Changes in a Chaotic Fluctuation of Eye Movement Produced by Stiff Shoulder Treatment

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Abstract: Many Japanese people experience physical symptoms known as Katakori (shoulder stiffness or neck pain), which is considered a psychosomatic phenomenon that is strongly correlated with psychological stress and stress caused by human relationships. This study examined changes in the chaos of eye movement accompanied by changes in depression by treating shoulder stiffness. Participants scoring over 1SD from the mean score having high depression and shoulder stiffness were included in the intervention group and provided stretching intervention. The control group included participants having high depression and shoulder stiffness, but they were not provided with the stretching intervention. Moreover, participants scoring lower than 1SD from the mean score having low depression and no shoulder stiffness were included in the Low group. The experimental group exercised using a neck and shoulder relaxation technique using a stretch pole recommended by the stretch pole official site. The results of the experiment indicated that eye movement LLE(Largest Lyapunov Exponent) changed more significantly when the depression level was high. Moreover, LLE and the degree of change in LLE decreased after receiving treatment for the stiff shoulder. It is suggested that the chaotic fluctuation of eye movement might decrease when depression improved, i.e., in people with low depression.

1 INTRODUCTION

Many Japanese people experience physical symptoms known as *Katakori* (shoulder stiffness or neck pain), which is considered a psychosomatic phenomenon that is strongly correlated with psychological stress and stress caused by human relationships. According to Yokota (2000), the expression, "having a stiff shoulder" was first used by Soseki Natsume (1867-1916), a famous Japanese novelist. *Katakori* is a symptom of subjectively, having a sense of discomfort, depression, and mild pain caused by movement in the neck, upper scapular, scapular, and middle scapular regions. Objectively, when palpating these muscles, they are abnormally tense, and there are tender points or lumps. The mechanisms of *Katakori* are diverse, and the causes of *Katakori* are as follows; overuse of muscles, accumulation of fatigue factors caused by blood circulation disorders, poor blood circulation in shoulder muscles caused by arteriosclerosis, insufficient blood circulation caused by maintaining a particular posture for a long time, such as unnatural body position, bad posture, humpback, sloping shoulders, and scoliosis, psychological tension, and fibrositis of muscles, among others (Sasaki, 1994). Currently, in Japan, complaints of *Katakori* are placed first in the ranking of complaints of physical symptoms in women, and second in men after backache (Ministry of Health, Labor and Welfare, 2010). Thus, *Katakori* is a symptom with a high ratio of complaints in Japan. In English, however, *Katakori* is mainly expressed by using "neck" as follows; neck pain, chronic neck pain, chronic nonspecific neck pain, cervical strain, neck tension, stiff neck, and neck. There are a few terms related to shoulders. "Neck pain" or "chronic nonspecific neck pain," which are often used in documents, are considered close to the symptom of *Katakori* in Japan (Morimoto, 2010). According to Sasaki (1994), internationally, there are many translations of *Katakori*, suggesting there are differences in the sensory expression of *Katakori* depending on the country. Sasaki (1994) indicated that "shoulder stiffness" might be the most appropriate translation of *Katakori* for writing academic papers. Therefore, in

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this article, we used shoulder stiffness as the term expressing *Katakori*.

In Japan, shoulder stiffness is regarded as a physical symptom caused by mental factors. Takaguchi & Ishoshima(1989) reported that the frequency of shoulder stiffness associated with neurosis, i.e. “psychogenic” shoulder stiffness, was 72% in a survey conducted in 1981. Matsuura, Fuzimoto, Koga, Yasuno, & Sakai(2016) reported that university students having shoulder stiffness had high perceived stress or anxiety, and their mental and physical health levels were rather low. Nagao, Endo, & Yokota (2011) indicated that although there are individual physical differences in the position of shoulder stiffness on the surface or muscle quality, the correlation between self-palpation of stiffness and the feeling of stress was relatively high, suggesting there might be psychogenic factors in shoulder stiffness. Moreover, Tanaka & Suzuki (2012) reported that shoulder stiffness and depression, as well as anxiety, are correlated, and depression was significantly reduced by providing treatment for shoulder stiffness.

1.1 Chaos

At the end of the twentieth century, terms such as “Chaos”, “Fractals”, and “Complex systems” got much attention in the field of science. Along with The Theory of Relativity and quantum mechanics, chaos was sometimes referred to as the three biggest findings of the twentieth century in the field of science. Chaos, as academic jargon, in general terms does not mean, “disordered”. Chaos might be the order with a dynamic fluctuation. There has been no strict definition of chaos to date. According to Aihara (1993), chaos is “a phenomenon with very complicated, irregular, and unstable behaviors because of the nonlinearity of the system, although the system is following deterministic laws, and it is impossible to predict the future state.” Chaos might be expressed as a “fluctuation” to facilitate understanding. A chaotic fluctuation is observed in various phenomena. The fluctuation is expressed by quantitative values such as Largest Lyapunov Exponent (LLE), which is a quantification of sensitivity to the initial conditions, which is one of the characteristics of chaos. To date, many bio-information is reported as chaos. Among them, research on brain waves from the perspective of chaos is most advanced because of the ease of measurement. Many researchers have indicated a correlation between a chaotic fluctuation expressed by LLE and mental and physical health.

