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**Research article**

# Comparison of Proprioceptive Training and Muscular Strength Training to Improve Balance Ability of Taekwondo Poomsae Athletes: A Randomized Controlled Trials

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**Abstract**
Maintaining balance while performing "Hakdariseogi" in Taekwondo, which involves standing on one leg, is a critical aspect of the Poomsae competition. The purpose of this study was to investigate the effect of proprioceptive training and lower-limb muscular strength training on the balance of Taekwondo Poomsae athletes over a 6-week period. Thirty Taekwondo Poomsae athletes were randomly assigned to three groups, namely, a proprioception training group, a lower-limb muscular strength training group, and a control group. Biomechanics data were collected using eight infrared cameras (Qualysis, Sweden) at 200 Hz and a force plate (Kistler, Switzerland) at 2,000 Hz while the participants performed "Hakdariseogi" before and after the 6-week intervention. Balance and stability variables were calculated using customized MATLAB R2014b software (Mathworks, Inc., USA). The medio-lateral (M/L) center of pressure (CoP) range, M/L CoP mean velocity, antero-posterior (A/P) CoP range, A/P CoP mean velocity, and the vertical ground reaction torque after the training were reduced at P1 in the PG groups ($p < 0.05$). A decrease in the A/P CoP range, A/P CoP mean velocity, and vertical ground reaction torque after the training were observed at P2 in the PG and SG groups ($p < 0.05$). The PG exhibited a smaller A/P CoP range and A/P CoP mean velocity, in comparison to CG ($p < 0.05$). The A/P CoP position at P1 was negatively correlated with the vertical ground reaction torque, A/P CoP range, and A/P CoP mean velocity at P2($r = -0.438$, $r = -0.626$, $r = -0.638$). Based on the above results, this study determined that both proprioception training and lower-extremity muscle strength training resulted in an improvement of athletic performance. It was also desirable to move the CoP position through conscious effort forward at P2 in order to maintain the crane stance without sway.

**Key words:** Taekwondo; crane stance, balance; proprioceptive training, muscular strength training

## Introduction

Balance is the ability to maintain the condition of equilibrium in the body. In sports activities, balance plays an important role in maintaining posture and conducting given tasks, owing to a close relation between balance and motor performance capacity (Davlin, 2004; Hahn et al., 1999). Balance can be applied to a static condition while standing on a base of support (BoS) with minimum movement, and also to a dynamic situation while maintaining a stable posture and performing techniques (Bressel et al., 2007). Thus, in sports, both static and dynamic balances are related to performance enhancement (Paillard et al., 2006). In biomechanics, balance can be measured by the analysis of the antero-posterior (A/P) and medio-lateral (M/L) displacement of the CoP, and the CoP velocity of the body (Doyle et al., 2007; Lugade et al., 2011; Pai and Patton, 1997; Rocchi et al., 2004; Ryu et al., 2012; Yoo and Ryu, 2012).

Balance is an important aspect of Taekwondo Poomsae competitions because Taekwondo Poomsae is a form of self-practice, which is designed to be performed by following the lines of movement in a pre-planned manner by using Taekwondo techniques against an imaginary opponent (Kukkiwon, 2006). According to the rules of the Taekwondo Poomsae competition, balance is defined as the ability to maintain a straight posture without inclining or tilting (Kukkiwon, 2006). In terms of biomechanics variables, balance can be evaluated by the center of mass (CoM) and the center of pressure (CoP) movement in the course of performing individual motions and connecting these motions. The CoP is positioned within the base of support, and balance ability may appear differently depending on changes in such position (Lugade et al., 2011). Furthermore, the ability to adjust the body weight into a motion without losing balance in the process of releasing the force at the target point is important for the purpose of competition (Korean Taekwondo Association (KTA), 2015; World Taekwondo Federation (WTF), 2015). In particular, it is challenging to maintain one's balance while performing both the 'Hakdariseogi' of the "Kumgang" Poomsae, which includes standing on one leg, and the front and turning sidekicks of the "Pyongwon" Poomsae, which connect at high speed. Thus, a small mistake in "Hakdariseogi" may change the final outcome of a competitive event (Kukkiwon, 2006). Therefore, balance is an essential element in assessing the proficiency of Taekwondo Poomsae athletes.

In studies where the balance of skilled Taekwondo Poomsae athletes were compared to the balance of less skilled athletes, differences existed in joint coordination and a close relationship existed between increased balance skill and lower-limb muscle strength (Ryu et al., 2012; Yoo and Ryu, 2012). However, studies on Taekwondo motion balance improvement have yet to be conducted even though balance is an important assessing factor in Taekwondo Poomsae competitive event. Thus, there is a need to study training methods in order to improve the balance of Taekwondo Poomsae athletes.

Various studies on proprioceptive training programs aiming to improve awareness of body aspects such as posture, movement, and change of balance have been reported. Proprioception is defined as the sense or ability to comprehend the position and speed of movement

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or weight, as well as the resistance of the body (Hoffman and Payne, 1995). Studies suggest that proprioceptive training improves the balance of unstable ankles, adjusts postural control, and diminishes ankle sprains (Eils and Rosenbaum, 2001; Matsusaka et al., 2001; Mcguine and Keene, 2006; Osborne et al., 2001; Ross et al., 2007; Soderman et al., 2000; Verhagen et al., 2004). Moreover, proprioceptive training has improved the balance of healthy adults and the balance capacity of athletes (Hoffman and Payne, 1995). In addition, it has been reported that this training modality produces effective results in five weeks (Hoffman and Payne, 1995). On the other hand, muscular strength training is also reported to improve balance. Muscle activation of the lower limbs is related to balance and the ability to control posture (Patel et al., 2009; Tanaka et al., 2007). Studies have suggested that increasing the muscular strength of the lower limbs may improve the balance of the body (Hasselgren et al., 2011; Horlings et al., 2009; Pant et al., 2006). In addition, studies also found that muscular strength training improves static and dynamic balance (Ramsbottom et al., 2004; Sarshin et al., 2012). It has been suggested that strength training using a low load is the most effective way to improve capabilities for balance (Orr et al., 2006; Ribeiro et al., 2009). Thus, it is necessary to examine lower limb muscular strength training and proprioceptive training to determine whether they play a positive role in improving the balance of Taekwondo Poomsae athletes.

