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Original Article

The influence of trait anxiety and illusory kinesthesia on pain threshold

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Abstract. [Purpose] It has also been reported that decreased activity in the reward pathway causes a decrease in brain activity in the descending pain control system in people with high trait anxiety. Activation of this system is dependent on both the reward pathway and motor areas. Recently, studies have also shown that motor areas are activated by illusory kinesthesia. It was aimed to explore whether anxiety trait modulates the influence of illusory kinesthesia on pain threshold. [Subjects and Methods] The pain threshold and trait anxiety at rest before vibratory tendon stimulation (the task) were measured. After the task, the pain threshold, the illusory kinesthesia angle, and the intensity of illusory kinesthesia for patients with and without illusory kinesthesia were measured. A total of 35 healthy right-handed students participated, among whom 22 and 13 were included in the illusion and no-illusion groups, respectively. [Results] There was a significant increase in the pain threshold after task completion in both groups; however, there was no statistically significant difference between the two groups. Correlational analysis revealed that State-Trait Anxiety Inventory-trait score correlated negatively with the pain threshold in the no-illusion group, but there was no correlation in the illusion group. [Conclusion] The pain threshold improved regardless of the size of trait anxiety in the illusion group, but did not improve merely through sensory input by vibratory stimulation in the no-illusion group. Thus, illusory kinesthesia has effect of increasing the pain threshold.
Key words: Illusory kinesthesia, Trait anxiety, Pain threshold

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INTRODUCTION

The relationship between pain and emotion has been reported to be important[1)]. Pain is defined by the International Association for the Study of Pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or describe in terms of such damage"[2)]. In addition, it is clear that the experience of pain has several components[3)]. Pain is not only dependent on sensory input but is also experienced through the prism of emotional and cognitive processing; indeed, a patient complaining of pain may have no objective tissue damage[4)]. Conventionally, pain research has focused on behavior, subject affect, physiology, and cognitio[3)], acknowledging that pain experiments must be considered in the context of the subjective experience, which is easily influenced by the central nervous system[5)]. However, psychological factors are involved in perception and can be changed by both the environment and the situation[6)], with roles for a variety of sensory inputs and environmental factors[7)]. Therefore, the same painful stimulus often results in variations in experiences among different individuals.

Anxiety is an important emotional factor that has consistently been shown to influence perception and adjustment to

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pain. Others researching anxiety and pain have focused more generally on trait anxiety, often using the State-Trait Anxiety Inventory (STAI)[8]. Trait anxiety reflects an individual's general disposition toward experiencing anxiety-related feelings or thoughts or to showing anxiety-related behaviors. Importantly, trait anxiety is a stable personality trait that describes the tendency to respond fearfully to a wide variety of nonspecific stressors, and it is regarded as a risk factor for anxiety disorders[9, 10]. Highly trait-anxious subjects tend to perceive situations as threats and to experience intense and sustained anxiety states compared with subjects with low trait anxiety[10, 11]. Trait anxiety has also been shown to be important in chronic pain; for example, after fracturing the distal radius, patients with trait anxiety have been reported a higher risk of developing complex regional pain syndrome type I[12].

In people with trait anxiety, decreased activity of the reward pathway might be important, including the medial prefrontal cortex and nucleus accumbens. In particular, it has been strongly associated with post-traumatic stress disorder patients[13, 14]. It has also been reported that decreased activity in the reward pathway causes a decrease in brain activity in the descending pain control system[15–17]. However, activation of the descending pain control system is dependent on both the reward pathway and motor areas. This makes it difficult to control the descending pain control system by activating the reward pathway alone in people with high trait anxiety. Instead, relief may be obtained through the descending pain control system by activation of motor areas. Actually, it has been reported pain is improved by exercise[18]. However, severe pain experiences during exercise or joint moments are stored in the brain. If the experience is repeated, fear-avoidance is caused—the so-called "fear-avoidance model"[19]. In fact, it has been reported that PTSD patients perceive "fear" after non-painful stimuli[20]. It has been revealed that the memories such as the fear-avoidance model are difficult to eradicate[21].

