Effect of Yoga practice on reducing cognitive-motor interference for improving dynamic balance control in healthy adults

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ABSTRACT

Objective: The purpose of our study was to investigate the effects of Yoga on reducing cognitive-motor interference (CMI) for maintaining balance control during varied balance tasks.
Method: Yoga (N = 10) and age-similar non-practitioners (N = 10) performed three balance tasks including the Limits of Stability test (LOS – Intentional balance), Motor Control test (MCT – Reactive balance), and Sensory Organization Test (SOT –condition 6: inducing both somatosensory and visual conflicts) under single-task (ST) and dual-task (DT, addition of a cognitive working memory task) conditions. The motor performance was assessed by recording the response time (RT) and movement velocity (MV) of the center of pressure (CoP) on LOS test, weight symmetry (WS) of CoP on the MCT test and equilibrium (EQ) of CoP on the SOT test. Cognitive performance was recorded as the number of correct responses enumerated in sitting (ST) and under DT conditions. The motor cost (MC) and cognitive cost (CC) were computed using the formula ([ST-DT]/ST)*100 for all the variables. Greater cost indicates lower performance under DT versus ST condition.
Results: The Yoga group showed a significantly lesser MC for both MCT and SOT tests (p < 0.05) in comparison to their counterparts. The CC were significantly lower on LOS and MCT test for the Yoga group (p < 0.05).
Conclusion: Results suggest that Yoga practice can significantly reduce CMI by improving allocation and utilization of attentional resources for both balance control and executive cognitive functioning; thus resulting in better performance under DT conditions.

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1. Introduction

Many daily activities need individuals to perform functional tasks requiring balance control concurrently with cognitive tasks.[1] Studies that have examined the attentional demands of the motor tasks during simultaneous performance of balance control and cognitive tasks (dual-tasking – DT),[2,3] had observed that the performance on either or both the tasks declines under DT conditions. These studies suggest sharing of central resources between balance and cognitive tasks, causes lesser attention to be focused on either one or both the tasks. This phenomenon is referred to as cognitive-motor interference (CMI).[4]

Dual-task studies have demonstrated a decline in performance of gait (gait speed, swing time, increased swing time variability) and cognition (executive function), dynamic balance (decrease in muscle response amplitude) and obstacle crossing (decrease in toe clearance and reactive time and increase in stepping time), demonstrating decline in performance of either one or both tasks when performed concurrently.[5–8] The pattern of interaction between integrating cognitive and motor tasks may depend on several factors, the type of cognitive task and the complexity of the balance control task.[9–10]

Many studies have demonstrated that Yoga training leads to improvement in balance control.[11–13] A systematic review indicated that Yoga improved performance on clinical balance control tests such as the Berg balance scale in both young and older healthy adults.[14] Another study compared the effect of a custom-designed Yoga program with Tai Chi training in healthy older adults and concluded that Yoga was as effective as Tai Chi for improving both static and dynamic balance control.[15]

Furthermore, recent studies have reported that Yoga is effective in improving various higher cognitive functions such as executive control, mental flexibility, and working memory. A randomized controlled trial study examined the effects of an 8-week Hatha Yoga training on executive function, measures of task switching and working memory capacity in comparison with stretching-strengthening exercises in healthy older adults. The results showed a significant improvement in executive cognitive function, working memory capacity and mental set shifting and flexibility compared with their counterparts.[16] Another study demonstrated greater cognitive performance (increased accuracy) with an hour of Yoga practice, relative to aerobic exercise in healthy young adults on working memory function tested with the N-back task.[17] In spite of wide practice and balance control and cognitive benefits of Yoga, there has been no study yet evaluating the CMI under DT conditions, a necessary part to assess effects of Yoga practice.[18]

Thus, the purpose of this study was to investigate the effects of Yoga on CMI for maintaining balance control (intentional, reactive and both somatosensory and visual conflicts induced) while each of them is concurrently performed with a working memory function task. We hypothesized that the Yoga practitioners would perform significantly better in all the three balance control tasks in comparison to their age-similar non-practitioners in DT condition. Yoga practitioners would also have a significantly higher cognitive performance demonstrating decreased mutual CMI under DT conditions.

