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The Relationship Between Ankle Muscles and An EMG-Based Physically Interactive Game

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Purpose: This study was to identify the relationship between the game score and muscle strength in order to elucidate whether the obtained score for the dorsiflexor and plantar flexor muscles in the ankle joint using an EMG-based interactive game system can reflect muscle strength as measured conventionally.
Methods: Forty adults were enrolled in the present study. They had no congenital deformities, and no neurological or orthopedic disorders in the 6 months prior to the start of the study. The Biodex were used to measure the isokinetic concentric maximal strength of the plantar flexor and dorsiflexor muscles in the ankle joint. EMG electrodes were attached to the tibialis anterior and gastrocnemius.
Results: (1) There was a positive relationship between the obtained game score by the plantar flexor (sPF) and muscle strength of the plantar flexor (tPF) and dorsiflexor (tDF). In addition, the tPF affected the sPF, but the tDF did not. Thus, the higher the tPF, the higher the sPF. (2) There was no relationship between the obtained game score of dorsiflexor (sDF) and tPF or tDF. In addition, neither the tDF or tPF affected the sDF.
Conclusion: The game score had a relationship with muscle strength, which is related to ankle instability and re-impairment. Thus we suggest that this game system can be used to predict the degree of weakness of muscle strength.

Keywords: Muscle strength, Dorsiflexor, Plantar flexor, Interactive game, Game score

INTRODUCTION

Rehabilitation is any treatment performed to recover physical, mental, or social ability when the quality of life has been decreased by disability, temporary trauma, pain, or disorders.[1,2] One of the typical treatments is therapeutic exercise, where a therapist helps to recover or maintain a patient's motor function by moving the patient's joint passively, or by educating and assisting the patient's gait. This therapeutic exercise is needed for a long period of time for treatment and endurance, and the patient's potential power of recovery and active will to participate are key factors.[3] In particular, how cooperative a patient is in active participation is vital to the level of improvement during rehabilitation and the maintenance of rehabilitation activities, and becomes a new power in life without specific treatment,

enhancing personal relations and independence.[3,4] Jang & Yoon[4] showed that rehabilitation will can have a huge effect on treatment success.

Kang[5] developed an EMG-based physically interactive game system to improve rehabilitation environments as the necessity to improve monotonous or boring long-lasting rehabilitation had been recognized, as the application of this game system using EMG biofeedback was shown to improve a patient's active will for participation, and to increase patient satisfaction. EMG biofeedback from Kang's study is used widely in medical science, rehabilitation medicine, human engineering, and sports science, due to the fact that it can be an important factor to improve the efficiency of therapeutic exercise by checking a patient's muscles and applying patient training[6,7] Biofeedback training can identify real-time vital signs seen by

the patient themselves, thus it can enhance small increases in achievement towards goals, and rapidly facilitate the process of rehabilitation.[8-10] Biofeedback training using EMG is the best method to recover injured motor function of the upper limb.[11] This application of a game system using EMG biofeedback can induce correct movement through the use of EMG signals relating to paralyzed or weakened muscles, and improve motor performance by facilitating motor learning using vital signs that are provided in real-time.[8] A game system using EMG biofeedback may need proper timing of contraction and relaxation of muscles, control of neural networks of neuromuscular system, and accurate movement in order to control a game character through inducing muscle contraction, while general EMG biofeedback system provides simple visual information using numbers or graph about muscle activities or auditory information using beeps when muscle activity is over than threshold. Moreover, the application of a game system can enhance a patient's active will for participation and increase satisfaction of treatment by improving monotonous or boring rehabilitation environments.[6]

However, there is a question of whether the application of an EMG-based physically interactive game system can be used as rehabilitation. Due to the fact that Kang's study confirmed patients' subjective satisfaction regarding the application of a game system through questionnaires, therefore he could not provide the answer as to whether this system could be an alternative to other types of rehabilitation. Thus, to suggest a game system as an alternative to rehabilitation, an investigation was needed in order to recognize if the application of a game system could improve a patient's kinetic characteristics. Prior to this, it was necessary to identify whether the game system could replace existing measurement equipment by the verification that there is a significant relationship between the score obtained by the game system and the muscle strength measured with existing measurement equipment.

Chronic instability of the ankle joint is progressed by injury such as an ankle sprain, and is caused by weak muscle strength of the tibialis anterior and peroneus longus, as well as decreased proprioception.[12-14] The present study aims to analyze the relationship between the game score and muscle strength in order to elucidate whether the obtained score for the dorsiflexor and plantar flexor muscles in the ankle joint using an EMG-based physically interactive game system can reflect muscle strength as measured conventionally.

