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Gender Difference in Ability Using the Stretch-Shortening Cycle in the Upper Extremities

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Abstract

Miyaguchi, K and Demura, S. Gender difference in ability using the stretch-shortening cycle in the upper extremities. *J Strength Cond Res* 23(1): 231–236, 2009—A gender difference in ability using the stretch-shortening cycle (SSC ability) in the upper extremities has not been studied in detail. This study aimed to devise an index to evaluate SSC ability during powerful elbow flexion and to examine its gender differences. Thirty-three men athletes (19.9 ± 1.0 years) and 21 women athletes (20.6 ± 1.2 years) with mastered SSC movements participated in this study. They pulled a 20% load of maximal voluntary contraction (MVC) by elbow flexion as quickly as possible with the dominant upper extremity from the following two preliminary conditions: a static relaxed muscle state (SR condition) and using a countermovement (SSC condition). The muscle power was measured accurately by a power measurement device, which adopted the weight loading method. The peak power under both conditions showed significantly higher values in men than in women. In both genders, the peak power showed significantly lower values in the SSC condition than in the SR condition ($p < 0.05$). The potentiation of using the SSC was not found in the peak power test. However, the initial power showed significantly higher values under the SSC condition (men: 37.2 ± 6.4 W; women: 17.4 ± 5.1 W) than in the SR condition (men: 18.3 ± 4.3 W; women: 11.2 ± 3.1 W). Hence, assuming a difference between initial muscle power outputs of the SR and SSC conditions as a difference in SSC ability, an SSC index was devised to evaluate the above ability. The SSC index showed significantly higher values in men (50.1 ± 12.4) than in women (32.1 ± 23.2). However, the individual difference of SSC ability was very large in women. The ability of women to use SSC in the upper extremities may be inferior to that of men.

Key Words elbow flexion, muscle power, rotary encoder, countermovement

Introduction

In competitive sports such as baseball, handball, and javelin throwing, an overhand throw by an upper extremity frequently occurs. This throwing ability in women is usually inferior to that of men (26,36). As one of the causes of gender differences in such throwing ability, social or cultural influences have been considered. In fact, Halverson et al. (15) report that boys have more opportunities to learn the overhand throw during childhood than girls.

However, the boys' throwing ability measured by throwing distance is twice that of girls in Thailand or Indonesia, who have few opportunities to play baseball or catch (25,30). The most superior throwing ability for girls in Japan is almost the same as the general one for boys (29). These reports suggest that factors other than environmental ones contribute to throwing performances.

Muscle strength (an absolute value) of women is equivalent to 50–60% of men's when we compare isometric muscle strength among men and women (1,22). In particular, gender differences in muscle function of the upper extremities are more pronounced than those of the lower extremities (9). However, it was reported that this gender difference of muscle strength in the upper and lower extremities may be corrected to some extent when compared with relative values of muscle strength for cross-sectional area (21,22). Therefore, we cannot fully explain a large gender difference in throwing performance by a muscle strength difference.

In overhand throwing, a stretch-shortening cycle (SSC) with countermovement (e.g., back swing) is frequently used to exert explosive power (27). Concentric contraction using the SSC produces greater power output in a shorter period of time than a single concentric contraction only (18,37). Hence, the following was hypothesized: even if a gender difference is not found in relative muscle strength exerted by

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a single muscle contraction, there is a gender difference in SSC ability based on a combined muscle contraction pattern. Clarifying the above will be beneficial for explaining gender differences in performance in running/jumping as well as throwing.

This study aimed to devise an index to evaluate ability using SSC during powerful elbow flexion, and to examine its gender differences.

Methods

Experimental Approach to the Problem

In this study, elbow flexion was chosen as a measurement motion. When considering the motion style of an overhand throw, we should adopt elbow extension. However, a large burden to the elbow joints of the subjects was a concern. In addition, even women who are inexperienced in throwing can do the countermovement easily in the case of elbow flexion, and it was judged to be a valid measurement motion to examine a basic SSC ability. Assuming a difference between initial muscle power outputs of SR (noncountermovement) and SSC (using countermovement) conditions as a difference in SSC ability, an SSC index was devised to evaluate the above ability and examine the gender differences.

