Relationships among Jump Motion Control Ability, Knee Joint Position Sense, and Adjusting Muscle Contraction in Healthy Subjects

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Abstract. The purpose of this study was to investigate the correlations among motion control ability, joint position sense ability, and muscular strength adjustment ability in 15 healthy subjects. Motion control ability was measured by having participants jump with eyes closed to what they thought were distances of 25, 50, and 75% of their maximum jump in the vertical and standing broad jump. Joint position sense ability was measured by 8 tests at the left knee angle for subjects with closed eyes in seated and standing positions. Muscular strength adjustment ability was assessed by measuring the torque by Biodex System 3 of the demonstrated contraction when study subjects contracted their hip and knee extensors, and knee extensors to what they thought was 50% of their maximum voluntary muscle contraction. Results show relationships among the three abilities. We suggest that motion control ability is influenced by joint position sense ability and muscular strength adjustment ability.

Key words: Motion control, Joint position sense, Muscular strength adjustment ability

INTRODUCTION

Various motion controls are needed so that a human being can move in daily life. It is important to discover factors related to motion control ability in order to carry out physical therapy necessary for maintaining motion control ability1). If the factor is amenable to physical therapy, then motion control ability can derive beneficial effects from physical therapy. Abilities of joint position sense (JPS)2, 3) and muscular adjustment strength4) are factors related to motion control. However, in a search of the literature we could find no previous studies examining the relationships among motion control ability, JPS ability, and muscular strength adjustment ability.

The purpose of this study was to examine the control mechanism that centers on the intrinsic feedback mechanism between motion control ability, JPS ability, and muscular strength adjustment ability, and to investigate the relationship between abilities in healthy subjects. In motion control ability, jumps involving movement of the entire body were done with closed eyes in order to decrease feedback information as much as possible. Both vertical and standing broad jumps were done. JPS in a standing and in a seated position on the edge of a bed were measured at the knee joint and compared to what subjects thought of position sense in relation to related to the jump. Muscular strength adjustment ability was measured by isometric contraction of the hip and knee joint.
extensors, and the knee joint extensor alone. We hypothesized that JPS, muscular strength adjustment ability, and jump motion control ability relate to each other, and when JPS and/or muscular strength adjustment ability are high, there is excellent jump motion control ability.

**METHODS**

**Subjects**

Fifteen healthy subjects (14 males and 1 female) participated in this experiment. Approval for the study was obtained from the local ethics committee. All subjects gave their informed consent prior to participation in the study. No study subjects had a history of neurological disorders.

Jump motion control ability, knee JPS ability, and muscular strength adjustment ability were measured in the study subjects. The characteristics of the subjects were as follows: mean age 25.1 ± 4.5 years (SD), mean height 167.5 ± 6.9 cm (SD), mean weight 62.4 ± 10.7 kg (SD).

**Measurement of jump motion control ability**

Jump motion control ability was measured by vertical jump and standing broad jump. Each maximum jump was done twice, and the maximum value was adopted. Each subject jumped 3 times to what they thought was 25% of their maximum jump, then 3 times to 50%, and 3 times to 75%, for a total of 9 jumps with closed eyes. Three randomized measurements were conducted on 25, 50 and 75% of their maximum jump. The true values for 25, 50, and 75% values were obtained by calculation from the maximum value for each subject, and the difference between the calculated and the measured values were noted. In the standing broad jump, subjects were asked to match both their heels where their feet contacted the floor. The subjects had to line up their heels evenly and then a horizontal measure of the distance between the starting point and the landing place of the right heel was done. In the vertical jump, the subjects stood with their right side to a wall, extended the right elbow joint, flexed the right shoulder joint, and made a mark in chalk dust on the wall with the tip of their fingers. Then, they jumped in place vertically with their right arm/hand up to mark the height of their jump on the chalk-dusted wall with their fingertips.

**Measurement of knee JPS**

Knee JPS in the subjects was measured in triplicate using 8 types of tests. Details of the 8 tests are as follows:

1. Flexion of the knee joint from extension position to mild flexion position in a standing position.
2. Flexion of the knee joint from extension position to moderate flexion position in a standing position.
3. Extension of the knee joint from strong flexion position to mild flexion position in a squatting position.
4. Extension of the knee joint from strong flexion position to moderate flexion position in a squatting position.
5. Flexion of the knee joint from extension position to mild flexion position in a seated position on the edge of a bed.
6. Flexion of the knee joint from extension position to moderate flexion position in a seated position on the edge of a bed.
7. Extension of the knee joint from strong flexion position to mild flexion position in a seated position on the edge of a bed.
8. Extension of the knee joint from strong flexion position to moderate flexion position in a seated position on the edge of a bed.

