Journal of Medical Imaging and Health Informatics
Vol. 6, 1–3, 2016

Cortical or Subcortical Neural Networks During Dynamic Neuromuscular Core Stabilization: A fMRI Blood Oxygen-Level Dependent (BOLD) Analysis

Do Hyun Kim[1], Jae Jin Lee[2], Bong Soo Han[3,*], and Joshua H. You[2,*]

[1] *HIP and MAL Lab., Department of Rehabilitation Science, Inje University, Gimhae, Republic of South Korea*
[2] *Movement Healing Lab., Department of Physical Therapy, Yonsei University, Wonju, Republic of South Korea*
[3] *Department of Radiological Science, Yonsei University, Wonju, Republic of South Korea*

Background: While core stabilization techniques, abdominal drawing-in maneuver (ADIM) and dynamic neuromuscular stabilization (DNS) have recently been recognized as a powerful technique to mitigate or improve various medical conditions, the issue of whether the cortical or subcortical neural network contributes to dynamic neuromuscular core stabilization (yoga-like DNS breathing vs. ADIM) remains unknown. *Objectives*: To investigate the neural substrates mediating subconscious, implicit and conscious, explicit core stabilization exercises including abdominal drawing-in maneuver (ADIM) and dynamic neuromuscular stabilization (DNS) in individuals with core instability using fMRI. Design: Single case study. Settings: A major university hospital. Participant: A non-symptomatic participant with core instability. Intervention: All participants underwent conscious ADIM, conscious ADIM with hip flexion and extension (ADIM-HFE), subconscious HFE, and subconscious DNS-based HFE core stabilization exercise training. *Outcome Measures*: A 3T fMRI was used to determine cortical or subcortical activation during a series of implicit or explicit core stabilization tasks at an uncorrected $p < 0.001$. *Results*: During conscious ADIM, the contralateral primary motor area was activated. However, during subconscious DNS-based HFE, the subcortical thalamus and basal ganglia (BG) were activated along with the contralateral primary motor area. *Conclusion*: This is the first clinical evidence highlighting dissociated roles in cortical and subcortical neuromotor control mechanisms underpinning implicit and explicit core stabilization exercises.

Keywords: Core Stabilization, Brain Signals and Imaging, fMRI, Subcortical Structure.

1. INTRODUCTION

Core stabilization techniques, abdominal drawing-in maneuver (ADIM) and dynamic neuromuscular stabilization (DNS) have recently been recognized as a powerful technique to mitigate or improve various medical conditions, including back pain,[1] anxiety and depression, hypertension,[2] stress,[3] and general well-being.[4] The ADIM has gained widespread acceptance among many clinicians as the most effective strategy to improve the core stability of the lumbopelvic system.[5] In fact, ADIM, which involves a conscious activation of the deep abdominal core muscle (e.g., transverses abdominals and internal oblique) via a feedback mechanism, resulted in a remarkable reduction in back pain[6,7] and cortical reorganization of the pain matrix in a single case with chronic low back pain.[1] On the other hand, DNS involves automatically activates the diaphragm along with deep abdominal muscles prior to any purposeful human movement via a feedforward mechanism.[8] Janda first theorized that core stabilization associated with postural movement is primarily controlled by the subcortical motor network.[9] Horak and Nashner[10] demonstrated that a postural stability response occurred 73–110 ms after the perturbation, indicating that postural reaction is an automatic, involuntary response at the subcortical level rather than a cortical voluntary one.[10] Similarly, Hodges et al.[11] investigated the anticipatory postural response before shoulder movements and found that TrA was activated 3–15 ms prior to the initiation of the shoulder flexion motion.[11,12] This finding suggests that the central nervous system (CNS) anticipates movement via a feedforward mechanism and automatically stabilizes the entire lumbopelvic core musculature to provide a constant base for dynamic movements, such as reaching and locomotor tasks.[1] However, the issue of whether the cortical or subcortical neural network contributes to dynamic neuromuscular core stabilization (yoga-like DNS breathing vs. ADIM) remains unknown due to the inherent difficulty of dissociating cortical and subcortical motor learning and performance. The present study was to investigate the neural substrates mediating

*Authors to whom correspondence should be addressed.

subconscious, implicit and conscious, explicit core stabilization exercises in individuals with core instability using fMRI.