Therefore, the first purpose of this study was to investigate balance improvements of Taekwondo Poomsae athletes following proprioceptive training and low-load lower-limb muscular strength training. The second purpose of this study was to evaluate the relationship between CoP position within the BoS and balance variables. The first hypothesis of this study was that proprioceptive training and low-load lower-limb muscular strength training are both effective in improving the balance of Taekwondo Poomsae athletes. The second hypothesis of this study was that CoP within the base of support being in a more forward position would reduce the range and speed of CoP indicating improved balance ability.

## Methods

### Participants

Initially, 36 Taekwondo Poomsae athletes participated in the testing (Figure 1). However, 6 athletes were excluded from the study owing to injury or absence from training; therefore, the 30 athletes who completed the biomechanical analysis training were categorized as follows: proprioception training group (PG; n = 10; age = 20.0 ± 2.6 years; height = 171.8 ± 5.9 cm; body weight = 64.4 ± 6.5 kg), low-load lower-limb muscular strength training group (SG; n = 10; age = 19.2 ± 0.8 years; height = 171.9 ± 6.3 cm; body weight = 64.0 ± 11.2 kg), and control group (CG; n = 10; age = 19.1 ± 0.7 years; height = 172.1 ± 7.3 cm; body weight = 65.7 ± 8.9 kg). All groups were assigned 8 male and 2 female athletes.

### Experimental design

An initial sample size of 21 was determined using the M/L CoP range of previous studies (Ryu et al., 2012) with regard to balancing during the performance of the Taekwondo Poomsae "Hakdariseogi" stance. The mean and standard deviation of M/L CoP range from the afore-mentioned precedent study were used to calculate the effect size of 1.5 (G-power software), with a statistical power set to 0.80 and an alpha level of 0.05. However, considering that the athletes could be absent during the training period, 36 athletes with winning histories in the Korean National Taekwondo Poomsae competition, participated in the pre-test. All participants were recruited through

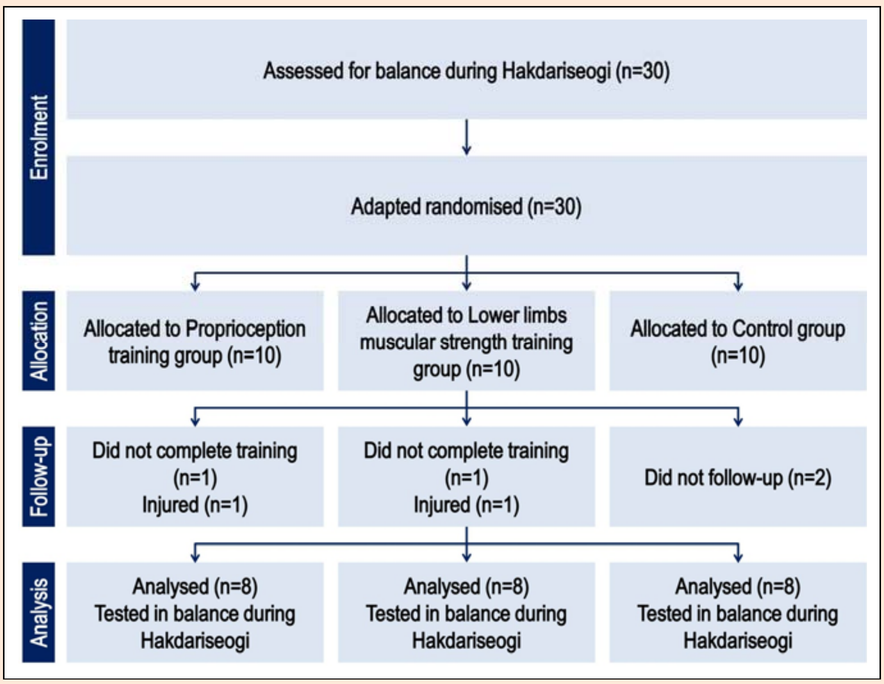


**Figure 1. Flow diagram of the progress through the parallel study design for each group.**

various announcment and local meetings organized by the Department of Taekwondo at the Korea National Sport University. The participants signed informed consent letters, and the study was approved by the university's ethics committee. In the pre-test, all participants performed Hakdariseogi, which is the stance in which it is most difficult to maintain balance during the Taekwondo Poomsae competition. In order to accurately observe the effect of training, three groups were assembled by the adapted randomization method (Kang et al., 2008) using the factors of sex, M/L CoP range, M/L CoP mean velocity, and root mean square (RMS) of the ground reaction torque in the pre-test. The adapted randomization method can be effectively used to balance important covariates among control and training groups (Hedden et al., 2006). In covariate adaptive randomization, the method for assigning participants to either the control or treatment group included (1) calculating P values for each of the covariates using a t test and analysis of variance (ANOVA) for continuous variables; (2) assigning the participant to the group with the larger P value to avoid more imbalances in groups. Using this approach, a smaller P value represents greater imbalances among treatment groups.

## Exercises

The 60-minute training sessions were completed 3 times per week over a period of 6 weeks. Warm-up exercises were performed as stretching during a 10-minute period. Warm-up exercises consisted of neck tilts, neck rotations, neck stretch, triceps stretch, shoulder stretch, torso rotations, chest expansions, side arm raises, arm rotations, hip rotations, knee circles, toe touches, hops on the spot, and side to side hops. Each exercise was performed 10 times. These exercises focused primarily on some large muscle groups and the joints of neck, shoulders, hips, knees and lower back.

Table 1 and Table 2 include detailed descriptions of the proprioception training developed by previous studies (Ross et al., 2007; Ruiz and Richardson, 2005; Soderman et al., 2000; Verhagen et al., 2004; 2005). The proprioceptive training program consisted of 4 ~ 6. All proprioceptive training sessions were conducted with eyes open.