Subjects

The subjects were 33 young adult men (mean age 19.9 ± 1.0 years, mean height 172.5 ± 4.1 cm, mean weight 67.3 ± 10.7 kg, and athletic careers 8.0 ± 3.5 years) and 21 women (mean age 20.6 ± 1.2 years, mean height 161.6 ± 5.9 cm, mean weight 56.4 ± 6.0 kg, and athletic careers 10.4 ± 3.0 years) who had experience in competitive sports related to SSC movement.

The subjects were selected from the following events: baseball, tennis, volleyball, basketball, etc., for men, and volleyball, tennis, table tennis, gymnastics, basketball, etc., for women. Most subjects performed sports training and resistance training two to four times per week routinely. It was judged that 29 men were right-handed and that 4 men were left-handed by Oldfield's (28) handedness inventory. All women were right-handed. Informed consent was obtained from all subjects after a full explanation of the experimental project and its procedures. The study was approved by the human rights committee of Kanazawa University.

Procedures

Experimental Device and Muscle Power Measurement. Muscle power was measured using a muscle power measurement instrument that adopted a weight loading method developed by Ikemoto et al. (16) (Yagami, Japan) (Figure 1). This measurement device consists of a rotary encoder (SUNX, ORE38-1200) attached to a fixed pulley and a recording device. The rotary encoder measures the rotational angle with a sampling frequency of 100 Hz via an analog-to-digital interface. The resolution of the rotary encoder was 1200 pulses per turn. The rotational angle was converted to the pulling velocity of the wire rope with the load in the recording device. The muscle power was drawn from the product of the pulling velocity and load mass, based on Newton's second law of motion. The formula for computation of muscle power was as follows:

$$\text{Peak power (W)} = \text{load mass (kg)} \times \text{acceleration of gravity } (9.807\text{m}\cdot^{-2}) \times \text{peak velocity } (\text{m}\cdot^{-1})$$

Each subject sat in an adjustable ergometric chair sideways and put his or her dominant arm on a table. Each subject then put his or her axilla on the edge of the table with supination of the forearm. A bowling protector was worn to restrict the movement of the wrist. Subjects touched their palm to the handle, and then they explosively pulled the handle by elbow flexion as quickly as possible in the opposite direction of a wire rope that was connected to a constant-load mass. The range of motion of the elbow flexion was from 80 to 120° (full-extension angle was 0°), and the starting position angle was 80°. To account for systematic error, the rotary encoder and load cell were calibrated before each measurement.

Load Setting. It was reported that the coupling time of SSC (the delay time between the cessation of the eccentric and onset of concentric muscle action) considerably influences SSC performance (8). Therefore, it is desirable to compare SSC ability exerted with the load setting that women can pull at the same speed as men. In addition, it was reported that the effect of prestretching is very high when performing a movement such as a flexible spring in the case of using SSC in the upper extremities (34). Therefore, a light-intensity

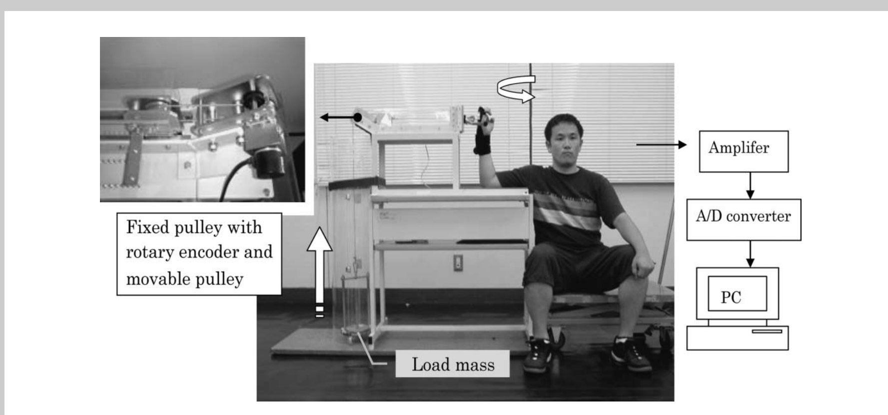

Figure 1. Schematic representation of experimental setup.

load, which can recognize weight without producing muscle tone, was chosen. As a result of the pilot study, it was confirmed that men and women could efficiently perform countermovement with 20%MVC and that the pulling velocity of men and women was equal. The weight corresponding to 20%MVC was 3.6 ± 0.7 kg in men, and that of women was 2.4 ± 0.4 kg.