2. Method

Participants: Twenty individuals, including Ten Yoga practitioners, ten non-practitioners, similar in age, sex, height and education participated in this study. All participants were from the Chicagoland area. Yoga practitioners were recruited from Yoga centers and age-similar non-practitioners from the university student pool. All the participants reported that they practiced Hatha and Kundalini yoga (45–60 min/session, 2–3 sessions a week ≥1 year), which are the most popular forms of thought in the west. The study was approved by the Institutional Review Board of the University of Illinois. Informed consent was obtained from all the participants.

2.1. Protocol

Each participant completed three balance control tasks including the Limits of Stability test (LOS) (intentional balance), Motor Control test (MCT) (reactive balance), and posturography with conflicting somatosensory and visual information Sensory Organization test (SOT – condition 6) with and without a serial subtraction task.[19,20] The posturography task was conducted for condition 6, as the age-associated decline in equilibrium has been excessively reported in this condition. Further, the decrease in equilibrium scores has been correlated with increased risk of falls in older adults.[21] Participants also performed the three balance control tasks and the serial subtraction cognitive task in isolation while seated. The Equitest (Computerized Dynamic Posturography) system used in this study records the signals from the force-sensing surface and the computer processes the signals to quantity postural stability under various test conditions, normalized to participant's height and weight. These trials were defined as single-task (ST) and dual-task (DT) conditions. The details of each test are further described below.

2.1.1. Single task conditions
2.1.1.1. Limits of stability test (Intentional balance control task).
The design, equipment and protocol for intentional balance control used in this study have been comprehensively detailed previously.[22] The outcome measures recorded by the software included movement velocity (MV) and response time (RT). Movement velocity was the average speed of the center of pressure movement in degrees per second. The Response time is calculated as the point in time at which the participants center of pressure (CoP) moves beyond the area occupied between the command to move and the onset of the individual's movement.

Formula: $Reaction\ time\ forward\ direction = \frac{0.5*S_{LF}+S_F+0.5*S_{RF}}{2}$ [23]

$S = Score$, $S_{LF} = Score\ of\ left\ forward\ movement$, $S_{RF} = Score\ of\ right\ forward\ movement$

2.1.1.2. Motor control test (MCT) (reactive balance control task).
The design, equipment and protocol for the reactive balance control task is described elsewhere.[22] The outcome measure recorded by the software was weight symmetry (WS) and response time (RT). Weight symmetry quantifies the distribution of total body weight over each lower extremity during completion of the test. The response time was quantified as the time between translation (stimulus) onset and initiation of the individual's active response in milliseconds.
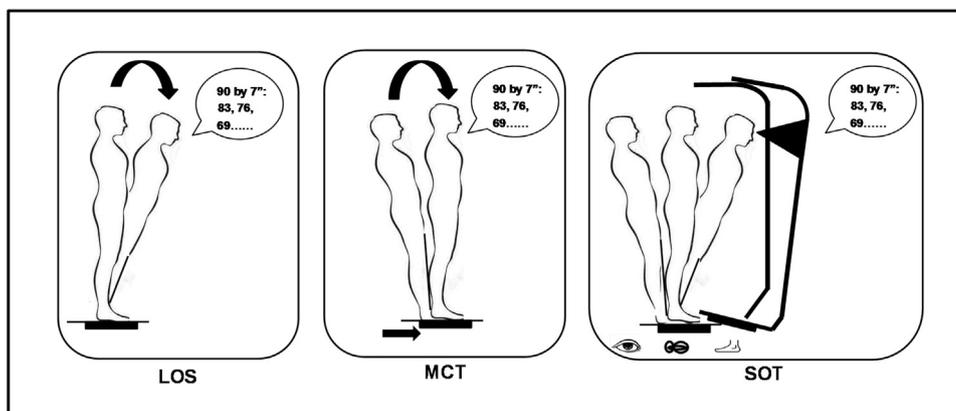
2.1.1.3. Sensory organization test (SOT – condition 6).
Posturography task with conflicting somatosensory and visual information: Assessed by SOT protocol of the Equitest (Computerized Dynamic Posturography) on condition 6 with eyes open on sway-referenced support surface and surround (in this situation, the participants both somatosensory and visual information was distorted and the input from only the vestibular system was given). Participants initial starting position was similar to that of the starting position during LOS and MCT balance control protocol tests and participants wore the safety harness system. Participants were instructed to stand still and were asked to maintain their balance without taking a step or falling with eyes open on condition 6. Scores are based on the assumption that a normal individual can exhibit anterior to posterior sway over a total range of approximately 12.5° without losing balance. The equilibrium (EQ) score for each trial was calculated by comparing the angular difference between the individual's maximum anterior to posterior CoP displacements to this theoretical maximum displacement. The result was expressed as an inverse percentage between 0 and 100. Scores approaching 0 indicate sway amplitudes approaching the LOS with a value of 100 indicating perfect stability. A score of 0 indicates that the patient "fell" on that trial.