**Table 1. The exercises used during proprioceptive training.**

| 1 step (on the floor) | 2 step (a pair on the floor) | 3 step (on balance board) | 4 step (a pair on balance board) |
|---|---|---|---|
| *Exercise 1* One legged stance with the knee flexed. Step out on the other leg with the knee flexed and keep balance for 60 seconds. Repeat 3 sets. | *Exercise 5* One legged stance with the knee flexed. Throw and catch under a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 10* One legged stance with the knee flexed. Step out on the other leg with the knee flexed and keep balance for 60 seconds. Repeat 3 sets. | *Exercise 14* One legged stance with the knee flexed. Throw and catch under a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. |
| *Exercise 2* One legged stance with the hip and the knee flexed. Step out on the other leg with the hip and the knee flexed, and keep balance for 60 seconds. Repeat 3 sets. | *Exercise 6* One legged stance with the knee flexed. Throw and catch over a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 11* One legged stance with the hip and the knee flexed. Step out on the other leg with the hip and the knee flexed, and keep balance for 60 seconds. Repeat 3 sets. | *Exercise 15* One legged stance with the knee flexed. Throw and catch over a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. |
| *Exercise 3* One legged stance with the knee flexed. Throw and catch a ball over head alone while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 7* One legged stance with the knee flexed. Throw and catch one hand under a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 12* One legged stance with the knee flexed. Throw and catch a ball over head alone while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 16* One legged stance with the knee flexed. Throw and catch one hand under a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. |
| *Exercise 4* One legged stance with the knee flexed. Throw and catch a ball over the wall alone while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 8* One legged stance with the knee flexed. Throw and catch one hand over a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 13* One legged stance with the knee flexed. Throw and catch a ball over the wall alone while maintaining balance for 60 seconds. Repeat 3 sets. | *Exercise 17* One legged stance with the knee flexed. Throw and catch one hand over a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. |
| - | *Exercise 9* One legged stance with the knee flexed. Throw and catch at the same time a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. | - | *Exercise 18* One legged stance with the knee flexed. Throw and catch at the same time a ball to each other while maintaining balance for 60 seconds. Repeat 3 sets. |

The lower-limb muscular strength training program consisted of squats, dead lifts, lunges performed using free weights, and leg extensions, leg curls, calf raises, and tibialis anterior raises performed using weight machines. Strength training loads were set to 20% of maximal strength (Orr et al., 2006; Ribeiro et al., 2009). One repetition maximum was calculated using the Brzycki equation (Brzycki, 1993). Each training was performed in 3 sets of 15 repetitions, rest periods between sets were 40 seconds, and rest periods between exercises were 2 minutes. All participants, including the control group, performed regular Taekwondo Poomsae practice for 2 hours, 5 times per week. However, the control group had no specific training intervention during these 6 weeks.

**Table 2. The six-week proprioceptive training program.**

| No. | Session | Exercise |
|---|---|---|
| 1 | Week 1 session 1 | 1 2 3 4 |
| 2 | Week 1 session 2 | 5 6 7 8 9 |
| 3 | Week 1 session 3 | 10 11 12 13 |
| 4 | Week 2 session 1 | 14 15 16 17 18 |
| 5 | Week 2 session 2 | 1 2 5 6 |
| 6 | Week 2 session 3 | 3 4 7 8 9 |
| 7 | Week 3 session 1 | 10 11 14 15 |
| 8 | Week 3 session 2 | 12 13 16 17 18 |
| 9 | Week 3 session 3 | 1 2 10 11 |
| 10 | Week 4 session 1 | 3 4 12 13 |
| 11 | Week 4 session 2 | 5 6 14 15 |
| 12 | Week 4 session 3 | 7 8 9 16 17 18 |
| 13 | Week 5 session 1 | 1 5 10 14 |
| 14 | Week 5 session 2 | 2 6 11 15 |
| 15 | Week 5 session 3 | 3 7 12 16 |
| 16 | Week 6 session 1 | 4 8 9 13 17 18 |
| 17 | Week 6 session 2 | 1 2 14 15 |
| 18 | Week 6 session 3 | 5 6 10 11 |

## Measures

The balance test of the Taekwondo Poomsae athletes was evaluated based on the Hakdariseogi motion of the "Kumgang" Poomsae. Hakdariseogi is named after the shape of a crane standing on one foot. The center of gravity is located on one foot, while the other foot is placed on the side of the supporting leg's knee in order to maintain balance (Kukkiwon, 2006). All participants conducted a sufficient warm-up for 20–30 m before the tests. Each participant was given a defined starting point for positioning the supporting foot on the force plate while performing Hakdariseogi (Kistler, Type 9286A, Switzerland). Six markers were attached in order to confirm the joint points and the BoS (left lateral malleolus, left medial malleolus, left second phalangeal, left lateral metatarsal-phalangeal joint, left medial metatarsal-phalangeal joint, and left heel bone) for the single standing leg (Lugade et al., 2011). Eight infrared cameras (Oqus 300, Qualisys, Sweden) were used in order to capture the participants' motion during the assigned tasks. The sampling rates were 200 Hz for motion analysis and 2,000 Hz for the force plate.

The Qualisys Track Manager Software (Qualisys, Sweden) and MATLAB R2009b software (Mathworks, USA) were used to analyze the balance variables in Hakdariseogi. The movement was divided into two phases: Phase 1, which involved balancing when shifting the CoM while changing from a normal standing position (P1) to a single-leg stand, and Phase 2, which involved maintaining balance in the single-leg stance without a tremor (P2). The analytical data were smoothed using a Butterworth second-order low-pass filter with a cut-off frequency of 6 Hz. The analysis phases are shown in Figure 2.

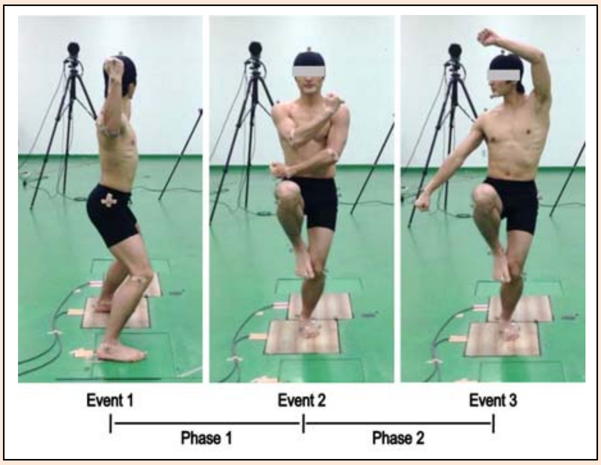


**Figure 2. Event (E1: right foot off, E2: right foot attach at left knee, E3: motion finish) and phase (P1: E1-E2, P2: E2-E3).**

In this study, the variables were calculated in the following manner. The A/P and M/L ranges, and the CoP velocities were calculated from the instantaneous ground reaction force ($F_x$, $F_y$, $F_z$) and moment ($M_x$, $M_y$, $M_z$) based on the following equations:

$$\mathrm{CoP_x} = \frac{\mathrm{M_y}}{\mathrm{F_z}},\ \mathrm{CoP_y} = \frac{\mathrm{M_x}}{\mathrm{F_z}},\ \text{and}\ T_z = M_z + (F_x \times CoP_y) - (F_y \times CoP_x),$$

where x indicates M/L, y indicates A/P, and $T_z$ indicates the ground reaction torque (Winter et al., 1998; Lugade et al., 2011; Pai and Patton, 1997).

