Journal of Psychology and Neuroscience

Dissecting The Meta-Awareness Process for Physical and Psychological Pain Through Yoga from Neurological and Biological Perspectives

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Submitted : 28 Nov 2024 ; **Published :** 10 Dec 2024

Citation: Shiota, S. (2024). Dissecting The Meta-Awareness Process for Physical and Psychological Pain Through Yoga from Neurological and Biological Perspectives. J Psychol Neurosci; 6(4):1-9. DOI : https://doi.org/10.47485/2693-2490.1097

Abstract
Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage. The statement of "sensory and emotional experience" means pain not only has sensory-discriminative (physical pain), but also psychological-discriminative, including emotional-affective, cognitive-evaluative, and spiritual dimensions (psychological pain). Both types of pain involve neural bases, such as the insula and central nervous system, and its activities are modulated by the autonomic nervous system, which is one of the peripheral nervous systems, and enkephalin and oxytocin, which are endogenous opioids or hormones. Individuals with physical and psychological pain have increased sympathetic activity and decreased enkephalin and oxytocin levels. Although yoga is an effective intervention for physical and psychological pain, little is known about its regulatory mechanisms. In this article, I focus on the cervical spine, thoracic spine, lumbar spine, and pelvis during asana and explain the role of the asana in driving them from neurological and biological perspectives. I then discuss the effects of yoga breathing techniques on the autonomic nervous system and hormones. Existing evidence suggests that the insula, the autonomic nervous system, enkephalin, and oxytocin are related to the recovery mechanisms of yoga for pain. From a psychological perspective, the insula, autonomic nervous system, enkephalin, and oxytocin are related to awareness of one's inner experiences (metacognition). This is similar to picking the ice surface with something that does not have a non-slip device. Yoga causes changes to the body's internal environment. This is similar to picking up an uneven surface with a non-slipping object. Basic and clinical studies based on this article should be conducted in the future. In conclusion, interventions with yoga based on this research will help people suffering from physical and mental illnesses.

Keywords: Yoga; insula; autonomic nervous system; enkephalin; oxytocin.

Neurological and Biological Bases of Physical and Psychological Pain (Fig. 1)

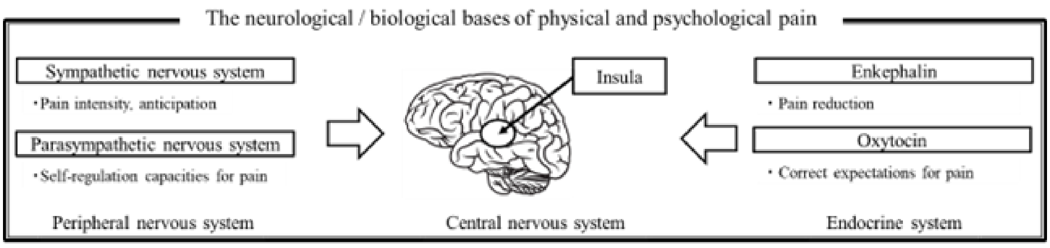

Figure 1: Neurological and biological bases of pain:

Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage (IASP Subcommittee on Taxonomy, 1979). The statement of "sensory and emotional experience" means pain not only has sensory-discriminative (physical pain), but also psychological-discriminative, including emotional-affective, cognitive-evaluative, and spiritual dimensions (psychological pain).

Numerous studies have elucidated the neurological and biological bases of both physical and psychological pain (Boss et al., 2015; Critchley et al., 2002; Forte et al., 2022; Herpertz et al., 2019; Hoeppli et al., 2022; Jauniaux et al., 2019; Seifert et al., 2013; Timäus et al., 2021; Vreijling et al., 2021; Younger et al., 2021).