Subjects were instructed to close their eyes, and stand erect on a firm level surface with their head in a mid-line position. The subjects placed their hands on their waist, and held both legs together. On command, subjects moved their legs to a light or moderate flexion position from the starting position at their preferred speed. At the required or criterion angle, subjects held their position for 5 seconds, and then returned to the starting position. Subjects were asked to reproduce the criterion angle at their preferred speed as closely as possible. Thus, the limbs were moved to a certain angle (mild or moderate flexion), the target angle. Subjects had to remember this position. After moving the limbs back to the start position, subjects had to reproduce the former position, generating the reproduction angle. The difference between the reproduction and the target angles, the error value, is seen as the ability of JPS. Subjects were clothed in shorts and footwear was removed. Subjects were marked with a seal on the skin surface over their greater trochanter, their lateral knee joint, and their lateral
malleolus as body landmarks. The seal was 2 cm in diameter and was mounted on a contrasting background; a 2.5 cm square seal on which the landmarks were placed. The JPS test was recorded using a video camera (Sony Corp, Tokyo, Japan) mounted on a tripod at a height of 77 cm and a distance of 185 cm from the subjects. The camera was positioned at knee level to produce a lateral view of the subject’s leg. For the seated position, the bed was positioned at a height of 80 cm from the floor. A computer running Scion Image software (beta version 4.0.2) on a Microsoft Windows platform was used. The settings and the precise positioning of the camera remained constant throughout the study. A standard explanation of the procedures was given to all subjects.

Measurement of muscular strength adjustment ability
Muscular strength adjustment ability was evaluated by measuring knee joint extensor, and hip and knee joint extensor isometric muscle contraction strength in a seated position with the use of a Biodex Multi-Joint System 3 (Biodex Medical Systems, Inc. New York). The knee joint angle was set at 60 degrees. The angle of the seat side and back was 100 degrees. The unilateral knee joint extensor isometric force was recorded by a standard strain-gauge transducer mounted inside a metal frame which was placed around the distal part of the ankle of the dominant leg above the malleoli using a Velcro belt. The hip and knee joint extensor isometric force was recorded by same transducer which was placed under the right calcaneus. Both extensors were measured twice at maximum muscular strength, and the muscular strength thought to be 50% of the maximum muscular strength value was demonstrated 3 times. The maximum muscular strength gave the maximum value. The maximum contraction was assumed for 5 seconds, followed by 5 seconds of rest between each muscle contraction each time. Afterwards, the 50% value of the maximum muscular strength was obtained by calculation, and muscle contraction practice to this 50% value, while observing the actually measured value on the monitor, was done 10 times. Next, the exercise was repeated 3 times, however, without the benefit of the subject seeing the monitor. The data of one second from 2 to 3 seconds during 5 seconds of contraction time was used. Data was sampled every 10 milliseconds, and 100 values were recorded in total. The variation between the calculation value and the measurement value was assumed to be the error margin value.

Data analysis
Error values (the absolute value of criterion angle minus the measured angle) were calculated from the individuals’ data, and used for analysis. One-way analysis of variance (ANOVA) followed by Bonferroni post-hoc comparisons were used to analyze the differences between each test of knee JPS.

In the analysis of muscular strength adjustment ability, before and after practice results were compared with the Mann-Whitney U test. The correlation of the mean value and the standard deviation of the margin of error value was analyzed for each relation between jump motion control ability, knee joint position ability, and muscular strength amount adjustment ability before and after practice with Pearson’s correlation coefficient. For all analyses, statistical significance was defined by a probability level of $p$ less than 0.05.

RESULTS
Jump motion control ability
Figure 1 shows the results of 25, 50, and 75% of maximum value jumps for the standing broad jump and the vertical jump for each subject. Overshooting target distances was generally seen in both types of jumps. Especially in the standing broad jump, and for the jumps in general—in all 3 target distances—the jumps themselves were actually 25 to 50% farther than the target values. There was both intra- and interindividual variation in the vertical jump, with the interindividual jumps varying widely.

The average and the standard error of the error margin value of 25, 50, and 75% in the standing broad jump were 23.6 ± 2.58%, 14.38 ± 2.13%, and 7.52 ± 0.96%, respectively. The difference was significant ($p<0.01$) between 25% and 50%, and 25% and 75%. In the vertical jump, the average of the margin of error value and the standard error value at 25, 50, and 75% jump were 23.81 ± 3.96, 17.34 ± 2.96%, and 8.81 ± 1.78%, respectively. The difference was significant ($p<0.01$) between 25% and 75%.