The center of the BoS was calculated using the following equations (see Figure 3):

$$\mathrm{C1} = X_2 + (X_1 - X_2) \times \frac{1}{2}, Y_2 + (Y_1 - Y_2) \times \frac{1}{2},$$
$$\mathrm{C2} = X_3 + (C1_X - X_3) \times \frac{2}{3}, Y_3 + (C1_Y - Y_3) \times \frac{2}{3},$$
$$\mathrm{C3} = X_4 + (C2_X - X_4) \times \frac{3}{4}, Y_4 + (C2_Y - Y_4) \times \frac{3}{4},$$
$$\mathrm{C4} = X_5 + (C3_X - X_5) \times \frac{4}{5}, Y_5 + (C3_Y - Y_5) \times \frac{4}{5},\ \text{and}$$
$$\text{Centre of BoS} = X_6 + (C4_X - X_6) \times \frac{5}{6}, Y_6 + (C4_Y - Y_6) \times \frac{5}{6},$$

where x indicates M/L, and y indicates A/P.

The CoP position within the BoS was calculated using the instantaneous CoP position, the position of the second phalangeal position (Y-axis) and the center of BoS (datum point) were calculated using the following steps (Figure 4).

(1) The CoP angle was calculated from the vector of the second phalangeal (Y-axis) position and the vector of the instantaneous CoP position (X, Y) on the basis of the center of BoS (datum point) by using the scalar product.

(2) The distance between the center of BoS and CoP position (D) was calculated.

(3) The CoP position within the BoS was calculated using the following equations:

$CoP_x = Dsin\theta$, and $CoP_y = Dcos\theta$,

where x indicates M/L and y indicates A/P.

(4) The CoP position within the BoS was normalized using the length of the foot.

### Statistical analysis

The mean difference between the pre-test and post-test is expressed with 95% confidence limits (lower to upper confidence interval). For each dependent variable, a 2 × 3 two-way repeated ANOVA measure was performed. If there was a time × group interaction, the Bonferroni post-hoc test was conducted in order to identify specific differences across the groups. In addition, a paired t-test was conducted in order to assess the differences in any of the three groups. The effect sizes were reported as partial eta squared ($\eta_p{}^2$), and the statistical power was also reported. The partial eta squared of the repeated ANOVA measures was interpreted as 0.01, 0.06, and 0.14 according to classifications recommended by Cohen (1988), which shows a small effect, intermediate effect, and large effect, respectively. The degree of relationship between the CoP position within the BoS and the balance variables was investigated using Pearson's correlation coefficients. A statistical program (SPSS version 18.0; SPSS Inc., Chicago, IL, USA) was used to identify the differences at an alpha level of 0.05, for all of the variables.

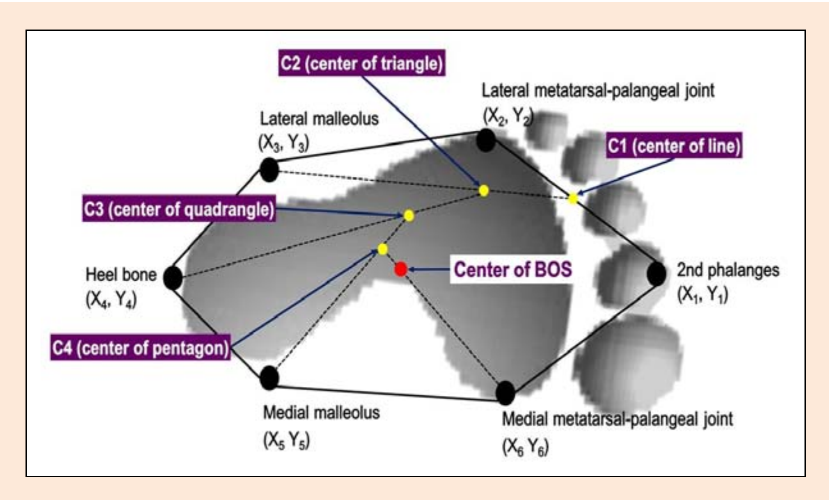


**Figure 3.** **Centre of BoS.**

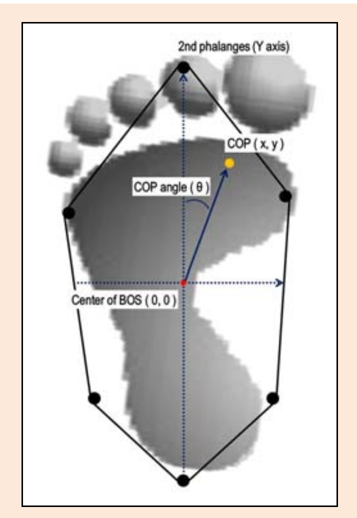


**Figure 4.** **Calculation of CoP position.**

## Results

The results for the main effects are listed in Table 4. The mean ± SD with 95% confidence interval for all variables are listed in Tables 4 and 5.

There was no significant main effect for the differences between time, group, and time × group, in the M/L CoP range at P1 and P2. However, there was a significant main effect for the differences between time in the M/L CoP mean velocity at P1 ($p < 0.05$). There was a significant main effect for the differences between time in the A/P CoP range and for the mean velocity at P1 ($p < 0.05$). Additionally, there was a significant main effect for the differences between the time and an interaction effect between the time × group in the A/P CoP range and the mean velocity at P2 ($p < 0.05$). However, for the differences between the groups, a significant effect was only observed in the A/P CoP range at P2 ($p < 0.05$). There was a significant main effect for the differences between the time for the vertical ground reaction torque at P1 and P2 ($p < 0.05$). There was a significant main effect for the differences between the time in the M/L CoP position within the BoS at P2 ($p < 0.05$). Finally, there was a significant main effect for the differences between time in the A/P CoP position within the BoS at P2 ($p < 0.05$). In addition, there was a significant interaction effect for the differences between time × group in the A/P CoP position within the BoS at P1 and P2 ($p < 0.05$, Table 3).

After six weeks, athletes in both the PG and SG showed improvement with regard to the variables of balance ability, decreased the M/L and A/P CoP range and mean velocity, and reduced vertical ground reaction torque (Table 4). In addition, the A/P CoP range and mean velocity of the control group were greater, in comparison to the PG and SG ($p < 0.05$).