For the neurological bases of physical pain, a study (Hoeppli et al., 2022) detected that in brain areas, including the putamen, caudate nucleus, secondary somatosensory cortex, insula, anterior cingulate cortex, and dorsolateral prefrontal cortex, there was increased activation corresponding to pain, whereas in the amygdala and hippocampus, primary somatosensory cortex, posterior cingulate cortex, and presumes, there was decreased activation corresponding to pain. According to a review (Forte et al., 2022), physical pain increases with sympathetic activity. Higher parasympathetic activity was associated with a better self-regulation capacity for physical pain. These results suggest a relationship between physical pain and the autonomic nervous system. (Seifert et al., 2013) examined the relationship between physical pain and brain and autonomic nervous activity. They revealed significant positive correlations between brain activity in the insula, ventrolateral prefrontal cortex, dorsolateral prefrontal cortex, and sympathetic activity during both physical pain experience and pain anticipation. The biological foundation of physical pain was proposed to be associated with enkephalin and oxytocin (Younger et al., 2021). Enkephalin is an endogenous opioid produced by the adrenal medulla, released into the blood across the blood–brain barrier, and transported to the brain, where it binds specifically to opioid receptors. Its main effects include analgesia, body temperature regulation, and feeding behavior. The brain areas with opioid receptors that bind to enkephalin include the lateral prefrontal cortex, cingulate cortex, insula, thalamus, and amygdala (Zubieta et al., 2001). Enkephalin produces analgesia with fewer adverse effects than those associated with conventional opioids (Hohenwarter, 2023). (Younger et al., 2009) examined the effects of low-dose naltrexone, an opioid antagonist used to treat alcohol and substance dependence in individuals with fibromyalgia symptoms. Low-dose naltrexone increases endogenous opioids such as enkephalin. (Younger et al., 2009) reported that low-dose naltrexone reduced fibromyalgia symptoms in the entire cohort, with a greater than 30% reduction in symptoms compared to that associated with placebo. Oxytocin is a hormone produced in the hypothalamus by the posterior pituitary gland and is induced by enkephalin (Hirose et al., 1997). Oxytocin is related to trust and empathy and its receptor is located in the insula (Wigton et al., 2015). (Herpertz et al., 2019) revealed that intranasally administered oxytocin increased correct expectations for physical pain and that there was a positive correlation between inter-individual differences in activation in the insula and inter-individual differences in correct expectations for physical pain.

One meta-analysis (Jauniaux et al., 2019) revealed that dorsolateral prefrontal cortex, anterior cingulate cortex, temporo-parietal junction, insula, fusiform gyrus, cerebellum, thalamus, amygdala, and striatum were related to neurological bases of psychological pain. (Vreijling et al., 2021) reported that psychological pain decreases the parasympathetic activity. (Critchley et al., 2002) investigated the relationship between psychological pain and brain and autonomic nervous activity. They demonstrated that patients with autonomic denervation had decreased conditioning-related activity in the insula when they watched threat stimuli. Consequently, (Critchley et al., 2002) suggested that the expression of conditioning-related neural activity is modulated by representations of the bodily states of autonomic arousal. (Timäus et al., 2021) showed that a low-dose of naltrexone improved psychological pain. (Bos et al., 2015) examined the effects of intranasal oxytocin for psychological pain. They reported that pain-related activation in the neural circuitry of pain, specifically in the insula, was strongly reduced after intranasal oxytocin administration. The authors suggested that oxytocin remarkably decreased psychological pain.

Therefore, physical and psychological pain may have a similar neurological and biological basis. Interestingly, pain involves neural bases, such as the insula and central nervous system, and its activities are modulated by the autonomic nervous system, which is a peripheral nervous system, and enkephalin and oxytocin, which are endogenous opioids or hormones. Hence, interventions that modulate the autonomic nervous system, endogenous opioids, and hormones may reduce physical and psychological pain. It may also lead to improved symptoms of physical (e.g., lower back pain and chronic pain) or mental illness (e.g., self-injury and post-traumatic stress disorder). Yoga is attracting attention as an intervention for physical and psychological pain (Davis et al., 2020; Zhu et al., 2020). However, little is known about the yoga recovery processes. This article explains the role of asana (pose) and breathing techniques, which are components of yoga practice. Furthermore, the recovery process after yoga from a neurological and biological perspective has also been discussed.