In the case of a lightweight load of 20–30% MVC, Ikemoto et al. (16) reported that there was an insignificant difference between women and men in the time of motion execution in explosive gripping using the same device. Therefore, we judged that the influence of individual differences in 20–30% MVC is small, and we selected a fixed load of 4 kg in men and 2 kg in women for convenience.

Experimental Conditions. Muscle power output was measured to evaluate the ability of using SSC under the following two conditions:

1. SR condition: Each subject pulled the handle from a static relaxed arm muscle state, keeping an 80° (full-extension angle was 0°) elbow joint by only concentric contraction.
2. SSC condition: Each subject stood still once, having maintained a load at an angle of 110°, and, after a signal from a tester, pulled the handle using a voluntary countermovement once, according to the subject's original rhythm and timing within the range of 80–110°. The starting angle of concentric contraction on elbow flexion was determined by a beeping sound from a device to be 80°. The subjects conducted some practical trials to get accustomed to the device and explosive contraction. The power test was performed twice for the above-stated two conditions, and the higher value was used for the data analysis. The experimental design was a crossover design where the subjects were arranged at random under each condition. The interval between trials and conditions was set for 3 minutes, in consideration of the influence of muscle fatigue. Test-retest reliability in the peak power test was high (men SR: ICC = 0.85, SSC: ICC = 0.90; women SR: ICC = 0.92, SSC: ICC = 0.92).

Evaluation Parameters

In this study, the following five evaluation parameters were selected by referring to previous studies (23): 1) peak velocity ($m \cdot s^{-1}$), 2) time to peak velocity (seconds), 3) peak power (W), 4) 0.1-second velocity during concentric contraction ($m \cdot s^{-1}$), and 5) 0.1-second initial power (W) (Figure 2).

In addition, we assumed that a muscle power output difference between the SR condition and the SSC condition was related to a difference in SSC ability, and we devised an index to evaluate SSC ability. It was reported that the use of SSC in the upper limbs is extremely effective in enhancement of initial muscle contraction velocity (23). Therefore, the initial power output value (0.1-second initial power) at which an SSC potentiation is observed conspicuously was adopted. The formula for the computation of SSC index was as follows:

$$\text{SSC index} = \frac{(\text{0.1-second initial power} - \text{SR 0.1-second initial power}) \times 100}{\text{SSC 0.1-second initial power}}$$

Statistical Analyses

The relation of pulling velocity between SR and SSC conditions was examined using the Pearson correlation coefficient. A *t*-test was used to reveal the mean differences in physical characteristics and parameters between men and women, and effect size (ES) values were calculated to examine the sizes of the mean differences. The criterion for significance was set at $p \leq 0.05$.

Results

Figure 3 shows the relationships between the SR and SSC conditions for 0.1-second velocity and peak velocity in both genders. The SR condition showed significant, high correlations (men: $r = 0.84$; women: $r = 0.78$) with the SSC condition in peak velocity in both genders, but not in 0.1-second velocity.

Table 1 shows the results of a *t*-test to reveal gender differences in physical characteristics and evaluation parameters. The peak power under both conditions showed significantly higher values in men than in women. In both genders, the peak power showed significantly lower values under the SSC condition than under the SR condition ($p < 0.05$). The potentiation of using the SSC was not found in the peak power test. However, the initial power showed significantly higher values under the SSC condition (men: 37.2 ± 6.4 W;

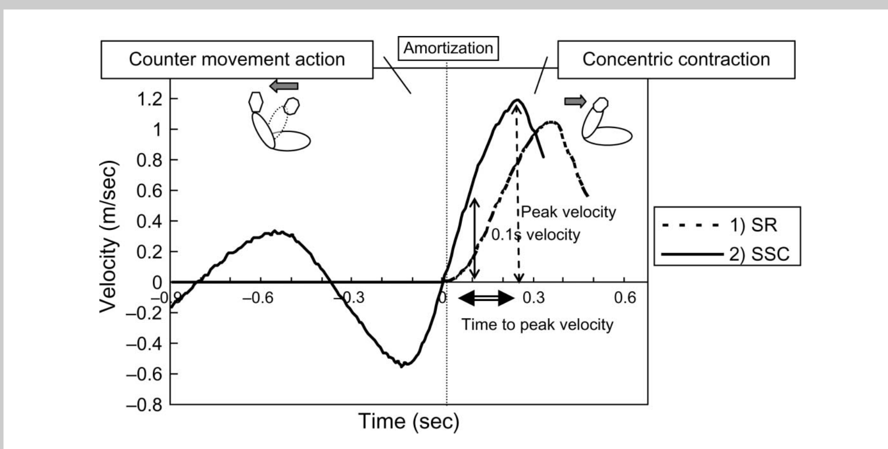

Figure 2. Typical time-series velocity curve of static relaxed muscle (SR) and stretch-shortening cycle (SSC) conditions and parameters.