Regarding the location of the CoP during performance, with regard to the center of BoS (Table 5), the post-hoc tests revealed that the A/P CoP position within the BoS was more anteriorly located in the PG, in comparison to the CG in the post-test in P1 ($p < 0.05$). The A/P CoP position within the BoS was also more anteriorly located in the PG and SG, in comparison to the CG in the post-test in P2 ($p < 0.05$).

Pearson's correlation coefficients between the CoP positions within the BoS and the balance variables are presented in Table 6. The A/P CoP position at P1 was negatively correlated with the vertical ground reaction torque, A/P CoP range, and A/P CoP mean velocity at P2 ($r = -0.438$, $p < 0.05$; $r = -0.626$, $p < 0.05$; $r = -0.638$, $p < 0.05$).

**Table 3.** **Effect sizes and statistical power for main effects over time and between groups.**

| Variables | Phase | Analysis F tests | *F* value | *P* value | Effect size ($\eta_p^2$) | Statistical power |
|---|---|---|---|---|---|---|
| **Medio-lateral CoP range (cm)** | P1 | Time | 4.063 | .057 | .162 | .485 |
| | | Group | .150 | .861 | .014 | .070 |
| | | Time x Group | 1.311 | .291 | .111 | .252 |
| | P2 | Time | .076 | .785 | .004 | .058 |
| | | Group | 1.018 | .378 | .088 | .204 |
| | | Time x Group | .665 | .525 | .060 | .147 |
| **Antero-posterior CoP range (cm)** | P1 | Time | 6.314 | .020* | .231 | .669 |
| | | Group | .753 | .483 | .067 | .161 |
| | | Time x Group | 1.562 | .233 | .129 | .294 |
| | P2 | Time | 7.211 | .014* | .256 | .726 |
| | | Group | 5.888 | .009* | .359 | .822 |
| | | Time x Group | 4.643 | .021* | .307 | .719 |
| **Medio-lateral CoP mean velocity (cm/s)** | P1 | Time | 5.928 | .024* | .220 | .642 |
| | | Group | .025 | .975 | .002 | .053 |
| | | Time x Group | .738 | .490 | .066 | .158 |
| | P2 | Time | .221 | .643 | .010 | .073 |
| | | Group | .410 | .669 | .038 | .108 |
| | | Time x Group | 2.194 | .136 | .173 | .397 |
| **Antero-posterior CoP mean velocity (cm/s)** | P1 | Time | 8.994 | .007* | .300 | .816 |
| | | Group | .736 | .491 | .065 | .158 |
| | | Time x Group | 1.766 | .195 | .144 | .328 |
| | P2 | Time | 6.944 | .015* | .249 | .710 |
| | | Group | 1.727 | .202 | .141 | .321 |
| | | Time x Group | 5.402 | .013* | .340 | .787 |
| **Vertical ground reaction torque (Nm)** | P1 | Time | 17.259 | .000* | .451 | .977 |
| | | Group | 2.169 | .139 | .171 | .393 |
| | | Time x Group | 1.601 | .225 | .132 | .300 |
| | P2 | Time | 14.046 | .001* | .401 | .946 |
| | | Group | .025 | .975 | .002 | .053 |
| | | Time x Group | 2.838 | .081 | .213 | .497 |
| **Medio-lateral CoP position within BoS (%)** | P1 | Time | .574 | .457 | .027 | .112 |
| | | Group | 1.926 | .171 | .155 | .354 |
| | | Time x Group | 1.870 | .179 | .151 | .345 |
| | P2 | Time | 12.194 | .002* | .367 | .914 |
| | | Group | .533 | .594 | .048 | .126 |
| | | Time x Group | 1.068 | .362 | .092 | .212 |
| **Antero-posterior CoP position within BoS (%)** | P1 | Time | 4.254 | .052 | .168 | .503 |
| | | Group | 2.757 | .086 | .208 | .484 |
| | | Time x Group | 4.060 | .032* | .279 | .657 |
| | P2 | Time | 9.294 | .006* | .307 | .828 |
| | | Group | 2.520 | .104 | .194 | .449 |
| | | Time x Group | 7.761 | .003* | .425 | .916 |

* Indicates statistically significant difference $p < 0.05$.

**Table 4.** Mean±SD and 95% confidence intervals for balance variables in the study for three groups.

| Variable | Phase | Group | Pre-test | Post-test | 95% confidence levels Lower | Upper |
|---|---|---|---|---|---|---|
| Medio-lateral CoP range (cm) | P1 | PG | 3.40±1.32 | 2.70±0.89 | 0.11 | 1.30 |
| | | SG | 2.92±0.89 | 2.82±0.87 | -0.50 | 0.69 |
| | | CG | 2.91±0.97 | 2.72±0.88 | -0.40 | 0.79 |
| | P2 | PG | 2.32±0.29 | 2.13±0.46 | -0.17 | 0.54 |
| | | SG | 2.25±0.30 | 2.26±0.40 | -0.37 | 0.35 |
| | | CG | 2.44±0.62 | 2.53±0.62 | -0.45 | 0.27 |
| Antero-posterior CoP range (cm) | P1 | PG | 4.14±1.05 | 2.58±0.49* | 0.41 | 2.73 |
| | | SG | 3.87±0.82 | 3.22±0.66 | -0.50 | 1.81 |
| | | CG | 4.10±2.19 | 3.90±1.86 | -0.96 | 1.36 |
| | P2 | PG | 4.90±0.79 | 2.97±0.35* | 0.66 | 3.19 |
| | | SG | 4.74±0.87 | 3.30±0.97* | 0.18 | 2.71 |
| | | CG | 4.73±1.09 | 5.27±1.93[ab] | -1.81 | 0.72 |
| Medio-lateral CoP mean velocity (cm/s) | P1 | PG | 6.04±2.12 | 4.79±1.59 | 0.10 | 2.40 |
| | | SG | 5.76±1.60 | 4.99±0.83 | -0.37 | 1.92 |
| | | CG | 5.68±1.80 | 5.38±1.62 | -0.85 | 1.45 |
| | P2 | PG | 1.51±0.26 | 1.37±0.25 | -0.05 | 0.34 |
| | | SG | 1.42±0.15 | 1.36±0.15 | -0.13 | 0.26 |
| | | CG | 1.42±0.20 | 1.55±0.40 | -0.33 | 0.07 |
| Antero-posterior CoP mean velocity (cm/s) | P1 | PG | 7.60±2.37 | 4.84±1.28* | 0.82 | 4.71 |
| | | SG | 7.71±1.63 | 5.92±1.42 | -0.15 | 3.74 |
| | | CG | 7.33±2.73 | 7.03±2.53 | -1.65 | 2.24 |
| | P2 | PG | 2.54±0.42 | 1.59±0.28* | 0.28 | 1.60 |
| | | SG | 2.57±0.38 | 1.69±0.32* | 0.21 | 1.53 |
| | | CG | 2.24±0.32 | 2.60±1.26[a] | -1.03 | 0.29 |
| Vertical ground reaction torque (Nm) | P1 | PG | 8.60±2.87 | 4.87±2.31* | 1.69 | 5.76 |
| | | SG | 5.69±2.20 | 4.35±1.18 | -0.70 | 3.37 |
| | | CG | 8.05±3.41 | 6.08±2.61 | -0.06 | 4.01 |
| | P2 | PG | 11.65±4.51 | 8.22±3.33* | 0.87 | 5.99 |
| | | SG | 12.39±2.16 | 8.13±2.60* | 1.69 | 6.82 |
| | | CG | 10.35±4.13 | 10.03±3.61 | -2.25 | 2.88 |