Effects of Yoga on Health Problems

The body-mind approach focuses on the relationships between the brain, mind, body, and behavior, and their effects on health and disease. Yoga is a body-minded approach. The conceptual background of yoga originates from ancient Indian philosophy (Büssing et al., 2012). Yoga is constructed through the practice of asana (postures), pranayama (breathing techniques), and meditation (Shiota & Nomura, 2018). Yoga is growing worldwide (Singh, 2017). Yoga has become widely known and has been used for the treatment and management of symptoms of chronic physical or mental health conditions such as post-traumatic stress disorder (Cramer et al., 2018; Macy et al., 2018), low back pain (Holtzman & Beggs, 2013). breast cancer (Cramer et al., 2012), headache (Anheyer et al., 2020), pregnancy (Corrigan et al., 2022), asthma (Singh et al., 2023), substance use (Walia et al., 2021), and mild cognitive impairment (Brenes et al., 2019).

(Villemure et al., 2014) examined the relationships between yoga experience and pain tolerance for the effects of yoga on the central and peripheral nervous systems. They reported that the gray matter volume of the insula was positively correlated with pain tolerance. In addition, yoga practitioners have increased gray matter volume in the insula compared to those observed in controls. Gray matter volume in the insula was positively correlated with the duration of yoga experience. (Krishna et al., 2014) examined the effects of yoga in patients with heart failure. They demonstrated that the LF and LF-HF ratios significantly decreased in the intervention group and significantly increased in the HF group compared to those observed in the control group. Christa et al., (2019) investigated the effects of yoga in individuals with myocardial infarction. The yoga group had significantly increased HF levels compared to those observed in the control group.

As effects of yoga for one's biological bases, previous studies (Hareni et al., 2023; Posadzki & Ernst, 2011) have suggested that yoga increases one's enkephalin. (Uebelacker et al. (2019) performed an intervention using yoga in individuals with opioid-dependent disorders. They reported that participants had significantly improved anxiety and pain after the intervention compared to that at the baseline. (Dhawan et al., 2015) examined the effects of yoga on quality of life in individuals with opioid-dependent disorders. They reported that the intervention group had significantly enhanced physical, psychological, and environmental domains of quality of life compared to those observed in the pre-intervention group. Varshney et al. (2021) also revealed that yoga intervention increased endorphin levels in individuals with opioid-dependent disorders. Jayaram et al., (2013) demonstrated that yoga intervention increased oxytocin levels in individuals with schizophrenia.

Therefore, yoga is an effective intervention for the treatment and management of symptoms related to chronic physical or mental health problems. However, the yoga process that contributes to health, especially the role of the asana in these processes, is not well understood. In the next section, I will focus on the cervical spine, thoracic spine, lumbar spine, and pelvis and explain the role of the asana that drives them for one's regain process from an anatomical perspective.

Role of Asana on One's Regain Process

Asana points to specific physical postures that involve using the entire body during yoga practice (Shiota & Nomura, 2018). These physical postures are categorized as standing, seated, and supine; they also include forward folds, forward bends, back bends, hip openers, twists, and inversions (Schmalzl et al., 2015). For example, in a downward dog, the person places both hands and feet on the floor, raises the buttocks, and forms a triangle with entire body. They then brought their faces and upper bodies closer to their feet. During the lord of the fishes, the participants sat in a long seat, bent the right leg, raised the left leg at the knee, straddled the right leg and hooked it outside the thigh. Asanas move their whole body. To elucidate the role of the asana in regaining, I will explain the anatomy of the cervical spine, thoracic spine, lumbar spine, and pelvis, which move in accordance with the practice of the asana.