$Equilibrium = \frac{12.5° - (\theta max - \theta min) \times 100}{12.5°}$ [23]

2.1.1.4. Cognitive task.
Each participant performed a test of executive function, serial subtraction task in a sitting position (single-task condition, ST). The serial subtraction task requires the transient holding and processing of new and existing information and can assess the working memory function. Participants were given predetermined numbers and asked to perform a serial subtraction (e.g. subtract 8 from 96 as many times as you can until stopped).[24]

2.1.2. Dual-task conditions
Under dual-task (DT) conditions, participants performed the three balance control tasks (LOS, MCT, and SOT tests) in conjunction with the serial subtraction task (Fig. 1). For the LOS test participants were asked to start serial subtraction from the given numbers as soon as they heard the start beep, while simultaneously shifting their weight in a given direction with feet in place. Similarly, for the MCT test they were asked to recite as many numbers as possible starting from the given numbers, while trying to maintain their balance and upright posture without taking a step or falling in response to sudden movement of the platform underneath their feet. For the SOT test, participants were asked to recite as many numbers as possible, while trying to maintain their standing balance with eyes open while the standing surface and the surrounding environment

Fig. 1. Schematic of dual-task (DT) conditions where participants performed the three balance control tasks LOS (Limits of stability), MCT (Motor control test), and SOT (Sensory organization test) in conjunction with the Counting backward (CB), a serial subtraction cognitive task.

sways (condition 6). To minimize the potential for learning, different sets of serial subtraction numbers were provided for each test under DT condition. To allow for accurate comparison of cognitive performance between ST and DT conditions, the same set of serial subtraction numbers were used for the seated cognitive task (ST) and the balance tasks under DT conditions and the participants were not specifically instructed to prioritize either of the cognitive or the balance task. The numbers for each trial condition remained the same between participants.

All tests were completed in one test session, lasting approximately one hour and 20 min. The order of all balance ST and DT trials was randomized using a computerized random number generator software and was the same across all the participants (Fig. 2). Each participant was given a total of six familiarization trials, one trial each for ST and DT conditions for LOS, MCT, and SOT tests. To avoid fatigue, a 1–2-min rest period was provided between trials. To avoid a recall bias, an interval of 15 min was given between the seated cognitive task and DT conditions trials. The assessor, participant and the person analyzing the data were all blinded in this study.