The averages and the margin of error values for the vertical jump and standing broad jump were
evaluated for possible correlation between the two; however, no relationship was found.

**Margin of error value for the JPS**

The mean value and standard error for each knee JPS test were from tests 1 to 8: $2.4 \pm 0.25^\circ$, $3.09 \pm 0.39^\circ$, $5.11 \pm 0.44^\circ$, $4.04 \pm 0.78^\circ$, $2.07 \pm 0.36^\circ$, $4.67 \pm 0.56^\circ$, $1.93 \pm 0.3^\circ$, and $2.89 \pm 0.34^\circ$, in ascending order. The range of error is from $1.93^\circ$ to $5.11^\circ$, and it is comparatively accurate. Table 1 shows one-way ANOVA of JPS and test. The difference was significant ($p<0.005$) between 1 and 3, 3 and 7, 5 and 6, and 6 and 7.

**Muscular strength adjustment ability**

The muscular strength demonstrated value to the target value, that is, the margin of error value for the knee joint extensor muscular strength was $10.86 \pm 7.67\%$, and for the hip and knee joint extensor muscular strength it was $9.66 \pm 7.55\%$; no significant difference was found. There was no correlation between the margin of error and the maximum muscular power of the knee joint extensor muscular strength or the hip and knee joint extensor muscular strength. Moreover, in many study subjects neither the knee joint extensor muscular strength, nor the hip and knee joint extensor muscular strength came up to the target value for the subjects (Fig. 2). Five study subjects achieved the value of the target value to within $\pm 10\%$ for both the knee joint extensor muscular strength and the hip and knee joint extensor muscular strength. In addition, there is diffusion in the distribution of the margin of error value for the knee joint extensor muscular strength, and the hip

**Table 1.** One-way ANOVA output for regression analysis: JPS (angle) and test

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<th>Mean Square</th>
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<td>63</td>
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**Fig. 1.** The results of 25, 50, and 75% of maximum value jumps in the standing broad jump and the vertical jump for each subject. Top: standing broad jump, Bottom: vertical jump.

**Fig. 2.** The adjustment ability for 50% voluntary muscle contraction. The average value and difference for each subject is shown.
and knee joint extensor muscular strength (Fig. 3).

**Short-term result after practice**

In the after-practice results, the margin of error value for the knee joint extensor muscular strength was, $6.02 \pm 7.31\%$, and for the hip and knee joint extensor muscular strength it was $5.82 \pm 6.72\%$. The margin of error values in the knee joint extensor muscles, and the hip and knee joint extensor muscles when each subject concentrated on achieving the target value (50% MVC value) are shown in Fig. 4. The number of study subjects able to reach the value of the target value to within $\pm 10\%$ increased to 9 individuals. With respect to the distribution of the margin of error values, for both the knee joint extensor muscular strength and the hip and knee joint extensor muscular strength, it approached 0%.

There was no significant difference in muscular strength adjustment ability between the knee joint extensor muscular strength, and the hip and knee joint extensor muscular strength. On average, an error of approximately 10% was seen. After having practiced voluntary muscle contraction, the mean value of the margin of error value improved to about 6%. The variation in knee extensor muscular strength ability before and after practice was statistically significant ($p<0.05$).

**Correlation between jump motion control ability and JPS ability**

In test 1, the correlation coefficient for the relationship between the average margin of error value in the knee JPS and the standard deviation of the margin of error value for 25% demand value in the standing broad jump was $r=0.552$, $p<0.05$. For the relationship between the standard deviation of the margin of error value in the knee JPS and the standard deviation of the margin of error value for 25% demand value in the vertical jump the coefficient was $r=0.452$, $p<0.05$.

In test 2, the correlation coefficient for the relationship between the average margin of error value in the knee JPS and the average margin of error values for 25 and 50% demand value in the vertical jump were $r=0.460$, $p<0.05$, and $r=0.461$, $p<0.05$, respectively. The coefficient for the association between the average margin of error value in the knee JPS and the standard deviation of the margin of error value for 75% target value in the standing broad jump gave a coefficient of $r=0.490$, $p<0.05$. Between the standard deviation of the error margin value in the knee JPS and the standard deviation of the margin of error value for 75% target value in the
vertical jump, the correlation coefficient was \( r = 0.546, p < 0.05 \).