2. METHODS

2.1. Participant

This is a single case study design where the subject was 25 years old Asian female with core instability participated in the experiment approved by the Institutional Review Board (2012-09). Core instability was determined by an ability to stabilize the target pressure levels (64–70 mmHg) during the straight leg lowering test.[13]

2.2. Intervention

Prior to the fMRI experimental tasks, the participant performed the four different core stabilization exercises for 30 minutes each day for three consecutive days and successfully completed the intervention. The core stabilization exercises included (1) conscious ADIM, (2) conscious ADIM with hip flexion and extension (ADIM-HFE), (3) subconscious hip flexion and extension (HFE), and (4) subconscious DNS-based HFE. Specifically, the conscious ADIM task involved consciously drawing his or her belly button back towards the spine so that the pressure recorded from the pressure biofeedback unit (PBU) located underneath the lumbar spine increased by 4–10 mmHg from its starting point of 40 mmHg. The subconscious HFE task required the participant to perform a cyclic hip flexion and extension movement (70° to 90° range). The subconscious DNS-based HFE exercise involved the maintenance of the target pressure (20 mmHg) under the PBU, which was placed under the heel, while performing the same cyclic HFE. The real time ultrasound biofeedback was provided for accurate core training.[13] Figure 1 represents the experimental fMRI paradigm for core stabilization tasks.

2.3. fMRI Data Acquisition

3T Philips Achieva fMRI scanner (Philips, the Netherlands) was used to determine neural substrates by measuring fMRI blood oxygen-level dependent (BOLD) signals.[14] A block paradigm included 30 seconds of control with 30 seconds of stimulus at a frequency of 0.5 Hz and was repeated three times for each core stabilization task.

All data were acquired using an eight-channel phased array head coil. Thirty axial images parallel to the anterior commissure (AC)-posterior commissure (PC) line were acquired using a single-shot echo-planar imaging (EPI) sequence (TR/TE = 3000/35 ms, flip angle 90°, FOV = 220 × 220 mm2, scan matrix = 80 × 79 (reconstruction matrix = 128 × 128), slice thickness = 4 mm and no gap). T1-weighted anatomic images were obtained using a conventional spin echo sequence with the following imaging parameters: TR/TE = 385/10 ms, flip angle = 90°, FOV = 220 × 220 mm2, scan matrix = 224 × 232 (reconstruction matrix = 512 × 512), slice thickness = 4 mm, and the same slice positions as those of the fMRI images. SPM2 software was used to analyze the fMRI data using an 8-mm Gaussian kernel and then co-registered to the T1-weighted structural image.

Fig. 1. Experimental fMRI paradigm.

Table I. Cortical activation patterns during four different core stabilization exercises.

Conscious		Subconscious	
ADIM	ADIM-HFE	HFE	DNS-based HFE
Motor cortex (trunk)	Motor cortex (trunk and leg)	Motor cortex (trunk, leg), caudate nucleus, putamen	Thalamus, hypothalamus, globus pallidus, caudate nucleus, cerebellum

Notes: ADIM: Abdominal draw-in maneuver, HFE: Hip flexion and extension, DNS: Dynamic neuromuscular stabilization.

Significant voxels were obtained by applying a criterion of an uncorrected p-value of less than 0.001.

3. RESULTS

Table I represents the cortical activation patterns during different core stabilization exercise paradigms. During conscious ADIM, the contralateral primary motor area that topographically represents the abdomen was activated. In conscious ADIM-HFE, the contralateral primary motor area was activated. However, during subconscious HFE, the contralateral primary motor area topographically representing the leg was activated in a participant. During subconscious DNS-based HFE, the subcortical activation in the thalamus and BG was activated (Fig. 2).

4. DISCUSSION

The present investigation is the first evidence demonstrating neural substrates and networks underpinning core stabilization paradigms such as yoga, pilates, and abdominal drawing-in maneuver. Most importantly, a subcortical motor control network was selectively activated during the "involuntary" subconscious HFE and DNS-based HFE, whereas a cortical motor network was utilized during other "voluntary" conscious ADIM and ADIM-HFE motor tasks.