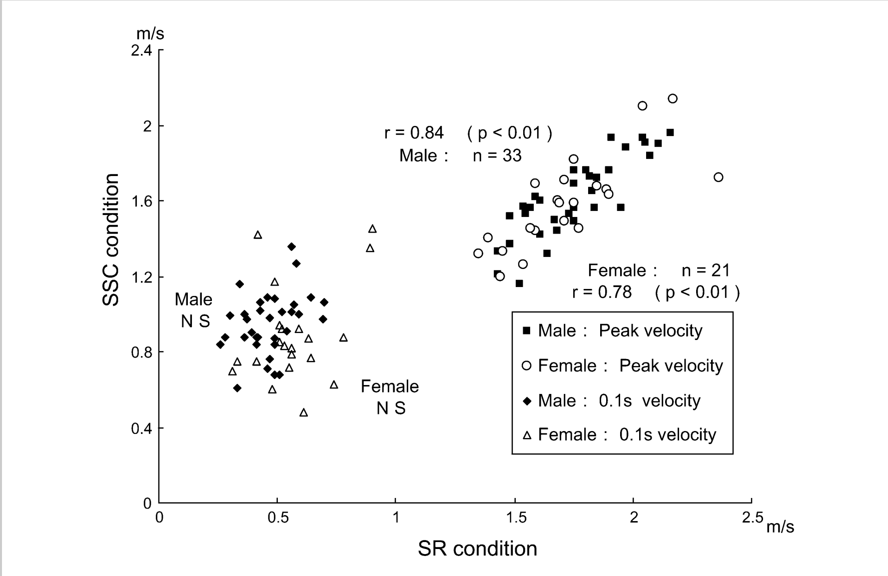

Figure 3. Relationships between static relaxed muscle (SR) and stretch-shortening cycle (SSC) conditions for 0.1-second velocity and peak velocity.

As for the SSC index of men and women, men (50.1 ± 12.4) showed a significant and higher value than women (32.1 ± 23.2). In the SSC index, the ratio for men to women was 64.1%. The CV of the SSC index was much larger in women (72.3) than in men (24.8).

women: 17.4 ± 5.1 W) than under the SR condition (men: 18.3 ± 4.3 W; women: 11.2 ± 3.1 W).

The peak velocity of both conditions by the load setting in this study (men: 2 kg; women: 1 kg) was almost the same level in men and women. On the other hand, in 0.1-second velocity from the SR condition, women (0.57 m·s^{-1}) showed higher values than men (0.47 m·s^{-1}), but not in the SSC condition. Time to peak velocity showed a higher value in women than men in the SR condition, but not in the SSC condition.

Discussion

The SSC has been mainly examined by jump movement (3,7,35), and there are some reports on gender differences. However, the mechanism of SSC in the upper extremities has not been examined in detail, and the gender differences are unclear. This study aimed to evaluate SSC ability of the upper extremities, which is related closely to throwing performances, and to examine its gender differences.

The SR condition showed significant, high correlations (men: $r = 0.84$; women: $r = 0.78$) with the SSC condition for peak velocity in both genders, but not for 0.1-second velocity. The above suggests that physical abilities (a physiological factor) related to the peak velocity of both conditions are similar, but a different factor contributes to the initial velocity. In particular, it is inferred that the influence (recycling of resilience including myotatic reflex action, etc.) of elastic

Table 1. Gender differences in physical characteristics and evaluation parameters.