Recently, clinical intervention with vibratory stimulation has attracted attention. Researchers have used magnetoencephalography, functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS) to record the brain activity of subjects while they experienced illusory kinesthesia evoked by applying vibratory stimuli over tendons in the limbs[22, 23]. This revealed that neural activation occurred in motor areas during illusory kinesthesia. In particular, illusory kinesthesia by vibratory tendon stimulation has been shown to improve the sensory and emotional aspect of pain after orthopedic surgery for distal radius fractures[24]. In addition, illusory kinesthesia did not result in pain after orthopedic surgery for distal radius fractures. The illusory kinesthesia elicited by vibrating a limb tendon at the appropriate frequency is mediated by firing of Ia afferent fibers in response to muscle spindle activity. Given that muscle spindle receptors are sensitive to the direction and speed of limb movements, subjects experience an illusory kinesthesia during tendon vibration, such as the sense of stretching of the affected muscle[25–27].

In the present study, we aimed to examine whether anxiety trait modulates the influence of illusory kinesthesia on pain threshold. We hypothesized that pain threshold of subjects with high anxiety trait does not change by only vibration stimulation, but is increased by illusory kinesthesia that there is activity in the motor cortex.

SUBJECTS AND METHODS

The participants were students recruited from a Kio university campus. Participants with severe chronic uncontrolled pain or central/peripheral nervous system disorders were excluded. All participants were informed at the start of the study that they could discontinue participation at any time. A total of 35 healthy right-handed students (14 males, 21 females; mean age, 22.5 ± 1.5 years) participated in this study. We explained the details of the experimental procedure, but, to limit bias in the results, we did not explain the purpose of the experiment. Before participating, the participants provided written informed consent. The study protocol was approved by the ethics committee of our university (approval number: H25-25) and the study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki (and subsequent revisions). All included participants provided informed consent.

The STAI-trait was used to examine trait anxiety[8]. The widely used STAI-trait is a 20-item self-report questionnaire that measures predisposition to trait anxiety. We asked participants to give self-ratings regarding how they generally felt on four-item scales from 1 (almost never) to 4 (almost always). The sum the scores for the 20 items gave the total score. The STAI-trait was administered only one time before the task because trait anxiety is not known to change in the short term.

Pain thresholds were measured by applying stimuli to the back of the right forearm (5 cm from the extensor digitorum muscle tendons at the radiocarpal joint) using a thermal stimulator (UDH-105, UNIQUE MEDICAL, Tokyo, Japan). The thermal probe was 20 mm in size and was placed directly on the measurement point. Measurement was performed in accordance with the protocol described by Yarnitsky et al[28]. The thermal stimulus started at 32 °C with a 1 °C increase per second. The temperature at which the participant felt the stimulus as painful was recorded as the pain threshold. At the moment they felt pain, participants were instructed to press the switch on the remote control in their right hand to prevent further temperature increase. Before formal testing, thermal stimuli were introduced a few times to a non-assessed area, such as the center of the back of the hand, to allow participants to become sufficiently accustomed to the pain caused by the thermal stimuli. The maximum temperature of the administered stimuli was 50°C. The pain threshold was measured three times and recorded as the mean of the three values.

In the present study, the method for illusory kinesthesia followed that outlined by Imai et al[23]. For vibratory stimulation, a vibratory stimulation device (SL-0105 LP; Asahi Seisakusho Co., Ltd., Saitama, Japan) was set at 80 Hz according to previous research, which stated that the optimal tendon vibration frequency for eliciting illusory kinesthesia was 70–80 Hz[25–27].

Table 1. Comparison of the pain threshold before and after the task in the illusion group and no-illusion group

	Illusion group		No illusion group	
	Pre	Post	Pre	Post
Pain threshold	42.9 (2.4)	42.6 (2.4)*	43.4 (1.8)	42.8 (1.8)*

Values are means (SD). *Significant at $p<0.05$

Table 2. Correlation for the amount of change in pain threshold and trait anxiety in the illusion and no-illusion groups

		State trait anxiety, r (p)
Pain threshold	Illusion group	−0.09 (0.72)
	No illusion group	−0.78 (0.03)*

Pearson product-moment correlation coefficient
*Significant at $p<0.05$

Participants were instructed to relax in a sitting position with their eyes closed during the trial, because it has been reported that illusory kinesthesia is unlikely to occur without muscle relaxation[26] and because visual information can disrupt the illusion of motion[29], respectively.