Our neuroimaging data are consistent with Lazar et al.'s finding that reported increased cortical activations in the right anterior insula, right middle and superior frontal sulci and left superior temporal gyrus amongst the long-term "voluntary" mediators than in controls.[15] Such cortical reorganization is intriguing because these areas underlie attention, emotions, and sensory perception and motor control processes. In fact, abdominal breathing core exercise helped mitigate stress-related emotional responses and depression[16] as well as inhibit the perception of noxious or pain sensory stimuli.[1] However, the results in the present study are also distinguished in that we found

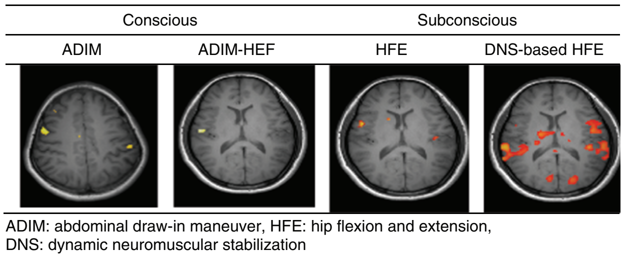

Fig. 2. fMRI BOLD analysis of the neural activation pattern during the four different core stabilization exercises: (1) Conscious ADIM, (2) conscious ADIM-HFE, (3) subconscious HFE, and (4) subconscious DNS-based HFE.

greater overall activations in the subcortical network rather than the cortical network during the subconscious DNS-based HFE paradigm when compared to actual meditation. In the present study, fMRI BOLD signals recorded during the subconscious DNS-based HFE paradigm showed increased activations in the thalamus and basal ganglia along with the cerebellum, representing subcortical network involvement. During the conscious ADIM and ADIM-HFE tasks, the contralateral primary motor area that topographically represents the abdomen was activated. The anterior cingulate and anterior insular cortices were also activated during the subconscious DNS-based HFE. Similarly, this subcortical network activation was consistently observed in other neuroimaging studies, which showed significantly increased activations in the anterior cingulate cortex, anterior insular cortices, midbrain, pontine raphe magnus, amygdala, and the brainstem.[16,17] This subcortical network may account for the regulation of respiration as seen during the yoga-like DNS core stabilization exercise. Recently, Tsao et al.[18] examined cortical changes underlying the postural motor control impairment in recurrent low back by concurrently assessing onset of TrA EMG during single rapid arm flexion and extension tasks and motor thresholds (MTs) using transcranial magnetic stimulation (TMS). MTs were determined by measuring responses to TrA to TMS over the contralateral cortex, which were mapped during voluntary contractions at 10% of maximal contraction, were compared between normal and low back pain groups. Cortical map was shifted to more posterior and lateral in the LBP group than normal controls. The MTs required to evoke responses ipsilateral to the stimulated cortex was substantially lesser in the LBP group than the normal controls, suggesting altered cortical organization in individuals with recurrent low back.[18] However, our fMRI findings showed that postural control associated with core stabilization is not only mediated by cortical motor network, but also modulated by subcortical motor network depending on subconscious or implicit motor tasks (i.e., subconscious HFE or DNS-based HFE) versus explicit, explicit motor tasks (i.e., conscious ADIM or ADIM-HFE). Certainly, the present study provides important theoretical and therapeutic foundation for neuromotor control (cortical vs. subcortical) and learning (subconscious, implicit vs. conscious, explicit) associated with core stabilization in individuals with core instability. In the experiment, subconscious tasks were performed after conscious tasks. In future, it would be of great interest to examine neural activation patterns if the tasks were counterbalanced.

5. CONCLUSION

Collectively, these results suggest that the primary motor cortex plays an important role in the "voluntary" core stabilization paradigm, but the basal ganglia and cerebellum constitute a crucial role during the "involuntary or automatic" core stabilization paradigm. Our novel fMRI BOLD neuroimaging paradigm was useful in deciphering the underlying neural substrates and control mechanisms for core stabilizations. A careful interpretation should be made when generalizing our findings because we investigated neural substrates underlying different implicit and explicit core stabilization exercises in a individual with core instability.