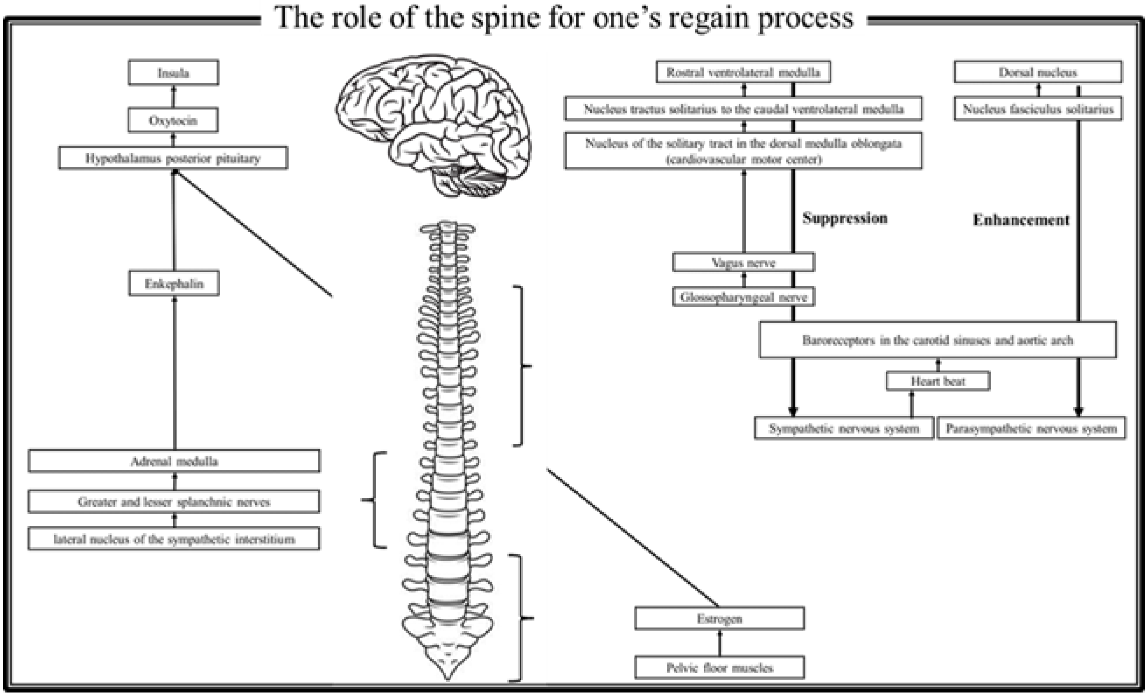

Figure 2: Relationships between one's spine and regain process:

Anatomical features of the cervical spine

The cervical spine supports the skull and is involved in movements such as forward and backward bending and rotation. The sternocleidomastoid muscle is on the side of the cervical spine. The sternocleidomastoid muscle is innervated by the accessory nerve, which functions similarly to the parasympathetic nerve. It originates from the sternum and clavicle, and ends at the mastoid process of the temporal bone. Similar to the cervical spine, the sternocleidomastoid muscle is involved in forward and backward bending and rotation.

Previous studies (Lu & Chao, 2019; Matsui et al., 2020; Wende & Markowitz, 2021) have reported the relationship between the sternocleidomastoid muscle and the autonomic nervous system. For example, Lu and Chao (2019) indicated that a relationship between sternocleidomastoid muscle abnormalities and tinnitus. Wende and Markowitz (2021) reported a relationship between sternocleidomastoid muscle abnormalities and continuous migraine. (Matsui et al., 2020) also revealed that abnormalities in neck muscles, including the sternocleidomastoid muscle, lead to the onset of autonomic nervous system imbalance. Therefore, neck exercises that relax the sternocleidomastoid muscle may improve the autonomic nervous system function.