METHODS

1. Subjects

40 subjects (mean age 22.8 ± 2.3 years old, height 166.9 ± 7.6 cm, body weight 56.9 ± 9.8 kg, and BMI $20.3 \pm 2.2\%$) were enrolled in the present study. They had no congenital deformities, and no neurological or orthopedic disorders in the 6 months prior to the start of the study. The subjects' general characteristics were measured including their height and body weight before experiments. 12 subjects were male with a mean age of 25.1 ± 2.0 years old, a height of 176.3 ± 4.1 cm, a body weight of 69.1 ± 6.7 kg, and a BMI of $22.3 \pm 2.2\%$. 28 subjects were female with a mean age of 21.8 ± 1.7 years old, a height of 162.8 ± 4.5 cm, a body weight of 51.6 ± 5.0 kg, and a BMI of $19.5 \pm 1.5\%$. The subjects agreed to participate in the study following an explanation of the experiments.

2. Experimental methods

1) Measurements

(1) Biodex system

The Biodex system 4 Pro Dynamometer and the Biodex Advantage Software Package (Biodex Medical System Inc., Shirley, USA) were used to measure the isokinetic concentric maximal strength of the plantar flexor and dorsiflexor muscles in the ankle joint. The lower leg was on a support with a height of 40 cm, and fixed using a strap in a full lying posture on a chair. The axis of the joint corresponded to the axis of the dynamometer. The opposite thigh, which was not being measured, was fixed using a strap in the 90° knee flexion position, with the foot on a support. Isokinetic concentric maximal strength was calculated as the peak torque divided by the body weight, and the angular velocity was 60°/sec. Measurements were taken 5 times, and the mean value was used for analysis. Subjects were encouraged by bulbar command consistently.

(2) EMG-based biofeedback game system

EMG electrodes were attached to the tibialis anterior and gastrocnemius to obtain the game score using the EMG-based biofeedback game system QEMG-4XL (Laxtha, Korea). Electrodes on the tibialis anterior (ankle dorsiflexor) were attached 2 cm laterally on the tibial line, and electrodes on the gastrocnemius (ankle plantar flexor) were attached 2 cm inferiorly and medially from the center line of the popliteal fossa.[15] Following attachment of the EMG electrodes,

individual muscle strengths were calibrated to consider individual variations. The game was then performed 3 times, and the mean score was used for analysis. The relationship between the mean game score and the peak torque/body weight was analyzed.

The game character could be moved up or down according to the EMG signal obtained by each muscle contraction, and was designed so that various types of fish were to be passed from the right to left hand side of the screen. When the game character made contact with a passing fish, a point was acquired, whereas when the character could not contact a fish three times, the game was over.

2) Statistical Analysis

SPSS version 18.0 for windows was used for statistical analysis. Pearson correlation was used to elucidate the relationship between the game score and muscle strength, and regression was used to elucidate whether muscle strength had an effect on the game score. The significance level was set at 0.05.

RESULTS

(1) The relationship between the game score and muscle strength of the plantar flexor.

There was a positive relationship between the obtained game score by the plantar flexor (sPF) and muscle strength of the plantar flexor (tPF) and dorsiflexor (tDF) (Table 1).

In addition, the tPF affected the sPF, but the tDF did not. Thus, the higher the tPF, the higher the sPF (Table 2).

(2) The relationship between the game score and muscle strength of the dorsiflexor.

There was no relationship between the obtained game score by the dorsiflexor (sDF) and tPF or tDF (Table 1). In addition, neither the tPF or tDF affected the sDF (Table 3).

Table 1. The correlation between peak torque/body weight and game score of ankle plantar flexor and dorsiflexor

	tPF	tDF	sPF	sDF
value(M±SD)	27.52±22.08	17.58±20.26	192.37±45.53	220.53±20.26
tPF	1	0.65*	0.58*	0.28
tDF		1	0.05	0.25
sPF			1	0.30

tPF: Peak torque/body weight of plantar flexor in ankle joint, tDF: Peak torque/body weight of dorsiflexor in ankle joint, sPF: Game score of plantar flexor in ankle joint, sDF: Game score of dorsiflexor in ankle joint.
*Statistically significant at the level of p＜0.01.

Table 2. The results of regression between game score and peak torque/body weight of plantar flexor in ankle joint

		R2	B(β)	SE	F	t	p
tPF	Constant		225.34	9.82		22.96	0.00
	tPF	0.34	1.20 (0.58)	0.28	18.35	4.28	0.00*
tDF	Constant		197.32	16.90		11.67	0.00
	tDF	0.00	0.28 (0.05)	0.85	0.11	0.33	0.75
sDF	Constant		46.42	79.25		0.59	0.56
	sDF	0.08	0.66 (0.30)	0.36	3.42	1.85	0.07

tPF: Peak torque/body weight of plantar flexor in ankle joint, tDF: Peak torque/body weight of dorsiflexor in ankle joint, sDF: Game score of dorsiflexor in ankle joint.
*Statistically significant at the level of p＜0.01.