1.2 Eye Movement

Previous studies have reported that various mental symptoms and eye movements are correlated. Eye Movement Desensitization and Reprocessing (EMDR) is a well-known example of treatment using eye movement. It is a technique of cognitive behavioral therapy, developed mainly for PTSD treatment, effective for mood disorders and anxiety disorders caused by traumatic experiences (Arimura et al., 2000).

Sharifa et al. (2013) indicated that the interval between blinks and the mean duration of blinks were shorter in patients with depression, compared to healthy participants. Based on the results depression screening using eye movement has been developed. Nishiura, Morita, Ishii, Igimi, & Maeda (2009) compared exploratory eye movements between patients with schizophrenia and healthy participants by presenting a circle and a photo of an infant’s face. The results indicated that the total moving distance of the left exploratory eye movement of schizophrenia patients is shortened when presenting an infant’s smiling face and a circle, which was different from healthy participants. Therefore, exploratory eye movement is regarded as a useful psychophysiological index.

As described above, eye movement and mental conditions are correlated. However, correlations between the chaos of eye movement and mental conditions have not been sufficiently examined. Murata & Matsuura (2015) reported that LLE of eye movement when conducting a visual search tended to increase as the stimulus became more complicated. Moreover, Yoshida & Suzuki(2019) measured LLE of eye movement in university students with high or low depression to examine correlations between LLE of eye movement and depression, indicating the maximum value of LLE of eye movement became higher when students had higher depression.

Based on the above, it is suggested that shoulder stiffness and depression, as well as the chaos of eye movement, might be correlated. This study examined changes in the chaos of eye movement accompanied by changes in depression by treating shoulder stiffness.

2 METHODS

The Japanese version of the Carroll Rating Scale for Depression (Shima, Shikano, Kitamura, & Asai ,1985) and the *Katakori* scale (Tanaka & Suzuki, 2012) were administered to university students in

Tokyo (*N*=490) from July to November in 2011. The results indicated a mean score of 13.08 (*SD*=7.24). Participants scoring over 1*SD* from the mean score having high depression and shoulder stiffness were included in the intervention group (*n*=12) and provided stretching intervention. The control group included participants having high depression and shoulder stiffness (*n* = 11), but they were not provided with the stretching intervention. Moreover, participants scoring lower than 1*SD* from the mean score having low depression and no shoulder stiffness were included in the Low group (*n* =11).

2.1 Equipment, Materials, Psychological Scales

Eye Link CL Illuminator TT-890 (SR Research Ltd.) was used to measure eye movements. In this system, the direction of the eyeball is recorded by using an infrared camera, and blinks, saccades, the pupilar diameter, the amplitude of the gaze point in the vertical and horizontal directions are measured in real-time. The non-contact remote model of this equipment was used to reduce participants' burden. The distance between the camera and a participant was 70cm. A height-adjustable chair was used to adjust the eye height of the participants to the center of the monitor. The PC monitor was 31.0cm height x 45.0cm wide. A 16mm lens was used for remote photography. The sampling rate was 500Hz for one eye. Shoulder stiffness was treated using the Stretch Pole EX (LPN Corporation) (Figure 1).

Figure 1: Stretch Pole EX (LPN Corporation) (Stretch Pole Official Site(http://stretchpole.com/)).

2.1.1 The Japanese Version of the Carroll Rating Scale for Depression

This scale was developed by Shima, Shikano, Kitamura, & Asai (1985) to assess depressive mood and includes 52 items. Participants are required to respond regarding their recent condition using a two-point scale consisting of "Yes" or "No." This scale corresponds to the Hamilton Rating Scale for Depression (HRSD), which is used to assess the severity of depression in clinical psychiatry. Therefore, the consistency with the clinical diagnosis can be easily established when clinical samples are included as research subjects. The total score on this scale is 0-52 points. Shima, Shikano, Kitamura, & Asai (1985) reported that the mean score of a normal control group on the scale was 6.7 (*SD*=6.0). A score of 17 is recommended as the cut-off point for identifying depression..