References and Notes

1. G. L. Moseley, Widespread brain activity during an abdominal task markedly reduced after pain physiology education: fMRI evaluation of a single patient with chronic low back pain. *Aust. J. Physiother.* 51, 49 **(2005)**.
2. R. Mamtani and R. Mamtani, Ayurveda and yoga in cardiovascular diseases. *Cardiol. Rev.* 13, 155 **(2005)**.
3. J. A. Astin, Stress reduction through mindfulness meditation. *Psychother. Psychosom.* 66, 97 **(1997)**.
4. S. N. Culos-Reed, L. E. Carlson, L. M. Daroux, and S. Hately-Aldous, A pilot study of yoga for breast cancer survivors: Physical and psychological benefits. *Psychooncology* 15, 891 **(2006)**.
5. B. K. Hölzel, J. Carmody, M. Vangel, C. Congleton, S. M. Yerramsetti, T. Gard, et al., Mindfulness practice leads to increases in regional brain gray matter density. *Neuroimaging* 191, 36 **(2011)**.
6. D. S. Teyhen, C. E. Miltenberger, H. M. Deiters, Y. M. Del Toro, J. N. Pulliam, J. D. Childs, et al., The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. *J. Orthop. Sports Phys. Ther.* 35, 346 **(2005)**.
7. P. H. Ferreira, M. L. Ferreira, C. G. Maher, K. Refshauge, R. D. Herbert, and P. W. Hodges, Changes in recruitment of transversus abdominis correlate with disability in people with chronic low back pain. *Br. J. Sports Med.* 44, 1166 **(2010)**.
8. D. D. Juehring and M. R. Barber, A case study utilizing vojta/dynamic neuromuscular stabilization therapy to control symptoms of a chronic migraine sufferer. *J. Bodyw. Mov. Ther.* 15, 538 **(2011)**.
9. P. Page, C. Frank, and R. Lardner, Assessment and treatment of muscle imbalance: The Janda approach: Human Kinetics; **(2010)**.
10. F. B. Horak and L. M. Nashner, Central programming of postural movements: Adaptation to altered support-surface configurations. *J. Neurophysiol.* 55, 1369 **(1986)**.
11. P. Hodges, A. Cresswell, and A. Thorstensson, Preparatory trunk motion accompanies rapid upper limb movement. *Exp. Brain Res.* 124, 69 **(1999)**.
12. P. W. Hodges and C. A. Richardson, Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. *Arch. Phys. Med. Rehabil.* 80, 1005 **(1999)**.
13. C. Richardson, P. Hodges, and J. Hides, Therapeutic exercise for lumbopelvic stabilization: A motor control approach for the treatment and prevention of low back pain. *Churchill Livingstone* **(2004)**.
14. N. Harel, S.-P. Lee, T. Nagaoka, D.-S. Kim, and S.-G. Kim, Origin of negative blood oxygenation level–dependent fMRI signals. *Metabolism* 22, 908 **(2002)**.
15. S. W. Lazar, C. E. Kerr, R. H. Wasserman, J. R. Gray, D. N. Greve, M. T. Treadway, et al., Meditation experience is associated with increased cortical thickness. *Neuroreport* 16, 1893 **(2005)**.
16. D. L. Cohen, N. Wintering, V. Tolles, R. R. Townsend, J. T. Farrar, M. L. Galantino, et al., Cerebral blood flow effects of yoga training: Preliminary evaluation of 4 cases. *J. Altern. Complement Med.* 15, 9 **(2009)**.
17. K. C. Evans, D. D. Dougherty, A. M. Schmid, E. Scannell, A. McCallister, H. Benson, et al., Modulation of spontaneous breathing via limbic/paralimbic–bulbar circuitry: An event-related fMRI study. *Neuroimage* 47, 961 **(2009)**.
18. H. Tsao, M. Galea, and P. Hodges, Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. *Brain* 131, 2161 **(2008)**.

Received: 22 February 2016. Revised/Accepted: 11 April 2016.