[a] Indicates statistically significant ($p < 0.05$) difference between PG and CG at the same test. [b] Indicates statistically significant ($p < 0.05$) difference between SG and CG at the same test. [c] Indicates statistically significant ($p < 0.05$) difference between PG and SG at the same test. $p < .05$. * Indicates statistically significant ($p < 0.05$) difference between pre-test and post-test at the same group.

**Table 5.** Mean±SD and 95% confidence intervals for CoP position variables in the study for three groups.

| Variable | Phase | Group | Pre-test | Post-test | 95% confidence levels Lower | Upper |
|---|---|---|---|---|---|---|
| Medio-lateral CoP position within BoS (%) | P1 | PG | 16.13±13.05 | 10.00±11.78 | -7.75 | 20.00 |
| | | SG | 9.50±8.49 | 16.88±25.60 | -21.25 | 6.50 |
| | | CG | 8.13±14.75 | -1.88±10.52 | -3.87 | 23.87 |
| | P2 | PG | 16.88±12.11 | 0.38±14.73 | 4.64 | 28.36 |
| | | SG | 16.00±9.58 | 3.00±17.99 | 1.14 | 24.86 |
| | | CG | 6.00±17.76 | 1.00±15.54 | -6.86 | 16.86 |
| Antero-posterior CoP position within BoS (%) | P1 | PG | 27.00±3.85 | 36.00±5.76 | -15.62 | -2.38 |
| | | SG | 24.38±7.41 | 30.13±8.17 | -12.37 | 0.87 |
| | | CG | 27.00±8.25 | 23.63±7.65[a] | -3.25 | 10.00 |
| | P2 | PG | 20.75±5.18 | 34.38±7.76* | -23.08 | -4.17 |
| | | SG | 19.25±5.23 | 36.13±14.46* | -26.33 | -7.42 |
| | | CG | 24.13±11.29 | 17.63±9.29[ab] | -2.95 | 15.95 |

[a] Indicates statistically significant ($p < 0.05$) difference between PG and CG at the same test. [b] Indicates statistically significant ($p < 0.05$) difference between SG and CG at the same test. [c] Indicates statistically significant ($p < 0.05$) difference between PG and SG at the same test. * Indicates statistically significant ($p < 0.05$) difference between pre-test and post-test at the same group.

## Discussion

This study was conducted in order to investigate the effect of a six-week intervention consisting of either proprioception training or lower-extremity strength training on the balance ability of athletes in Taekwondo Poomsae.

The results of the COP were similar to the result of study by conducted by Paillard et al. (2006) which compared the balance ability of soccer players, the CoP mean velocity of soccer players was 1.67 ± 0.47 cm/s. In the current study, the M/L CoP mean velocity, A/P CoP range, A/P CoP mean velocity, and the vertical ground reaction torque following training were reduced at P1 in the

**Table 6.** **Pearson's correlation coefficient for CoP position and balance variables.**

| Phase | Variables | Phase 1 | | Phase 1 | |
|---|---|---|---|---|---|
| | | M/L CoP within BoS | A/P CoP within BoS | M/L CoP within BoS | A/P CoP within BoS |
| P1 | M/L CoP range | r=.018(p=.903) | - | - | - |
| | M/L CoP mean velocity | r=-.187(p=.203) | - | - | - |
| | Vertical ground reaction torque | r=-.020(p=.892) | r=-.219(p=.136) | - | - |
| | A/P CoP range | - | r=-.274(p=.059) | - | - |
| | A/P CoP mean velocity | - | r=-.301(p=.038) | - | - |
| P2 | M/L CoP range | - | - | r=-.234(p=.110) | - |
| | M/L CoP mean velocity | - | - | r=-.023(p=.877) | - |
| | Vertical ground reaction torque | - | - | r=.019(p=.898) | r=-.438(p=.002)* |
| | A/P CoP range | - | - | - | r=-.626(p=.000)* |
| | A/P CoP mean velocity | - | - | - | r=-.638(p=.000)* |

* Indicates statistically significant ($p < .05$) difference.

PG, which required balancing while lifting one leg. A decrease in the A/P CoP range, A/P CoP mean velocity, and vertical ground reaction torque after the training was observed at P2 from both the PG and SG groups, which required the maintenance of balance while lifting one leg. In particular, the PG exhibited a smaller A/P CoP range and A/P CoP mean velocity, in comparison to the CG after the training. In the meantime, no difference was observed between any of the groups before the training.

Proprioception is the sense or ability to understand the position and velocity of body movements, weight and resistance (Hoffman and Payne, 1995). As reported in various studies (Eils and Rosenbaum, 2001; Matsusaka et al., 2001; Mcguine and Keene, 2006; Osborne et al., 2001; Ross et al., 2007; Soderman et al., 2000; Verhagen et al., 2004), proprioception training seems to have a positive effect on improving the balance of Taekwondo Poomsae players. Hoffman and Payne (1995) demonstrated that a five-week proprioceptive training program improved the balance of healthy adults as well as the balance ability of athletes. The six-week proprioception training in the current study was also sufficient to improve balance. However, Verhagen et al. (2005) argued that 5.5 week proprioception training did not cause any decrease in the CoP range. By considering that the participants in the study were engaged in exercise only for 15 minutes, twice a week, we may conclude that the obtained result is not surprising. The participants in our study were required to exercise for 1 hour, 3 times per week, for a total period of 6 weeks, in order to increase the intervention effect. On the other hand, studies have also suggested that muscular strength training improves balance, as the muscle activation of the lower extremities is closely related to balance ability and the ability to control posture (Patel et al. 2009; Tanaka et al., 2007). Furthermore, several studies have reported high relevance between balance and muscular strength that lead to plantarflexion and dorsiflexion of the ankle joint (Pant et al., 2006; Suponitsky et al., 2008). Strength training seems to have a positive effect on improving the anterior-posterior balance of Taekwondo Poomsae players as A/P CoP range and A/P CoP mean velocity after training was decreased in strength training group. These findings indicate that low-load strength training is an effective method for improving body balance.