2.2 Procedures

1. Eye movement measurement devices and a PC monitor were set up in a psychology laboratory (a dark room).
2. Psychological tests and the *Katakori* scale were administered (the results were excluded from analysis in this study).
3. The experimenter assessed the subjective shoulder stiffnrss(*Katakori)* of participants with a physical therapist.
4. The dominant eye was selected. Participants were requested to make a circle with their fingers and look at the object with both eyes so that the object is positioned at the center of the circle. Next, they closed one eye, and then the other eye. The eye that could observe the object equally well as when using both eyes was decided as the dominant eye.
5. After conducting the calibration and validating the use of the eye movement measurement devices, participants were requested to fixate a black circle with a diameter of 18cm on a white drawing paper for 180 seconds, which was adjusted to the size of the PC monitor.
6. The experimental group exercised using the Stretch Pole EX, by referring to basic techniques of its use, and relaxation methods for the neck and shoulders, recommended by the official site of the stretch pole. They conduct breast exercise, diagonal exercise, floor polishing exercise, scapular exercise, arm abduction exercise, small fluctuation exercise, sidelong glance exercise, and neck flexion exercise (Figure2) for about 10 minutes until they felt comfortable and felt no pain.
7. Psychological tests and the *Katakori* scale were administered (the results were excluded from the analysis of this study).
8. The experimenter assessed the subjective *Katakori* of the participants with a physical therapist.

The control group and the Low group conducted the procedure 7 after 5.

Figure 2: Examples of exercise. (Stretch Pole Official Blog(https://stretchpole-blog.com/stretchpole/stretchpole-use).

2.3 Ethical Considerations

The experiment was conducted after being examined for research ethics and getting the approval of the first author's research institution. Participants were instructed that they could quit the experiment even in the middle for any reasons and that they would incur no disadvantages for not responding, quitting the experiment, or based on the content of their responses. Moreover, they were explained that the experimental results would be statistically processed and used only for academic purposes and that the data would be stored in a USB memory stick that has been encrypted. They were also told that no individuals would be identified from the data. The participated took part in the experiment after giving their consent to the explanation.

3 RESULTS

Eyeball positions data measured at 500Hz for 180 seconds were analyzed. Since LLE of eye movement is affected by blinks data under 5*SD*, and over 5*SD* from the mean value of eye movement data were excluded from the analysis. The calculation method of LLE was referred to Pham, Thang, Oyama-Higa, Nguyen, Saji & Sugiyama(2013). Table1 shows fundamental statistics of LLE of eye movement in high and low depression groups. The mean eye movement LLE value in the high depression groups (intervention group and control group) was 15.63 (*SD*=5.67), whereas in the low depression group was 17.96 (*SD*=8.82). The mean standard deviation value of eye movement LLE in the high depression groups was 9.08 (*SD*=6.37), whereas that in the low depression group was 5.46 (*SD*=4.00). Table 2 shows fundamental LLE statistics of intervention and control groups for the high depression groups. The mean eye movement LLE value of the intervention group was 15.81 (*SD*=6.76), whereas that of the control group was 15.44 (*SD*=4.16). The mean standard deviation value of eye movement LLE in the intervention group was 13.00 (*SD*=6.58), whereas, in the control group, it was 4.80 (*SD*=1.57). The mean eye movement LLE value of the intervention group after the intervention was 5.72 (*SD*=4.54), and the mean standard deviation value of eye movement LLE was 5.31 (*SD*=2.64).

Table 1: Fundamental statistics of LLE of eye movement in high and low depression groups.

	High depression group(N=23)				
	Mean	SD	SE	95%CI Lower	95%CI Upper
LLE of eye movement(pre)	15.63	5.67	1.18	13.18	18.09
Deviation of LLE of eye movement(pre)	9.08	6.37	1.33	6.32	11.83
	Low depression groups(N=11)				
	Mean	SD	SE	95%CI Lower	95%CI Upper
LLE of eye movement(pre)	17.96	8.82	2.66	12.03	23.89
Deviation of LLE of eye movement(pre)	5.46	4.00	1.21	2.77	8.15

Table 2: Fundamental LLE statistics of intervention and control groups for the high depression groups.

	Intervention group(N=12)				
	Mean	SD	SE	95%CI Lower	95%CI Upper
LLE of eye movement(pre)	15.81	6.76	1.95	11.52	20.11
Deviation of LLE of eye movement(pre)	13.00	6.58	1.90	8.81	17.18
LLE of eye movement(post)	5.72	4.54	1.37	2.67	8.77
Deviation of LLE of eye movement(post)	5.31	2.64	0.80	3.53	7.08
	Control group(N=11)				
	Mean	SD	SE	95%CI Lower	95%CI Upper
LLE of eye movement(pre)	15.44	4.16	1.26	12.64	18.24
Deviation of LLE of eye movement(pre)	4.80	1.57	0.47	3.75	5.86

3.1 Analysis of Variance (ANOVA) based on the Depression Level

An ANOVA was conducted between high and low depression groups to examine for significant differences in eye movement LLE and the standard deviation of the LLE based on the depression level. Results indicated no significant difference in the eye movement LLE (F(1,32)=0.81, p=0.38,η^2=0.03), although the effect size η^2 showed a small effect. On the other hand, the standard deviation of the eye movement LLE in the high depression group was higher than in the low depression group (F(1,32)=2.813, p=0.10,η^2=0.08), and the effect size η^2 showed a mid-sized effect. The above results indicated that LLE of eye movements tended to be low when the depression level was high, and the degree of change in eye movement LLE was larger.