2.2. Statistical analysis

The means and standard deviations of the absolute values of the balance outcome measures (Movement velocity, weight symmetry and equilibrium and response time of the CoP) were obtained. In order to compare the reaction time for reactive and voluntary balance control task in this study, we had converted the reactive balance milliseconds units to seconds. Following, which to determine any change in performance between ST and DT (cognitive-motor interference) conditions, we calculated the DT costs for each of the balance outcome measures and the cognitive measure. Dual-task cost was computed using the formula

Movement velocity, equilibrium and response time cost $= \left[\frac{ST - DT}{DT} \right] * 100$

Weight symmetry $= - \left[\frac{ST - DT}{DT} \right] * 100$ [25,26]

As movement velocity and equilibrium were likely to decrease during DT conditions, lesser cost demonstrates (better performance), while greater cost indicates better performance in weight symmetry. As the response latency was expected to increase during DT conditions, a greater cost (lower performance) would be indicated by greater negative values. A value of 0 indicated no difference in response time between ST and DT, and positive values indicated a reduced cost under DT conditions. A 3×2 repeated measures ANOVA was performed the independent variables: motor and cognitive cost. Motor cost (MC) and cognitive cost (CC) were considered as the primary outcome variables for this study. The

Table 1
Demographics of Yoga practitioners and age-similar non-practitioners.

| Characteristics	Yoga practitioners (n = 10)	Age-similar non-practitioners (n = 10)	p-value
Age (year)	27.5 ± 9.33	26.7 ± 6.48	0.681
Height (cm)	163.4 ± 8.22	165.9 ± 7.34	0.267
Weight (lb)	136.8 ± 16.17	142.7 ± 8.9	0.264
Sex (male/female)	2/8	2/8	0.157

Values are mean ± SD.

three balance tasks were treated as the independent within group (repeated) factor and the two groups as the between-group factor. Significant test x group interactions were resolved with post hoc paired and independent t-tests. The alpha level was adjusted to account for the multiple comparisons. The Bonferroni correction was used to make the adjustment of P values. Among the three balance tests, the SOT test does not generate response time. However, as movement initiation ability (response time), is an important aspect of balance control, we evaluated the changes in the response time cost between the LOS and MCT tests, for both groups (practitioners and non-practitioners) x motor tasks compared using 2×2 ANOVAs. Significant test (LOS and MCT tests) x group interactions were resolved with post hoc t-tests. Age, weight, and height were compared between the Yoga practitioners and the age similar non-practitioners using independent t-tests. A χ^2 test was used to compare the sex distributions of the groups. Analyses were performed using the SPSS version 17.0 of the commercially available Statistical Package for the Social Sciences (SPSS).

3. Results

The Yoga practitioners and age similar non-practitioners were similar in demographics (age, gender, and height) and are represented in Table 1. The cognitive measure, the number of correct cognitive responses from the total number of responses, were computed and presented for two groups for the ST and the DT conditions (Table 2).

3.1. Effect of dual-tasking on balance performance

A significant group (practitioners and non-practitioners) x motor tasks (LOS, MCT, and SOT tests) was observed [F(2,40) = 22.205, (p < 0.001)]. There was a significant main effect of type of motor task cost on the LOS, MCT and SOT test (movement velocity, weight symmetry and equilibrium respectively) with [F(2,40) = 13.152, (p = 0.01)] and a main effect of group with
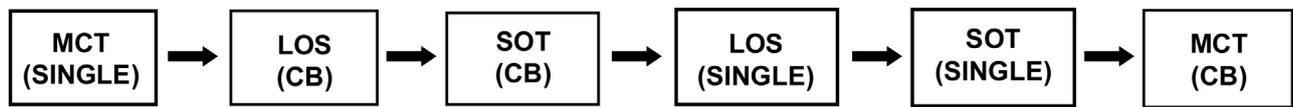
Fig. 2. Schematics of the study design for the balance test. MCT (SINGLE) = Motor control test with single task, LOS (SINGLE) = Limits of stability with dual-task (counting backward), SOT = Sensory organization test with dual-task (counting backward), LOS (SINGLE) = Limits of stability with single task, SOT (SINGLE) = Sensory organization test with single task, MCT = Motor control test with dual-task (counting backward).