Anatomical features of the thoracic spine

Considering the anatomical features of the thoracic spine, the spine and autonomic nervous system are exercised by twisting the upper body. T2 thoracic spine exercise stimulates the sympathetic nervous system. This afferent stimulation was sent to the heart, causing it to beat faster. The increase in blood pressure caused by a faster heartbeat is detected by the baroreceptors in the carotid sinuses and aortic arch. These afferent inputs are input via the glossopharyngeal and vagus nerves to the nucleus of the solitary tract in the dorsal medulla oblongata, which is a cardiovascular motor center. Moreover, this signal was projected from the nucleus tractus solitarius to the caudal ventrolateral medulla, and from the caudal ventrolateral medulla to the rostral ventrolateral medulla. Eventually, sympathetic nerve activity is suppressed. Simultaneously, the afferent input detected by the baroreceptors is the input from the nucleus fasciculus solitarius to the nucleus simulant and dorsal nucleus of the vagus nerve. The nucleus susceptor and dorsal nucleus of the vagus nerve project to the cardiac parasympathetic nerves, and the activity of the parasympathetic nerves increases. In a study that supported this hypothesis, Minarini et al., (2018) examined the effect of thoracic spine manipulation in the thoracic spine T5 on one's autonomic nervous system. Consequently, rMSSD, which is an index of heart rate variability that reflects parasympathetic activity, significantly improved after the intervention compared to that at the baseline. The thoracic spine may be involved in heartbeats and that their drive increases the activity of the cardiac parasympathetic nervous system.

Anatomical features of the lumbar spine

The endocrine system comprises glands and organs that regulate various functions in the body by producing and secreting hormones. The adrenal glands are part of the endocrine system. The adrenal glands are divided into the adrenal cortex, which is controlled by the hypothalamus, and the adrenal medulla, which is controlled by the lateral nucleus of the sympathetic intermediate located between the lumbar spine T5 and T12. For example, exercises of lumbar vertebrae T5–T12 stimulate the lateral nucleus of the sympathetic interstitium. It is input into the adrenal medulla via the greater and lesser splanchnic nerves, where catecholamines (adrenaline) and enkephalins are produced. The effects of catecholamines include vasoconstriction and increased blood pressure and heart rate. Enkephalins specifically bind to opioid receptors and affect analgesia, body temperature regulation, and feeding behavior. In a study that supported this hypothesis, (Steinberg et al., 2000) reported that exercising the spine increases adrenaline in the blood and that lumbar spine T6 is particularly associated with increased amounts of adrenaline. (Sato et al., 2013) revealed that enkephalins are increased by spinal cord stimulation. Therefore, driving the lumbar spine stimulates the endocrine system and produces adrenaline and enkephalin.

Anatomical features of the pelvis

The pelvis is a group of strong bones that supports the body between the femur and spinal column. The pelvis consists of a pair of right and left hip bones, the sacrum, and the coccyx. The pelvic floor muscles are located at the bottom of the pelvis between the coccyx and ischia. The pelvic floor muscles are involved in maintaining the organs in the pelvis, such as the bladder, uterus, and intestines, in the correct position (Bali et al., 2023) and are also involved in estrogen production (Ramadan et al., 2022). For example, Ramadan et al. (2022) reported that training, including squats, which exercise the pelvic floor muscles, increases estrogen levels. Estrogen is an oxytocin-inducing hormone produced in the paraventricular nucleus of the hypothalamus and supraoptic nucleus. The drive of the pelvis, including the pelvic floor muscles, is correlated with organ misalignment and is involved in the production of oxytocin, which is related to childcare (Hiraoka et al., 2020).

During the asana sequences, participants exercised their cervical spine, including the thoracic spine, lumbar spine, and pelvis. Corresponding to these exercises, the functions of the autonomic nervous system may increase, especially the function of the parasympathetic nervous system. It has also been suggested that enkephalins are released into the blood. To speculate on the effects of yoga on physical and psychological pain, these biological changes caused by asana matter the most. Next, I will discuss the effects of breathing techniques on yoga practice.