3.2 ANOVA of Pre and Post-intervention Changes in Eye Movement LLE

An ANOVA was conducted to examine significant differences in eye movement LLE and the standard deviation of LLE between pre and post-intervention. The results indicated that eye movement LLE decreased significantly after the intervention (F(1,11)=18.61,p=0.00,η^2=0.63), with a large effect size η^2 (Figure3). Regarding the standard deviation of LLE of eye movement, it also significantly decreased after the intervention (F(1.11)=9.582, p=0.01,η^2=0.47), with a large effect size η^2 (Figure4). Based on the results above, it was indicated that LLE of eye movement and the amount of the change of LLE of eye movement decreased by the intervention..

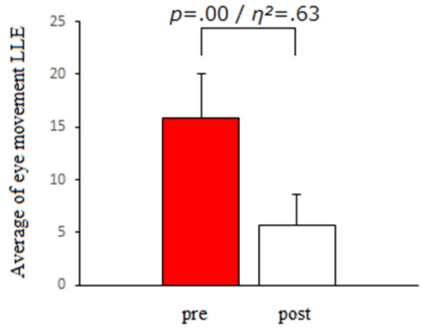

Figure 3: ANOVA of pre and post-intervention changes in eye movement LLE.

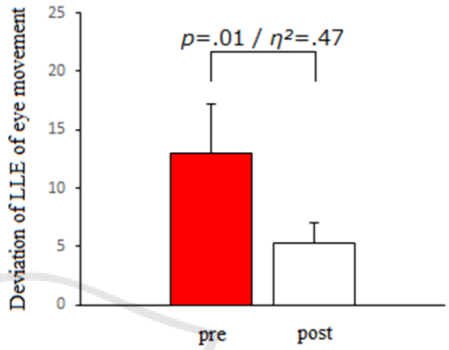

Figure 4: ANOVA of pre and post-intervention changes in deviation eye movement LLE.

4 DISCUSSION

The results of the experiment indicated that eye movement LLE changed more significantly when the depression level was high. Moreover, LLE and the degree of change in LLE decreased after receiving treatment for the stiff shoulder. It is suggested that the chaotic fluctuation of eye movement might decrease when depression improved, *i.e.*, in people with low depression.

Saime et al. (2015) reported that the frontal and parietal lobes of patients with depression tended to be highly chaotic. On the other hand, Oyama (2012) reported less chaotic tendencies in the finger plethysmogram of patients with depression. On the other hand, for respiration Yeragani, Radhakrishna, Tancer,& uhde(2002) reported that the LLE for respiration in panic disorder patients in a standing position was higher than with the healthy control group, while Yeragani, Rao, Tancer,& Uhde(2004)pointed out that serotonin reuptake inhibitors are effective at decreasing overly-high LLE in panic disorder patients, indicative of differences between the findings of preceding studies. Sometimes, the LLE of healthy participants is lower than patients with depression. Therefore, the results require careful discussion. Participants in this study were ordinary students, and they were classified based only on the level of depression. On the other hand, the study by Oyama (2012) included patients with depression. Comparing the results of the current study with Oyama (2012) suggests that the chaotic tendencies in the LLE of biological signals might increase in people with depressive tendencies. However, chaotic tendencies might decrease when a person is diagnosed as depressed (*i.e.*, a high level of depression). The above discussion is based on speculation because Saime et al. (2015) also dealt with patients with depression. Further analysis is required because sufficient chaos analysis of biological signals such as eye movement has not been conducted.

As described above, shoulder stiffness is regarded as a physical symptom caused by psychological factors. According to Takaguchi & Ishozima (1991), when administering Dosulepin (a medication for depression) to participants in depressed conditions with shoulder stiffness, the shoulder stiffness improved in 13 (52%) participants, which is close to the efficacy rate for shoulder treatment at that time. Aoyagi, Suganuma, Kaneko, & Shinbo (2019) indicated that students with neurotic tendencies complain not only about psychological symptoms but also physical symptoms such as headache, fatigue, and the feeling of suffocation, among others, suggesting that psychological health might affect the body and appear as physical symptoms including shoulder stiffness. Considering such psychosomatic correlations, although speculative, this study suggests the possibility that psychological health might be assessed and treated based on physical symptoms as suggested by Sharifa et al. (2013), including depression screening by measuring eye movements. In the future, treatment and diagnosis might improve by examining how depression or shoulder stiffness is affected by moving or not moving the eyeballs according to certain rules.

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