Table 2
Raw scores of cognitive responses for Limits of Stability, Motor Control and Sensory ⌒Organization tests Yoga practitioners and age similar non-Yoga practitioners.

Variable		LOS		MCT		SOT	
		Single	Dual	Single	Dual	Single	Dual
Total responses	Y	3.6 ± 0.76	3.92 ± 1.49	7.86 ± 2	7.5 ± 2.4	7 ± 1.63	5.5 ± 1.98
	NY	4.6 ± 1.54	4.5 ± 1.66	6.79 ± 2.15	5.07 ± 1.66	6 ± 2.63	5.07 ± 1.20
Wrong responses	Y	0.14 ± 0.36	0.5 ± 0.94	2.28 ± 1.54	2.42 ± 2.44	1 ± 1.03	2 ± 1.09
	NY	0.5 ± 0.75	2.86 ± 0.67	1.64 ± 0.92	1.46 ± 1.2	1.43 ± 1.22	1.79 ± 1.25
Correct responses	Y	3.57 ± 0.76	3.92 ± 1.5	7.9 ± 2	7.5 ± 2.4	6.9 ± 1.98	6.29 ± 2.16
	NY	4.5 ± 1.65	2.2 ± 0.42	5.57 ± 1.79	3.6 ± 1.16	4.6 ± 1.5	3.2 ± 1.2

LOS = Limits of stability, MCT = Motor control test, SOT = Sensory organization test, Y = Yoga practitioners, NY = non-Yoga practitioners.
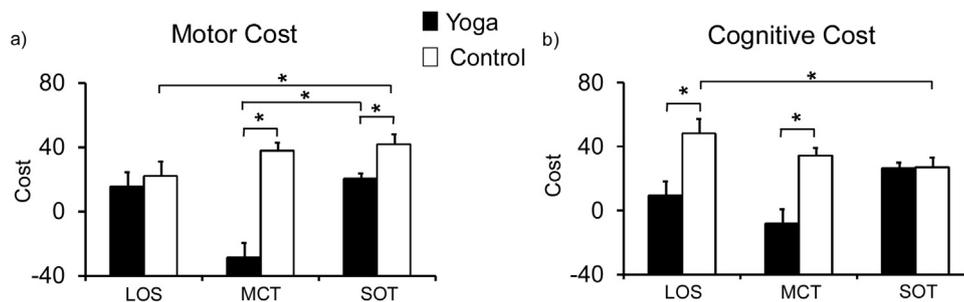
Fig. 3. Comparison of Motor cost between the Yoga practitioners and age similar non-practitioners for single and dual-task in Limits of Stability, Motor Control and Sensory Organization test condition 6 for spatial variables (Movement Velocity, Weight Symmetry, Equilibrium) (a) Motor Cost (b) Cognitive Cost.
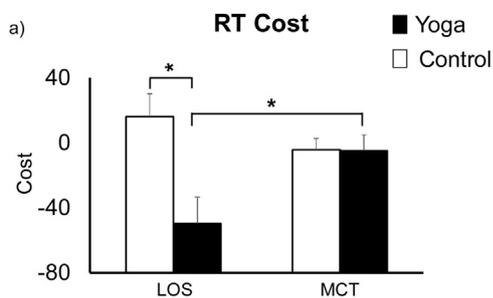
Fig. 4. Comparison of Response time cost between the Yoga practitioners and age similar non-practitioners for single and dual-task in Limits of Stability and Motor Control tests.