In support of the first hypothesis of this study, it was found that proprioceptive training and low-load lower-limb muscular strength training had a positive effect on the improvement of balance of Taekwondo Poomsae athletes. However, the study did not identify which of the two training methods was more effective in improving balance.

Yoo et al. (2014) mentioned that the CoP position within the BoS could potentially provide a method to improve balance ability. In P1, the CoP position of the PG was located at a relatively more forward position after the training, in comparison to its position before training. In particular, after the training, the CoP position of the PG was located at a more forward position, in comparison to CG. In P2, after the training, the CoP position of the PG was located at a relatively more central position, in comparison to its position before training. According to a study conducted by Yoo et al. (2014) on the effects of an exercise program for children who were proficient at sports involving single-leg standing balance, the CoP position within the BoS was moved in the direction of the toes by 30% after the exercise. This indicates that in order to maintain single-leg standing balance, the CoP position should be located at the fore-foot. In the future, more reliable results may be obtained if a greater number of participants are used and a greater variety of cases are studied in order to investigate the relationship between balance variables and CoP position within the BoS.

Finally, the correlation between the CoP position and balance was investigated. The results showed that the vertical ground reaction torque, A/P CoP range, and A/P CoP mean velocity at P2, became smaller as the position of the CoP at P2 moved forward. To stably perform a single-leg stand at P2, it was desirable to perform motion while moving the CoP position forward from the center point of the foot. It was also desirable to move the CoP position forward at P2 in order to maintain the crane stance without sway. For Taekwondo athletes to effectively maintain their balance when performing the crane stance, conscious effort to perform the stance with a greater load being applied to the forefoot area is needed, while it is also necessary to develop training methods focused on improving this skill.

Limitations in this study included the fact that participants in all groups performed Taekwondo training. Studies by Fong et al. (2012b; 2013a) reported that Taekwondo had a positive effect on the static balance of children with developmental disorders, while studies by Fong et al., Fu, & Ng (2012a; 2013b) reported that Taekwondo can improve postural control ability of adolescents. However, since all participants in this study performed the same Taekwondo training, it did not likely have an impact on testing the training effect.

## Conclusion

In this study, it was found that both proprioception training and lower-extremity muscle strength training improved athletic performance and raised the skill level of athletes with regard to maintaining the Taekwondo crane stance. Therefore, applying these training methods into Taekwondo training programs may have a positive effect on improving the competitive performance of Taekwondo athletes. In particular, the findings confirmed that conscious effort to perform the stance with load being applied to the forefoot area was related to maintenance of balance when performing the crane stance on one leg.

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## References

Bressel, E., Yonker, J.C., Kras, J. and Heath, E.M. (2007) Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic Training* **42(1),** 42-46.

Brzycki, M. (1993) Strength testing : predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance,* **64(1),** 88-90.

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences.* New York, NY: Routledge Academic.

Davlin, C.D. (2004) Dynamic balance in high level athletes. *Perceptual & Motor Skills* **98,** 1171-1176.

Doyle, R.J., Hsiao-Wechsler, E.T., Ragan, B.G. and Rosengren, K.S. (2007) Generalizability of center of pressure measures of quiet standing. *Gait & Posture* **25(2),** 166-171.

Eils, E. and Rosenbaum, D. (2001) A multi-station proprioceptive exercise program in patients with ankle instability. *Medicine and Science in Sports and Exercise* **33(12),** 1991-1998.

Fong, S.S.M., Chung, J.W.Y., Chow, L.P.Y., Ma, A.W.W. and Tsang, W.W.N. (2013a) Differential effect of taekwondo training on knee muscle strength and reactive and static balance control in children with developmental coordination disorder: a randomized controlled trial. *Research in Developmental Disabilities* **34,** 1446-1455.

Fong, S.S.M., Fu, S.N. and Ng, G.Y.F. (2012a) Taekwondo training speeds up the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport* **15,** 64-68.

Fong, S.S.M., Tsang, W.W.N. and Ng, G.Y.F. (2012b) Taekwondo training improves sensory organization and balance control in children with developmental coordination disorder: a randomized controlled trial. *Research in Developmental Disabilities* **33,** 85-95.

Fong, S.S.M., Tsang, W.W.N. and Ng, G.Y.F. (2013b) Lower limb joint sense, muscle strength and postural stability in adolescent Taekwondo practitioners. *International SportMed Journal* 14(2), 44-52.

Hahn, T., Foldspang, A., Vestergaard, E. and Ingemann-Hansen, T. (1999) One-leg standing balance and sports activity. *Scandinavian Journal of Medicine & Science in Sports* **9(1),** 15-18.

Hasselgren, L., Olsson, L.L. and Nyberg, L. (2011) Is leg muscle strength correlated with functional balance and mobility among inpatients in geriatric rehabilitation? *Archives of Gerontology and Geriatrics* **52(3),** 220-225.

Hedden, S.L., Woolson, R.F. and Malcolm, R.J. (2006) Randomization in substance abuse clinical trials. *Substance Abuse Treatment, Prevention, and Policy* **1(1),** 6.

Hoffman, M. and Payne, V.G. (1995) The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopaedic & Sports Physical Therapy* **21(2),** 90-93.

Horlings, C.G.C., Küng, U.M., Van Engelen, B.G.M., Voermans, N.C., Hengstman, G.J.D., Van Der Kooi, A.J., Bloem, B.R. and Allum, J.H.J. (2009). Balance control in patients with distal versus proximal muscle weakness, *Neurosience* **164(4),** 1876-1886.

Kang, M., Ragan, B. . and Park, J.H. (2008) Issues in outcomes research: an overview of randomization techniques for clinical trials. *Journal of Athletic Training* **43(2),** 215-221.

Korea Taekwondo Association. (2015) *Poomsae Competition Rules & Interpretation: Poomsae Competition Scoring Techniques Guideline*. Seoul: Korea Taekwondo Association Office.