	Men ($n = 33$), mean ± *SD*	Women ($n = 21$), mean ± *SD*	*t*-Test	ES
Height (cm)	172.5 ± 4.1	161.6 ± 5.9	†	0.46
Weight (kg)	67.3 ± 10.7	56.4 ± 6.0	†	0.18
MVC elbow flexion (kg)	17.8 ± 3.6	12.1 ± 1.9	†	0.28
SR peak velocity (m/s)	1.75 ± 0.21	1.72 ± 0.25	NS	0.03
SR 0.1s velocity (m/s)	0.47 ± 0.11	0.57 ± 0.16	†	−0.16
SR peak power (W)	68.7 ± 8.1	33.7 ± 4.9	†	0.76
SR 0.1s power (W)	18.3 ± 4.3	11.2 ± 3.1	†	0.29
SR time to peak velocity (s)	0.29 ± 0.03	0.27 ± 0.03	*	0.12
SSC peak velocity (m/s)	1.61 ± 0.21	1.58 ± 0.24	NS	0.03
SSC 0.1s velocity (m/s)	0.95 ± 0.16	0.89 ± 0.26	NS	0.07
SSC peak power (W)	63.3 ± 8.3	31.0 ± 4.7	†	0.69
SSC 0.1s power (W)	37.2 ± 6.4	17.4 ± 5.1	†	0.54
SSC time to peak velocity (s)	0.22 ± 0.02	0.23 ± 0.03	NS	−0.09

ES = effect size; MVC = maximal voluntary contraction; SR = static relaxed muscle state; SSC = stretch-shortening cycle; NS = nonsignificant.
* $p < 0.05$; † $p < 0.01$.

components contributes considerably to the initial velocity in an SSC condition. However, because the influence caused by elastic components is temporary (initial phase), and the contractive force of muscle (contractile component) finally contributes to peak velocity, the correlation between peak velocity under both conditions may have been high.

Even if the potentiation of SSC is observed in the initial phase of force exertion in the upper extremities, it disappears in the latter half (23,33). Therefore, it is possible that the SSC ability of the upper extremities cannot be properly evaluated with only peak performance (peak power) such as the jumping height of the lower extremities. This notion is further explained by the following: exercise by the upper extremities is an open–kinetic chain exercise that is a combination of successively arranged joints in which the terminal joint is free to move. In contrast, exercise by the lower extremities is a closed–kinetic chain exercise in which the terminal joint meets with considerable resistance that prohibits or restrains its free motion (32).

In addition, this result may be explained by a difference in the time to complete the exercise between the upper and lower extremities. The ground contact time of the drop jump, which jumps as quickly as possible, is $200\ m{\cdot}s^{-1}$ or less (6,38). On the other hand, the time to peak velocity during elbow flexion under the SSC condition is 0.22–0.23 seconds, and the total time to complete the exercise may become longer when the coupling time is added. Therefore, in the drop jump, because of flying up after reaching the ground immediately, the influence of SSC may be large. On the other hand, in the elbow flexion of this study (the SSC use), although the influence of SSC is large just after the coupling time, the movement may be performed by a different power exertion style, as for the end situation.

Therefore, we paid attention to 0.1-second muscle power output after starting the muscle contraction proposed by Miyaguchi and Demura (23), and we tried to devise an SSC index of the upper extremities. As a result, a gender difference was found in SSC ability, and the ability was superior in men as compared with women. This result supported the hypothesis of this study. The ability to use SSC in women was 64.1% that of men. Measurements comparing power outputs of competitive lifters revealed that during the entire snatch or clean pulling movements, the power output of women relative to total body weight was about 63% that of men (14). Similar findings regarding power output were observed in presumably untrained women (20). It is noteworthy that the gender differences are similar for these different activities relative to the SSC.

Generally, the absolute muscle strength of women is less than that of men in any muscle action type, and there also are gender differences in competition performance. It was reported that the dominance in women of type I muscle fibers (31) and a difference in the degree of inhibition in the nervous system (13) may be related to the gender difference in muscle strength. In addition, muscular morphologic characteristics (muscle fascicle length, muscle length, pennation angles) may be influential. However, when strength is expressed relative to muscle cross-sectional area, no significant difference exists between sexes, which indicates that muscle quality (peak force per cross-sectional area) is not sex specific (11,22). Although men still perform better than women in sports activities in general, it seems that differences in fat-free mass (muscle strength per cross-sectional area) are not entirely responsible for differences in performance.

According to previous studies (4,12), it was reported that ability using the elastic energy by eccentric muscle action is superior in women vs. men. Komi and Bosco (19) have pointed out that the ability to endure extension load is superior in men compared with women, but the ability to use elastic energy is inferior in men. Furthermore, Aura and Komi (4) report that women are superior in storage and recycling ability of elasticity energy compared with men when the extension load is small, but inferior when the load is large. This may depend on a gender difference of muscle stiffness and depression of the central nervous system (12). Because the muscular structural stiffness of women is inferior to that of men (5), and women's tendons are more compliant than those of men (17), it is inferred that women's tendons can easily save elastic energy but cannot bear the powerful counter-attack force required in SSC action. It has been reported that women basketball players were six times more likely to incur anterior cruciate ligament tears than men players (2). This may be related to the above-mentioned report.