$[F(1,20) = 4.808, (P = 0.04)]$. Post-hoc analyses revealed that the control group demonstrated significantly higher motor cost for the SOT in comparison with the LOS test ($p = 0.001$). On the other hand, Yoga practitioners demonstrated a significant lower motor cost on MCT compared with the SOT test ($p = 0.001$). The between-group analysis indicated that the non-practitioners in comparison to the Yoga practitioners group had higher motor cost for both MCT ($p = 0.002$) and SOT tests ($p = 0.001$) Fig. 3a. There was a significant task (LOS and MCT tests) x group interaction $[F(1,19) = 9.337$ ($p = 0.008$)] observed for the response time. The Yoga practitioners had a significantly greater cost (more negative values) during the LOS in comparison to the MCT task ($p = 0.04$). For between-group analyses, the control group had a significantly greater cost for the LOS task ($p = 0.03$) with no difference for the MCT test Fig. 4.

3.2. Effect of dual-tasking on cognitive performance

Cognitive cost across the three balance tasks differed between the groups, observed by a significant group x task interaction with $[F(2,40) = 2.481, (p = 0.04)]$. There was also significant main effect of dual-tasking on cognitive cost with $[F(2,40) = 1.339 (p = 0.04)]$. A significant difference in cognitive cost was observed between the groups $[F(1,20) = 12.428, (p = 0.002)]$. Post-hoc comparisons showed that the non-practitioners group had a significant lower cognitive cost for SOT test in comparison to LOS test ($p = 0.002$), while the Yoga practitioners did not show any difference on cognitive costs across the three balance tasks. Between groups analysis showed that the Yoga practitioners had significantly lower cognitive cost for both LOS ($p = 0.04$) and MCT ($p = 0.03$) tasks in comparison with age similar non-practitioners (Fig. 3b).

4. Discussion

This study explored the effects of Yoga on reducing CMI for maintaining balance control during varied balance tasks while each of them was concurrently performed with a working memory function task. The results, as hypothesized, demonstrated that Yoga practitioners displayed improved motor and cognitive cost on symmetrical body-weight distribution during the Motor Control test (MCT – reactive balance control). Yoga practitioners also had increased motor cost indicated by decreased center of pressure sway in stance during Sensory Organization test (SOT –posturography task with conflicting somatosensory and visual information) with no difference in cognitive cost in comparison to their age-matched non-practitioners. During dual-tasking on

the Limits of stability test (LOS –intentional balance control), Yoga practitioners demonstrated better cognitive control with no difference in motor cost compared to their age-matched counterparts.

4.1. Intentional balance control task between groups

While dual-tasking, the Yoga practitioners performed similarly to non-practitioners on the intentional balance control task (no different in motor cost) but displayed comparatively higher performance on the cognitive task with lower cognitive cost for this task. The increased cognitive ability while dual-tasking could have been due to automatization of the balance control task. Execution of Yoga practice requires the employment of intentional balance control.[27,28] Through regular practice, intentional balance control may have turned out to be almost automatic with limited involvement of cognitive resources among Yoga practitioners. Consequently, allowing more allocation of the available attentional resources towards cognitive performance.[29] In line with our results, recent studies have also shown that in a situation requiring performance of a complex cognitive task, concurrently with an excessively learned task, individuals tend to prioritize the performance of the cognitive task and the allotment of attentional capacity can be regulated voluntarily.[30] In addition to the prioritization of the cognitive task and automatization of the balance control task, Yoga practice positively influences executive function measures of working memory capacity.[16,17] Thus, all the above findings suggest that Yoga practice could have helped to increase performance on the cognitive task.

4.2. Reactive balance control task between groups

Lower motor and cognitive costs for the MCT task suggests significantly better performance on both symmetrical body-weight distribution and cognitive task while dual-tasking among the Yoga practitioners in comparison with the non-practitioners. It may be possible that symmetrical body-weight distribution is improved with training and the Yoga practitioners gain the training-induced ability to allocate better allocation of attentional resources toward the cognitive task.[31] Similar to the above results recent studies has shown that Yoga practice provides the potential for weight shift training, resulting in an improved symmetry in weight distribution.[32–34]

4.3. Response time cost on intentional and reactive balance control task between both groups

During dual-tasking, the Yoga practitioners showed a significantly lesser response time cost (higher performance) for intentional balance control task, while exhibited equal response time (similar performance) on the reactive balance control task in comparison to their age-matched counterparts. Although there are no studies that investigate response time on voluntary balance control, other studies have examined auditory, visual and execution response time for various other tasks and have shown improvement with Yoga practice.[32–34] Given the distinct neural pathway,[35–38] CMI among both intentional and reactive balance control and that Yoga practice focuses on voluntarily attaining difference poses it may effectively reduce response time in only intentional balance control and not in automatic reactive balance control system.