Recovery Mechanism of Breathing Technique

Everyone must breathe without serious interruptions from birth to death (Del Negro et al., 2018). In healthy and at rest, breathing occurs naturally, effortlessly, and without thought (Del Negro et al., 2018). Fast-cycle breathing activates the sympathetic nervous system, and slow-cycle breathing activates the parasympathetic nervous system (Sinha et al., 2013; Spiesshoefer et al., 2022). Changes in breathing due to disease may alter the autonomic nervous system and hormone production (Bellosta-Batalla et al., 2020; Drummond et al., 2013; Perri et al., 2004; Sürücü et al., 2021). For example, in a study that examined changes in breathing due to disease (Perri et al., 2004), patients with chronic pain had faulty breathing patterns. There was a positive correlation between symptom improvement and correct (deep and slow) breathing patterns. Drummond et al. (2013). demonstrated that patients who received patient-controlled morphine analgesia after surgery exhibited abnormal breathing patterns are extremely common. Cyclical airway obstruction is frequent and associated with a typical pattern of changes in chest wall movement. Previous studies have investigated the relationships among changes in breathing, changes in the autonomic nervous system (Sürücü et al., 2021), and slow and controlled breathing exercises that improve parasympathetic activity in individuals. According to a study examining the relationship between changes in breathing and hormone production (Bellosta-Batalla et al., 2020), mindfulness meditation and abdominal breathing increased oxytocin levels.

During yoga practice, participants work on several yoga breathing techniques (prāṇāyāma). (Udupa et al., 2003) showed that the effect of prāṇāyāma training increases parasympathetic activity and decreases sympathetic activity in healthy individuals. Shinha et al., (2013) indicated that Alternate Nostril Breathing that is one of prāṇāyāma enhances parasympathetic activity. To my knowledge, few studies have investigated the effect of yoga breathing techniques on hormone production. Nevertheless, according to a study that examined the relationship between breathing changes and hormone production (Bellosta-Batalla et al., 2020). yoga breathing techniques might have the same effect. Similar to asana, an effect of the yoga breathing technique is the modulation of the autonomic nervous system and the production of hormones. The effects of meditation, a component of yoga, on the autonomic nervous and endocrine systems are well-known (Rådmark et al., 2019; Pascoe et al., 2020). This study omitted these details. In the next section, I discuss the effects of yoga practice on physical and psychological pain.

Effects of Yoga on Physical and Psychological Pain

Yoga is an effective intervention for physical and psychological conditions such as headache (Anheyer et al., 2020), low back pain (Li et al., 2019), self-injurious behavior (Sharma & Sharma, 2016), and post-traumatic disorder (Cramer et al., 2022). Although numerous studies have revealed the effects of yoga on physical and psychological pain, to my knowledge, few studies have demonstrated the mechanisms by which yoga reduces pain. Regarding the neurological regain mechanism of yoga on pain, (Villemure et al., 2014) revealed that yoga practitioners have increased gray matter volume in the insula, the brain area related to pain tolerance, compared to those observed in controls. (Telles et al., 2016) examined the effects of yoga intervention in individuals with chronic low back pain. The yoga group showed a significant decrease in the LF of heart rate variability and an increase in the HF of heart rate variability after intervention compared to that at the baseline. Regarding the biological regain mechanism of yoga on pain, (Uebelacker et al., 2019) examined the effects of yoga intervention on individuals with opioid use. A significant reduction in anxiety and pain was observed among the participants in the yoga group.