For the procedure, participants put their hands together in a resting position on the table with their eyes closed. Vibratory stimulation was then administered to the extensor digitorum muscle tendons on the radiocarpal joint. The intensity of the subjective illusory kinesthesia was evaluated on the basis of responses to the following the question: "Does it feel like the vibrated hand was flexed"? A 6-point verbal rating scale (VRS) from 0 (strongly disagree) to 5 (strongly agree) was used.

Based on the experience of subjective illusory kinesthesia, participants were divided into illusion and no-illusion groups. Among these, 22 were included in the illusion group and 13 were included in the no-illusion group. Those with any sense of illusory kinesthesia (VRS intensity 1–5) were placed in the illusion group, and those with no sense of illusory kinesthesia (i.e., VRS 0) were placed in the no-illusion group. The illusory kinesthesia angle was measured on a digital photograph of the side subject to vibration. This photograph was analyzed using the ImageJ software for measurement against the illusory kinesthetic angle. Digital photograph images are those of the position of wrist during vibratory stimulation and flexion. Flexion (illusory angle) was measured with the forearm in the neutral position with the radius as the standard axis and the second metacarpal bone as the axis of movement.

First, before the experimental task, we measured the pain threshold and trait anxiety in all participants at rest, in a sitting position. Second, vibratory tendon stimulation was performed as the experimental task. The task protocol involved three cycles of resting for 10 s followed by vibratory stimulation for 30 s, as described. After the task, we measured the pain threshold, the illusory kinesthetic angle, and the intensity of illusory kinesthesia. The intensity of illusory kinesthesia was evaluated using a 6-point VRS, and the illusory kinesthetic angle was reproduced on the side subject to vibration.

Participant age and STAI-trait score were compared between the illusion and no-illusion groups by t-tests, whereas gender comparisons were evaluated by χ^2 tests. The pain threshold was analyzed using two-way analysis of variance (ANOVA) for two binary factors, ''group'' (illusion vs no-illusion) and period (before vs. after the stimulation). The Bonferroni method was used for post hoc comparisons. Pearson product-moment correlation coefficient was used to investigate the relationship between the amount of change in pain threshold (for the illusion and no-illusion groups) and STAI-trait score. The significance level was set at $p<0.05$, and we used SPSS statistics, Version 17.0 (SPSS Institute Inc., Chicago, IL, USA) for statistical analysis.

RESULTS

There were no significant differences in age ($p=0.62$), gender ($p=0.76$), or the STAI-trait score ($p=0.32$) between the groups. The intensity of illusory kinesthesia was 5.4 ± 0.9 (mean ± standard deviation [SD]) and the illusory kinesthesia angle was 35.3 ± 10.1° (mean ± SD) in the illusion group. Two-way ANOVA showed a significant interaction between factors period and group ($F=27.87$, $p<0.05$) (Table 1). Moreover, post-hoc test revealed there was a significant post pain threshold compared with pre pain threshold in the illusion group. Finally, no significant correlation was observed between STAI-trait score and amount of change in pain threshold in the illusion group ($r=0.09$, $p=0.72$); however, a significant negative correlation was observed between STAI-trait score and the amount of change in pain threshold in the no-illusion group ($r=-0.78$, $p=0.03$) (Table 2).

DISCUSSION

In this study, there was a significant increase in the pain threshold after task completion in both the illusion and no-illusion groups; however, the difference between the groups was not significant. In addition, correlational analysis revealed that STAI-trait score correlated negatively with the pain threshold in the no-illusion group, but no correlation was observed in the illusion group. Finally, in the present study, we found that pain threshold of subjects with high anxiety trait does not change by only vibration stimulation, but is increased by illusory kinesthesia that there is activity in the motor cortex.