Table 3. The results of regression between game score and peak torque/body weight of dorsiflexor in ankle joint

		R2	B(β)	SE	F	t	p
tPF	Constant		227.46	5.16		44.06	0.00
	tPF	0.08	0.25(0.28)	0.15	2.93	1.71	0.10
tDF	Constant		230.78	7.29		31.67	0.00
	tDF	0.06	0.58	0.37	2.46	1.57	0.13
sDF	Constant		195.31	14.00		13.95	0.00
	sDF	0.09	0.13(0.30)	0.07	3.42	1.85	0.07

tPF: Peak torque/body weight of plantar flexor in ankle joint, tDF: Peak torque/body weight of dorsiflexor in ankle joint, sPF: Game score of plantar flexor in ankle joint.
*Statistically significant at the level of p＜0.01.

DISCUSSION

The present study examined whether the game score using an EMG-based physically interactive game system, which was developed to overcome monotonous and boring long-lasting rehabilitation training and to induce patients' active participation, is related to muscle strength as measured by traditional equipment.[16,17]

The peak torque/body weight of the plantar flexor was greater than the peak torque/body weight of the dorsiflexor. This is consistent with Ko's study in which it was reported that plantar flexor strength was greater than dorsiflexor strength when measuring the muscle strength balance index in the ankle joints of healthy young women.[18] The gastrocnemius as the plantar flexor may be stronger than the tibialis anterior as the dorsiflexor, due to the fact that the gastrocnemius has a larger motor unit, and a very strong power to lift body weight, such as lifting heels against body weight and gravity. The center of gravity on the body is just in front of the ankle joint on standing.[19] The dorsiflexor lifts only the weight of the foot, but the plantar flexor lifts body weight, thus the gastrocnemius should have a stronger power than the tibialis anterior. This is supported by the isokinetic concentric maximal strength/body weight in the present study.

Although the maximal strength of the plantar flexor was greater than that of the dorsiflexor, the obtained game score by the dorsiflexor (sDF) was higher than that of the plantar flexor. The dorsiflexor has a smaller motor unit because its size and isokinetic strength are smaller than that of the plantar flexor. Delicate control of the ankle joint was needed for the game system, and the dorsiflexor, which has a smaller motor unit, controls detailed movement of the ankle joint, thus the sDF was higher.

There was a positive relationship between the peak torque/body weight of the plantar flexor and the dorsiflexor, meaning that the stronger the plantar flexor strength, the stronger the dorsiflexor strength.

On the other hand, the obtained game score by the plantar flexor (sPF) was affected by the plantar flexor strength (tPF). The greater the tPF, the higher the sPF. Individuals with a lower sPF may have weak tPF. However, there was no relationship found between the sPF and dorsiflexor strength (tDF).

The sDF was not affected by the tPF or tDF. Subjects had a higher sDF unlike the sPF, meaning that there was no difference in sDF with respect to muscle strength. The game required more delicate control of the ankle joint than greater strength, thus the dorsiflexor, which has a smaller motor unit, controls detailed movements of the ankle joint. The present study measured the dorsiflexor in healthy young adults, and they did not have any severe muscle injury or pain in the ankle joint, therefore the sDF was higher in all subjects. Joint instability or pain in the ankle joint is related to poor strength of the dorsiflexor and decreased sense of position,[20] and it can be suggested that joint instability or pain affects the game score. Thus, measuring the game score can predict poor strength of the dorsiflexor or poor sense of position. On the other hand, in order to predict strength in a healthy ankle joint or proprioception without injury or pain, application of the game score using the plantar flexor can have a more accurate prediction than using the dorsiflexor.

As a result, tPF was greater than tDF, however the sDF was higher than sPF. The sPF was affected by tPF, but the sDF was not affected by the strength of either the plantar flexor or the dorsiflexor.

Chronic instability of the ankle joint is progressed by injury such as an ankle sprain, and is caused by weak muscle strength of the tibialis anterior and peroneus longus, as well as decreased proprioception.[12-14] If strength of the ankle joint and proprioception maintain a normal function, ankle stability is maintained, and re-impairment can be prevented.[21] The present study shows that the game score measured using an EMG-based physically interactive game system had a relationship with muscle strength, which is related to ankle instability and re-impairment. Thus we suggest that this game system can be used to predict the degree of weakness of muscle strength.

The limitations in this study were as following: first, there were no control groups, because this study investigated the relationship between the degree of the muscle strength and game score. Second, the game system was not used as an intervention.

In future studies, examination of the relationship between the game score obtained with this game system and proprioception or muscle balance index that causes instability needs to be carried out. Moreover, verification that this game system has therapeutic effects as rehabilitation equipment, by experiments conducted in healthy individuals and patients, is required.

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