In test 3, between the standard deviation of the margin of error value in the knee JPS and the average margin of error value for 25 and 50% target value in the vertical jump, the coefficients were \( r = 0.471, p < 0.05 \), and \( r = 0.520, p < 0.05 \), respectively.

In test 4, the coefficient for the relationship between the average margin of error value in the knee JPS and the standard deviation of the margin of error value for 25% target value in the vertical jump was \( r = 0.479, p < 0.05 \). Between the average margin of error value in the knee JPS and the standard deviation of the margin of error value for 75% target value in the standing broad jump, the coefficient was \( r = 0.493, p < 0.05 \). The relationship between the standard deviation of the margin of error value in the knee JPS and the standard deviation of the margin of error value for 75% target value in the standing broad jump showed \( r = 0.499, p < 0.05 \).

In test 5, the correlation coefficient for the relationship between the average margin of error value in the knee JPS and the standard deviation of the margin of error value for 50% target value in the vertical jump was \( r = 0.526, p < 0.05 \). No valuable association was found between the results of JPS test 6, 7, and 8, and jump motion control ability.

**Correlation between jump motion control ability and muscular strength adjustment ability**

The correlation coefficient and p value were calculated for the relationship between jump motion control ability and muscular strength adjustment ability from the margin of error value for each target value or standard deviation of the individually measured 3 trials and adjustment muscle contraction with and without practice. The following results were obtained for the vertical jump. The association between the average 25% target value and the average error of the margin of error value for the hip extensor after practice was \( r = 0.513, p < 0.05 \). Between the average error for 75% target value and the standard deviation of the margin of error value for the 3 trials of the hip and knee extensor after practice the relationship was \( r = 0.526, p < 0.05 \). Between the average error for 75% target value and the average error of the knee extensor before practice, the correlation coefficient was \( r = 0.508, p < 0.05 \). Between the standard deviation of the margin of error value for 50% target value and the standard deviation of the individually measured 3 trials margin of error value of the knee extensor before practice, the coefficient was \( r = 0.452, p < 0.05 \). Between the standard deviation of the margin of error value for 75% target value and the standard deviation of the margin of error value of the hip and knee extensor before practice, the association was \( r = 0.593, p < 0.05 \). The relationship between the standard deviation of the margin of error value for 75% demand value and the standard deviation of the margin of error value for the 3 trials of the hip and knee extensor after practice was \( r = 0.565, p < 0.05 \).

**DISCUSSION**

**Voluntary jump ability**

In the results of the voluntary jump ability, all subjects jumped greater than the 25% target value in both the vertical and standing broad jump. Almost all subjects jumped greater than the 50% target value. Similar to our findings, a previous study\(^5\,\,6\) reported that subjects jumped greater than the target value. Kawahara\(^9\) described why closed eyes
decreases visual inhibition of the circuit and subjects over-jump. In our results, we speculate that lack of information from the visual sense inhibited motor control.

As for the relationship between vertical jump and standing broad jump, Robertson et al. reported that muscles of the hip, knee, and foot joint contribute to the vertical jump at levels different from their contributions toward the standing broad jump. The specific contribution levels of the hip, knee, and foot joint muscles were 40.0%, 24.2%, and 35.8%, respectively, in the vertical jump, and they were 45.9%, 3.9%, and 50.2%, respectively, in the standing broad jump. It seems that the jump motion control ability between vertical and standing broad jump is a variant of the muscle specific contribution levels.

**JPS ability**

Koralewicz et al. reported that 117 knee arthritis patients and 40 normal subjects were compared in regard to proprioception of the knee. With the subject’s knee in 45° of knee flexion, the researcher hooked the boots to the lever arm of the Biodex. The researcher verified the 45° angle of flexion with a goniometer and made fine adjustments to obtain this angle. The Biodex machine extended or flexed the knee at 0.5° per second until the subject detected passive motion or a change in joint position and stopped the motion with a handheld stop button; he or she was then asked to identify the direction (flexion or extension) of the knee movement. In the results of their study the threshold of detection was 2.57° (range 0.61–4.43) in the direction of flexion, 2.71° (range 0–16.3) in the direction of flexion in the test subjects with knee arthritis, and 1.42° (range 0.26–4.08) in the direction of extension, 1.64° (range 0.61–4.43) in the direction of flexion with normal subjects. Barrack et al. measured knee JPS in the seated position, and reported the margin of error values in patients with total knee replacement (average age 62.4 years), an age matched control group (average age 63 years), and a young control group (average age 24.9 years). Their results were 5.9 ± 1.6° in the age matched control group and 3.8 ± 1.0° in the young control group. The data of Koralewicz et al. and Barrack et al. was not unlike our data. Liao et al. measured knee JPS in 9 below-knee amputees and 9 normal subjects within the range of 5–25° passive knee flexion. In Liao’s study, the results for the normal subjects were 2.19 ± 0.75° on the right side and 2.07 ± 0.55° on the left side. Barrett et al. examined knee flexion at 0–30° position sense in patients with diseased knee joints and in healthy subjects. Their results showed a decrease in position sense with age. Also their results showed about 2% variation of the margin of error value in thirty subjects.