In the illusion group, illusory kinesthesia probably activated motor regions, such as the primary motor cortex and the pre-motor cortex[23, 25, 30]. In contrast, motor regions were not activated by sensory input in the no-illusion group. In other research, it was shown that the pain of patients with fibromyalgia improved after using transcranial galvanic stimulation in a primary motor region, but to a lesser degree than after transcranial direct current stimulation[30, 31]. In this context, it has been proposed that excitement of the primary motor region allows activation of the cingulate gyrus and periaqueductal grey substance[32], with pain relief induced by modulation of descending pain control system[33]. In other words, if we accept that illusory kinesthesia activates the descending pain control system, pain relief should be the natural result. Illusory kinesthesia can be experienced as the perception of movement for exercise difficult people. Therefore, the neural activation occurred in the motor area during illusory kinesthesia as well as wrist movements, but only vibratory stimulation without illusory kinesthesia did not result in activation.

Unfortunately, someone with high trait anxiety is not expected to achieve an analgesic effect via the descending pain control system because of the role of the reward pathway, although descending pain control system could be triggered by activation of motor areas. Although decreasing the emotional aspect of pain is a little to improve, it is difficult with general physical rehabilitation therapy[34]. In the present study, correlational analysis revealed that STAI-trait score correlated negatively with pain threshold in the no-illusion group, but that STAI-trait score had no correlation in the illusion group. Illusory kinesthesia may be not influenced STAI-trait score, and easily obtained the activities of motor areas. Thus, illusory kinesthesia may be better in people with high trait anxiety and severe pain.

We showed that the pain threshold was improved after the use of a vibratory stimulus. One research group has reported that sensory perception is temporarily decreased by vibratory stimulation[35]. In the present study, several participants showed improved pain thresholds after vibrating stimulus without the sense of illusory kinesthesia. Previous studies of vibratory stimulation have shown that it can improve the experience of chronic pain[36], whereas other research has shown that chronic pain and pain pressure thresholds did not change in response to vibratory stimulation[37, 38]. In addition, the influence of whole body vibration on pain has benefits and drawbacks[39, 40], and it is not clear what factors provide pain relief during and after vibratory stimulus. This reason may be because a number of important psychological factors such as trait anxiety are involved.

Trait anxiety is considered fixed in the short term and cannot be easily changed by intervention; however, pain-related psychological factors such as trait anxiety may be improved. Therefore, it is necessary for physical therapists to select therapy that reflects the backgrounds of patients with high trait anxiety. This is very difficult and time consuming. In this study, participants developed increased pain thresholds is modulated by high anxiety traits after illusory kinesthesia, regardless of their baseline trait anxiety.

In this study, we did not measure brain activity by fNIRS, fMRI or electroencephalography during the task. Therefore, the difference in brain activity during illusory kinesthesia and vibratory stimulus is unclear. Furthermore, we did not measure brain activity in the motor-operated descending pain control system during illusory kinesthesia. In the future, we must measure brain activity to investigate whether the analgesic effect is obtained by illusory kinesthesia mediating the descending pain control system by tendon vibratory stimulation. The pain threshold may have changed after approximately 15 or 30 min. However, the pain threshold was not measured after 15 or 30 min in this study; hence, it is a limitation of the present study. Finally, further clinical study is needed to investigate whether there is an effect on people with high trait anxiety.

We aimed to examine whether anxiety trait modulates the influence of illusory kinesthesia on pain threshold. In results, there was a significant increase in the pain threshold after task completion in both the illusion and no-illusion groups; however, the difference between the groups was not significant. In addition, correlational analysis revealed that STAI-trait score correlated negatively with the pain threshold in the no-illusion group, but no correlation was observed in the illusion group. Finally, in the present study, we found that pain threshold is modulated by high anxiety trait by only vibration stimulation does not change, but is increased by illusory kinesthesia that there is activity in the motor cortex.

Conflict of interest

The authors declare no competing interests.

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