In conclusion, although the absolute muscle strength of women is less than that of men, particularly when exerting muscle power using the SSC, the muscle power output of women may also be less than that of men.

Practical Applications

Elbow flexion is a single joint movement without technical intervention and is different from overhand throws. Women subjects might have become considerably accustomed to the SSC movement from their athletic careers. However, the gender difference in ability using SSC was more than what had been expected. The above should be noted as one of the large causes of women's lower ability in overhand throwing.

In addition, because the upper-body strength of women tends to be less than that of men, the movement to exert explosive power in the upper limbs, such as in throwing and hitting, may cause larger gender differences in performance than in jumping or running.

However, the individual difference in the SSC index was larger in women than in men. This may suggest that the trainability of SSC in women is higher than in men. Therefore, in the case of women, when first raising the maximum strength of the upper body by the bench press as Miyaguchi and Demura (24) recommend, one should next perform plyometrics training (plyometrics for the upper body include medicine ball throws, catches, and several types of push-ups) in an attempt to strengthen the ligaments, and an improvement in SSC ability may result.

Recently, Caserotti et al. (10) have examined the gender difference of ability using SSC in the lower extremities among senior citizens; they report that women had a lower ability than men in this respect, which may increase the fall rate of women. A study on SSC may be important in rehabilitation for their function recovery, as well as in sports, in the future.