Kukkiwon. (2006) *Taekwondo Textbook: The Basics of Taekwondo*. Seoul: Osung.

Lee, H.J. and Chou, L.S. (2006) Detection of gait instability using the center of mass and center of pressure inclination angles. *Archives of Physical Medicine and Rehabilitation* **87(4),** 569-575.

Lugade, V., Lin, V. and Chou, L S.(2011) Center of mass and base of support interaction during gait. *Gait & Posture* **33(3),** 406-411.

Mandeville, D., Osternig, L.R. and Chou, L.S. (2008) The effect of total knee replacement surgery on gait stability. *Gait & Posture* **27(1),** 103-109.

Matsusaka, N., Yokoyama, S., Tsurusaki, T., Inokuchi, S. and Okita, M. (2001) Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle. *The American Journal of Sports Medicine* **29(1),** 25-30.

Mcguine, T.A. and Keene, J.S. (2006) The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Orthopaedic Society for Sports Medicine* **34(7),** 1103-1111.

Orr, R., de Vos, N.J., Singh, N.A., Ross, D.A., Stavrinos, T.M. and Fiatarone-Singh, M.A. (2006) Power training improves balance in healthy older adults. *The Journals of Gerontology* **61A(1),** 78-85.

Osborne, M.D., Chou, L.S., Laskowski, E.R., Smith, J. and Kaufman, K.R. (2001) The effect of ankle disk training on muscle reaction time in subjects with a history of ankle sprain. *American Orthopaedic Society for Sports Medicine* **29(5),** 627-632.

Pai, Y.C. and Patton, J. (1997) Center of mass velocity-position predictions for balance control. *Journal of Biomechanics* **30(4),** 347-354.

Paillard, T., Noé, F., Rivière, T., Marion, V., Montoya, R. and Dupui, P. (2006) Postural performance and strategy in the unipedal stance of soccer players at different levels of Competition. *Journal of Athletic Training* **41(2),** 172-176.

Pant, H., Sukumar, K., Sharma, H., Pandey, A.K. and Goel, S.N. (2006) Correlation between muscles strength in relation to dorsiflextion, planterflextion, eversion and inversion strength with body balance. *Journal of Biomechanics* **39(S1),** 557.

Patel, M., Gomez, S., Lush, D. and Fransson, P.A. (2009) Adaptation and vision change the relationship between muscle activity of the lower limbs and body movement during human balance perturbations. *Clinical Neurophysiology* **120(3),** 601-609.

Ramsbottom, R., Ambler, A., Potter, J., Jordan, B. Nevill, A. and Williams, C. (2004) The effect of 6 months training on leg power, balance, and functional mobility of independently living adults over 70 years old. *Journal of Aging and Physical Activity* **12(4),** 497-510.

Ribeiro, F., Teixeira, F., Brochado, G. and Oliveira, J. (2009) Impact of low cost strength training of dorsi-and plantar flexors on balance and functional mobility in institutionalized elderly people. *Geriatrics & Gerontology International* **9(1),** 75-80.

Rocchi, L., Chiari, L. and Cappello, A. (2004) Feature selection of stabilometric parameters based on principal component analysis. *Medical & biological Engineering & Computing* **42(1),** 71-79.

Ross, S.E., Arnold, B.L., Blackburn, J.T., Brown, C.N. and Guskiewicz, K.M. (2007) Enhanced balance associated with coordination training with stochastic resonance stimulation in subjects with functional ankle instability: an experimental trial. *Journal of NeuroEngineering and Rehabilitation* **17(4),** 47.

Ryu, J.S., Yoo, S.H., Park, S.K. and Yoon, S H. (2012) Comparisons between skilled and less-skilled players' balance in Hakdariseogi. *Korean Journal of Sport Biomechanics* **22(1),** 55-63.

Ruiz, R. and Richardson, M. (2005) Functional balance training using a domed device. *National Strength and Conditioning Association* **27(1),** 50-55.

Sarshin, A., Hojjat, S., Shojaedin, S. S. and Abbasi, A. (2012) The effect of ten weeks strength training and aquatic balance training on dynamic balance in inactive elder males. *Annals of Biological Research* **3(2),** 850-857.

Soderman, K., Werner, S., Pietila, T., Engstrom, B. and Alfredson, H. (2000) Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surgery Sports Traumatology Arthroscopy* **8(6),** 356-363.

Suponitsky, Y., Verbitsky, O., Peled, E. and Mizrahi, J. (2008) Effect of selective fatiguing of the shank muscles on single-leg-standing sway. *Journal of Electromyography and Kinesiology* **18(4),** 682-289.

Tanaka. N., Ishikawa, A., Yoshihira, M. and Hase, K. (2007) Relationship between leg muscle activities and medial-lateral balance in tandem stance. *Clinical Neurophysiology* **118(9),** e198.

Verhagen, E., Van der Beek, A., Twisk, J., Bouter, L., Bahr., R. and Van Mechelen, W. (2004) The effect of a proprioceptive balance board training program for the prevention of ankle sprains. *The American Journal of Sports Medicine* **32(6),** 1385-1393.

Verhagen, E., Bobbert, M., Inklaar, M., Van Kalken, M., Van der Beek, A., Bouter, L. and Van Mechelen, W. (2005) The effect of an balance training programme on centre of pressure excursion in one-leg stance. *Clinical Biomechanics* **20(10),** 1094-1100.

Winter, D.A., Patla, A.E., Prince, F., Ishac, M. and Gielo-Perczak, K. (1998) Stiffness control of balance in quiet standing. *Journal of Neurophysiology* **80(3),** 1211-1221.

World Taekwondo Federation. (2015) *Poomsae Competition Rules & Interpretation: Scoring Criteria*. Seongnam: World Taekwondo Federation.

Yoo. S.H. and Ryu. J.S. (2012) Comparison between the balance of skilled and less-skilled players during successful and failed front kick and turning side kick motions. *Korean Journal of Sport Biomechanics* **22(3),** 285-293.

Yoo. S.H., Gil, H.J., Kim, J.N., Ha, S.H., Ryu, J.S., Park, S.K. and Yoon, S.H. (2014) The effects of sports talented exercise program on single leg standing balance. *The Korean Journal of Physical Education* **53(3),** 721-730.

## Key points

- The proprioception training improved the balance of Taekwondo athletes.
- The lower-extremity muscle strength training improved the balance of Taekwondo athletes.
- It was desirable to move the CoP position through conscious effort forward in order to maintain the "Hakdariseogi" stance without sway.

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