The results of Liao et al. and Barrett et al. were almost the same as our data. Sharma et al. reported that the margin of error value was 2.43 ± 1.58° on the right side and 2.63 ± 1.22° on the left side for knee JPS in the seated position for subjects with an average age of 71 years. Our results support his data, and together they indicate that knee JPS does not decrease with aging. Ishii et al. measured knee JPS in the standing position. The margin of error in healthy subjects with an average age of 70 years was 6.5 ± 2.7° within knee flexion angles of 30° to 70°. Grob et al. reported that there was no correlation with margin of error value; the reason for no correlation was lack of contralateral reproducibility. Their results showed that there are no correlations between cognition and reproducibility. However, our data showed fewer variations than Grob’s data. We thought that there are correlations between cognition and reproducibility concerning JPS ability.

**Muscle strength adjustment ability**

The demonstrated muscular strength value was lower than the target value. Subjects showed that muscular strength was more than the expectation. In the demonstrated muscular strength adjustment ability in the knee joint extensor muscular strength and the hip and knee joint extensor muscular strength, there was no difference in the demonstrated muscular strength value to the target. We consider that the effect of a short-term practice suggested improvement because muscular strength adjustment approached the target value after practice.

**Correlation between jump motion control ability and JPS ability**

A relationship between standing JPS ability and vertical and standing broad jump control ability was seen in this part of the study. Our results reveal that subjects with low standing JPS also had low jump motion control ability. We thought that the relationship between JPS ability and reproducibility...
of the jump motion was poor because of the comparatively high knee JPS ability in all our subjects in a seated position.

**Correlation between jump motion control ability and muscular strength adjustment ability**

With respect to the relationship between jump motion control and muscular strength adjustment ability, a statistical correlation was seen for the vertical jump. No correlation was seen for the standing broad jump.

In the vertical jump, we found that jump motion control ability is significantly related to muscular strength adjustment ability. We suggest that subjects who are able to adjust muscular strength close to the target value, or who demonstrate consistent muscular strength, have the ability to reach the target value in the vertical jump. We also suggest that subjects who have low variation in demonstrated muscular strength 3 times before and after practice had high vertical jump control ability.

**Correlation between JPS ability and muscle strength adjustment ability**

A correlation was seen between JPS ability in the standing position and muscular strength adjustment ability. As for muscular strength adjustment, the influence of sensory input from the muscle spindle is especially strong. Moreover, the main sensory input influencing JPS ability is the muscle spindle. The two abilities seem to be related because both are controlled by a series of motor systems initiated by sensory input from the muscle spindle. We suggest that when these two abilities decrease, motion control ability will be decreased. As it turned out, these were factors that strongly related to motion control ability.

It is understood that movement is controlled even in the absence of visual input, despite daily reliance on vision in motor control. We wanted to investigate motion control by means of performance when the body searches how much it does by matching the joint position, and after practicing muscle strength adjustment. We want to plan the establishment of a methodology to improve motion adjustment ability and a physical therapy program. We want to investigate the relationship between falls and motion adjustment ability in the elderly.

**CONCLUSION**

In this study, we demonstrated correlations between jump motion control ability in the vertical jump and knee JPS ability in the standing position, jump motion control ability and muscular strength adjustment ability, and knee JPS ability and muscular strength adjustment ability. As for jump motion control, it was found that high JPS ability of the knee in a standing position translates to high motion control ability in the vertical jump. Motion control ability can be inferred from knee JPS ability in the standing position. Moreover, it has been shown that high muscular strength adjustment ability relates to high jump motion control ability, and one can infer a role for muscular strength adjustment ability in motion control. Because a learning effect is seen in muscular strength adjustment ability, it is necessary to train the ability for improved motion control. Our data suggest that voluntary muscular strength adjustment ability feeds back on motion control. Voluntary muscular strength adjustment ability provided the opportunity to make an adjustment; i.e., correction, when the subjects could see whether the measured value of their contraction differed from the target value.

**REFERENCES**

109.