4.4. Posturography under conflicting sensory information (both somatosensory and visual conflicts)

Individuals undergoing visual conflict along with a perturbed somatosensory system, are predisposed to a high postural insta-

bility, e.g., walking on a sandy beach.[39–40] An important property of the postural control system is its ability to "down-weight" poor sensory cues and "up-weight" more reliable cues, known as sensory reweighting.[41–43] Sensory reweighting targeted balance training may improve postural stability and thus contribute significantly towards lowering the center of pressure sway path when the balance is perturbed. In line with our results, which demonstrates decreased center of pressure sway on the posturography task with conflicting somatosensory and visual information other studies have also reported improved sensory contribution to postural stability with Yoga practice.[44] These studies have suggested that Yoga practice could have increased the capacity to influence sensory reweighting by the CNS via self-directed attention to postural stability. This corroborates with the principle that Yoga practitioners acquire the ability to allocate attentional resources for multisensory reweighting, which is a critical adaptive ability for an individual to maintain quite standing when sensory conditions change. Albeit, there was no significant difference in cognitive cost while dual – tasking. It could be possible that it was a more a complex task in comparison to the other balance tasks, requiring greater processing resources and considering the fact that training-induced expansion of attentional capacity is not possible, Yoga practitioners used all the resources on the balance over the cognitive task.

4.5. Reason for difference in CMI in varied balance control tasks

The CMI of dual-tasking in this study differed with respect to the type of balance control task performed concurrently with the working memory cognitive task. Yoga practitioners showed significantly reduced CMI on reactive balance control task, exhibiting least motor and cognitive cost in comparison to the other two balance control tasks. This indicates that Yoga practice that encompasses postural symmetry training could generalize to improve body-weight distribution and help restore stability when the balance is perturbed with support surface translations. The motor and cognitive costs for the intentional balance task and the posturography task were comparable among Yoga practitioners. Thus, improvement in intentional balance control as a result of Yoga practice, could have allowed prioritization of the cognitive task lowering its cost.

4.6. Mechanism

In a recent review study, Tang et al.[45] observed an increased anterior cingulate cortex involvement during rest among Yoga practitioners and suggested that this increased involvement could account for an improved executive attention. In another review, effects of Yoga practice on brain wave and structural changes have been reviewed and concluded that breathing, meditation, and posture-based Yoga, increased overall brain wave activity, which has been associated with improvements in cognition.[46] Furthermore, decrease in stress related anxiety attained through Yoga practice, can increase processing efficiency (executive functions involving attentional control: inhibition and shifting) leading to an improved dual-task ability.[47,48]

5. Conclusion

Cognitive-motor interference during dual-tasking has been a significant factor for the occurrence of imbalance and falls.[49] While the positive effect of conventional, multisensory and dual-task training modes on dual-tasking has been recognized, there is still uncertainty of the superiority of one method over the other.[50,51] While, this study had a small sample size and further larger sample size studies are still needed, our findings con-

vey that Yoga practitioners expended fewer motor and cognitive resources, thus, significantly reduce CMI during dual-tasking than non-practitioners. Suggesting long-term Yoga practice could effectively promote the ability to maintain optimal function under challenging dual-tasking conditions.

Conflict of interest

No commercial party having a direct financial interest in the research findings reported here has conferred or will confer a benefit on the authors or on any organization with which the authors are associated.

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