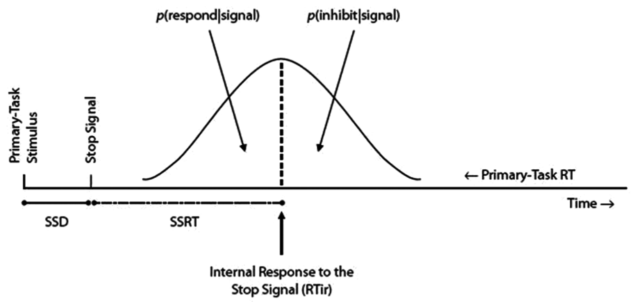

Figure 3: Illustration of the probabilities of responding on stop-signal trials based on the horserace model (Logan and Cowan, 1984), given the distribution of no-signal reaction times (primary task reaction time), the stop-signal delay, and the stop-signal reaction time. Probability of responding on stop-signal trials is represented by the area under the curve to the left of the dashed line. Image courtesy: Verbruggen *et al*., 2008

Table 2: Results of the repeated measures analysis of variance

Variable	Factor	*F*	df	*P*	Partial η²
SSRT	Session	4.74	2, 34	0.015	0.22
p (r/s)	Session	0.64	2. 34	0.53	0.036
Go RT	Session	1.076	2, 34	0.35	0.063

SSRT=Stop-signal reaction time, p (r/s)=Probability of responding on stop-signal trials, RT=Reaction time

in SSRT following YBH ($t(35)$ ≤1.89, $P < 0.05$) and YBA ($t(35)$ ≤0.2.71, $P < 0.05$) conditions when compared to the baseline. There was no significant difference between the two breathing practices ($t(35)$ ≤0.0.23, $P \geq 0.816$). Pair-wise comparison revealed no significant difference in both p (r/s) and go RT among the conditions.

Discussion

The current study was designed to ascertain whether the practice of YBH affects the response inhibition indicated through the performance in the SST. The findings indicate a significant reduction in SSRT following both YBH and YBA, which was in contrast to our initial hypothesis that YBH and YBA may have differential effects on response inhibition. We also could not elicit significant changes in the p (r/s) and the go RT in both interventions, when compared to the baseline.

There was a significant reduction in SSRT, suggesting that the practice of YBH and YBA resulted in enhanced response inhibition.[22] Further, although statistically insignificant, participants slowed down the go responses following both the conditions, which may be due to proactive response strategy to achieve a balance between competing goals, suggesting a flexible cognitive control.[30] Our results are concurrent to an earlier study on yoga breathing using SST paradigm.[18] The enhanced SSRT and slowing down of go RT represent better inhibitory control. A study performed on yoga in prison population showed enhanced response inhibition in a go/no-go task.[31] Studies have shown similar effects through the administration of medications for ADHD in healthy volunteers.[24,25]

The observed results may be attributed to relaxation and the autonomic balance attained through the practice, which is indicated in earlier studies on yoga breathings.[10,11] There was enhanced response inhibition following both YBH and YBA conditions. A blood oxygen level-dependent functional MRI study performed to understand neural correlates of the voluntary breath holding demonstrated activity at the bilateral network of cortical and subcortical structures including the insula, basal ganglia, frontal cortex, parietal cortex and thalamus, and pons.[32] Response inhibition in SST paradigm is mediated through roles of the prefrontal-caudate and striato-thalamic activities.[33] In addition, vagus nerve stimulation was found to enhance response inhibition in patients with epilepsy.[34] Therefore, we speculate that YBH may enhance the response inhibition through activation of cortical and subcortical brain areas as well as enhanced vagal tone due to slow breathing.

Breath awareness is the basis for several meditation techniques including *Vipasana*, mindfulness, and *Sudarshan Kriya Yoga*. It is understood from the existing literature that being aware of breath could help in enhancing the physiological and cognitive functions to optimal levels through promotion of relaxation and enhanced self-awareness.[35] Thus, the results following the YBA session could be attributed to focused attention of the volunteers on breathing and the relaxation attained through it. Further studies incorporating neuroimaging techniques could reveal the exact mechanisms involved with neurocognitive modulation through yoga breathing techniques.

Assessing the long-term effects of yoga breathing on response inhibition was beyond the scope of the present study. Since our study included population of healthy young adults, the results may not be generalized to clinical populations at this stage. Further studies may be taken up to understand how different yoga breathing practices may alter response inhibition. A major limitation of the present study was the inability to ascertain the exact mechanism of action for the observations. It would be interesting to add neuroimaging techniques to further studies, to understand the underlying mechanisms of action. Altered response inhibition is observed in patients with ADHDs,[36] schizophrenia,[37] epilepsy,[38] obsessive-compulsive disorders,[39] as well as stressful situations.[40] It would therefore be interesting to observe whether yoga breathing could influence the response inhibition in such population.

Conclusion

The present study indicated a positive impact of YBH on the SST indicating enhanced response inhibition among healthy volunteers. Future studies in clinical setting with neuroimaging techniques are warranted.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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