These results suggest that the regulatory mechanisms of yoga on pain, insula, autonomic nervous system, enkephalin, and oxytocin are related. Further studies from neurological and physiological perspectives are required to confirm this hypothesis. From a psychological perspective, the insula, autonomic nervous system, enkephalin, and oxytocin are related to awareness of one's inner experiences (metacognition). Yoga and mindfulness meditation have also been hypothesized to enhance metacognition. Nevertheless, I assume that this intervention does not enhance awareness. Instead, yoga is an intervention that changes the body state using peripheral input and makes meta-awareness easier. The next section describes the neurological and biological bases of metacognition. I also discuss the hypothesis of the recovery mechanism of yoga on pain.

Metacognitive Regain Process through Yoga

Metacognition is the cognitive function of objectively monitoring one's inner experiences and emotional events that vary from moment to moment (Kabat-Zinn, 2013). Metacognition refers to thinking and forming integrated ideas about oneself (Bonfils et al., 2019). The insula is involved in the neural correlates of metacognition (Critchley et al., 2004; Qin et al., 2020; Keller et al., 2020) revealed that cardiac variability involves both LF and HF input information for the insular and sensorimotor cortices, and this network is involved in the mechanism of interoceptive awareness. Previous studies have indicated that the endogenous opioid enkephalin reduces metacognition (Sadeghi et al., 2017), while oxytocin enhances it (Aydın et al., 2018).

Yoga interventions are speculated to be distinct from interventions (e.g., metacognitive therapy and behavioral activation) (Baird et al., 2014; Shiota et al., 2017; Valizade et al., 2013) that enhance metacognition itself. Instead, yoga adjusts the internal state of the body so that meta-awareness becomes easier. During asana sequence, the participant's cervical, thoracic, lumbar, and pelvic spines were exercised. Corresponding to these movements, the participant's autonomic nervous system was modulated, and parasympathetic activity was increased. Enkephalins are produced by the adrenal medulla by the asana sequence. Enkephalins are released into the blood across the blood–brain barrier and transported to the brain. Oxytocin, which is related to metacognition, is produced in the hypothalamus by the posterior pituitary gland, and this process is induced by enkephalin. The change in internal state of the body, such as parasympathetic activity, is centrally represented in the posterior insula, and the information in the posterior insula is integrated by the anterior insula (Nguyen et al., 2016). Enkephalin-induced oxytocin increases insular activity. In addition to asana, slow deep breathing in yoga increases parasympathetic activity. Oxytocin are produced through breathing techniques. Therefore, both asana and breathing techniques should adjust the internal state of the body. Individuals with physical and psychological pain show increased sympathetic activity and decreased enkephalin and oxytocin levels. This is similar to picking the ice surface with something that does not have a non-slip device. Yoga causes changes to the body's internal environment. This is similar to picking up an uneven surface with a non-slipping object. Yoga changes the body state by using input from the periphery, making it easier for meta-awareness of physical and psychological pain.

Conclusions

I have discussed the neurological and biological bases of pain as well as the role of asana and breathing techniques that are always used in yoga practice. In particular, the relationships among the insula, autonomic nervous system, enkephalin, and oxytocin are important. Yoga changes the body state by using input from the periphery, making it easier for meta-awareness of physical and psychological pain. I would like to mention some points for future research. To my knowledge, little is known about the relationship between the autonomic nervous system, enkephalin, and oxytocin. Therefore, these relationships require further research. Second, few studies have demonstrated the biological effects of yoga breathing techniques. According to clinical studies (Bellosta-Batalla, et al., 2020) yoga breathing techniques have may affect the endocrine system and hormones. Therefore, these relationships require further analyses. Finally, the role of each asana must be identified from neurological and biological perspectives and structured asana sequences must be developed for several physical and mental illnesses. Basic and clinical studies based on this paper should be conducted in the future. In conclusion, interventions with yoga based on this research will help people suffering from physical and mental illnesses.

Acknowledgment

I would like to thank everyone who has supported my study so far.

Funding

This study was supported by the Grant-in-Aid for the Japan Society for the Promotion of Science (JSPS) fellows (23K12903).

Conflict of Interest

The authors declare no conflict of interest.

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