References

1. Abe, T, Dehoyos, DV, Pollock, ML, and Garzarella, L. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur J Appl Physiol* 81: 174–180, 2000.
2. Arendt, E and Dick, R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *Am J Sports Med* 23: 694–701, 1995.
3. Asmussen, E and Bonde, PF. Storage of elastic energy in skeletal muscles in man. *Acta Physiol Scand* 91: 385–392, 1974.
4. Aura, O and Komi, PV. The mechanical efficiency of locomotion in men and women with special emphasis on stretch-shortening cycle exercises. *Eur J Appl Physiol* 55: 37–43, 1986.
5. Blackburn, JT, Padua, DA, Weinhold, PS, and Guskiewicz, KM. Comparison of triceps surae structural stiffness and material modulus across sex. *Clin Biomech (Bristol, Avon)* 21: 159–167, 2006.
6. Bobbert, MF, Huijing, PA, and van Ingen Schenau, GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Med Sci Sports Exerc* 19: 332–338, 1987.
7. Bosco, C and Komi, PV. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiol Scand* 106: 467–472, 1976.
8. Bosco, C, Komi, PV, and Ito, A. Prestretch potentiation of human skeletal muscle during ballistic movement. *Acta Physiol Scand* 111: 135–140, 1981.
9. Burger, ME and Burger, TA. Neuromuscular and hormonal adaptations to resistance training: implications for strength development in female athletes. *Strength Cond J* 24(3): 51–59, 2002.
10. Caserotti, P, Aagaard, P, Simonsen, EB, and Puggaard, L. Contraction-specific differences in maximal muscle power during stretch-shortening cycle movements in elderly males and females. *Eur J Appl Physiol* 84: 206–212, 2001.
11. Castro, M, McCann, D, Shaffrath, J, and Adams, W. Peak torque per unit cross-sectional area differs between strength-training and untrained adults. *Med Sci Sports Exerc* 27: 397–403, 1995.
12. Colliander, EB and Teach, PA. Bilateral eccentric and concentric torque of quadriceps and hamstring muscles in females and males. *J Appl Physiol* 59: 227–232, 1989.
13. Dudley, GA, Harris, RT, Duvoisin, MR, Hather, BM, and Buchanan, P. Effect of voluntary vs. artificial activation on the relationship of muscle torque to speed. *J Appl Physiol* 69: 2215–2221, 1990.
14. Garhammer, J. A comparison of maximal power outputs between elite male and female weightlifters in competition. *Int J Sport Biomech* 7: 3–11, 1991.
15. Halverson, LE, Roberton, MA, and Langendorfer, S. Development of the over-arm throw: movement and ball velocity changes by seventh grade. *Res Q Exerc Sport* 53: 198–205, 1982.
16. Ikemoto, Y, Demura, S, Yamaji, S, Nakada, M, Kitabayashi, T, and Nagasawa, Y. The characteristics of simple muscle power by gripping: gender differences and reliability of parameters using various loads. *J Sports Med Phys Fitness.* 46: 62–70, 2006.
17. Kato, E, Oda, T, Chino, K, Kurihara, T, Nagayoshi, T, Fukunaga, T, and Kawakami, Y. Musculotendinous factors influencing difference in ankle joint flexibility between women and men. *Int J Sport Health Sci* 3: 218–225, 2005.
18. Komi, PV. Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exerc Sport Sci Rev* 12: 81–121, 1984.
19. Komi, PV and Bosco, C. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports* 10: 261–265, 1978.
20. Komi, PV and Karlsson, J. Skeletal muscle fiber types, enzyme activities and physical performance in young males and females. *Acta Physiol Scand* 103: 210–218, 1978.
21. Maughan, RJ, Watson, JS, and Weir, J. Strength and cross-sectional area of human skeletal muscle. *J Physiol* 338: 37–49, 1983.
22. Miller, AE, Macdougall, JD, Tarnopolsky, MA, and Sale, DG. Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol* 66: 254–262, 1993.
23. Miyaguchi, K and Demura, S. Muscle power output properties using the stretch-shortening cycle of the upper limb and their relationships with a one-repetition maximum bench press. *J Physiol Anthropol* 25:239–245, 2006.
24. Miyaguchi, K and Demura, S. Relationships between muscle power output using the stretch-shortening cycle and eccentric maximum strength. *J Strength Cond Res* 22: 1735–1741, 2008.
25. Miyaguchi, K, Demura, S, Miyaguchi, H, and Maeda, M. Throwing ability in Japan and Indonesia [in Japanese]. *Jpn J Phys Fitness Sports Med* 42: 733, 1993.
26. Morris, AM, Williams, JM, Atwater, AE, and Wilmore, JH. Age and sex differences in motor performance of 3 through 6 year old children. *Res Q Exerc Sport* 53: 214–221, 1982.
27. Newton, RU, Murphy, AJ, Humphries, BJ, Wilson, GJ, Kraemer, WJ, and Hakkinen, K. Influence of load and stretch shortening cycle on the kinematics, kinetics, and muscle activation that occurs during explosive upper-body movements. *Eur J Appl Physiol* 75: 333–342, 1997.
28. Oldfield, RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9: 97–113, 1971.
29. Sakurai, S. "Basic exercise" and biomechanics [in Japanese]. *J Health Phys Educ Recreation* 31: 383–387, 1981.
30. Sakurai, S. *Science to Throw* [in Japanese]. Tokyo: Taisyukan, 1991. pp. 198–210.
31. Staron, RS, Hagerman, FC, Hikida, RS, Murray, TF, Hostler, DP, Crill, MT, Ragg, KE, and Toma, K. Fiber type composition of the vastus lateralis muscle of young men and women. *J Histochem Cytochem* 48: 623–629, 2000.
32. Steinder, A. The pathomechanics of the sacrolumbar junction. *Instr Course Lect* 12: 177–188, 1955.
33. Takamatsu, K, Aida, H, and Zushi, K. Effect of isometric and eccentric preliminary muscle contractions on elbow flexion velocity: with special reference to load and range of motion during concentric contraction. *Jpn J Phys Educ Health Sport Sci* 36: 127–139, 1991.
34. Tauchi, K, Yoon, S, and Takamatsu, K. The difference between the upper limbs and lower limbs in individuals on force output characteristics during stretch-shortening cycle movement. *Jpn J Phys Educ Health Sport Sci* 47: 533–546, 2002.
35. Walshe, AD, Wilson, GJ, and Murphy, AJ. The validity and reliability of a test of lower body musculotendinous stiffness. *Eur J Appl Physiol* 73: 332–339, 1996.
36. Wickstrom, RJ. *Fundamental Motor Patterns* (3rd ed.). Philadelphia: Lea & Febiger, 1983. pp. 101–135.
37. Wilson, GJ, Murphy, AJ, and Pryor, JF. Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. *J Appl Physiol* 76: 2714–2719, 1994.
38. Zushi, K, Takamatsu, K, and Kotoh, T. The specificity of leg strength and power in several sport athletes. *Jpn J Phys Educ Health Sport Sci* 38: 265–278, 1993.