doi: 10.2490/prm.20180008 Progress in Rehabilitation Medicine 2018; Vol. 3, 20180008

ORIGINAL ARTICLE

# Effects of Reach Balance Exercise on Toe Grip Strength and Balance in College Basketball Players

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**Objective**: This study was conducted to clarify the ground reaction force exerted on the foot during athletic movements and to demonstrate the effects of reach balance training (RB-T) on toe grip strength as an injury prevention exercise. **Methods**: RB-T was undertaken for 2 weeks by 11 male college basketball players and 22 healthy male college students (including 10 participants in the control group). The vertical ground reaction forces during athletic movements were measured using ground reaction force meters. Before and after RB-T intervention, toe grip strength was measured with a toe grip strength meter, and distances of the center of pressure (COP) to the center of the foot during movement were measured using a three-dimensional motion analyzer. **Results**: The vertical ground reaction force during athletic movement was highest during take-off and decreased in the following order: single-leg front landing, single-leg lateral landing, and turning. The toe grip strength of the BT group and the T group increased after RB-T intervention. For the BT group, RB-T also tended to decrease the COP lateral distance on turning in the dominant leg and the COP front distance on turning and take-off in both legs. **Conclusion**: RB-T could improve the toe grip strength and stabilize the COP position.

**Key words:** college basketball player; ground reaction force; motion analysis; stress fracture of the fifth metatarsal; toe grip strength

## INTRODUCTION

Stress fracture of the fifth metatarsal, which occurs mainly in the proximal epiphyseal region, tends to engender delayed union and nonunion.[1] It is an intractable fracture that requires basketball players to take long-term rest from athletic activities. Injury occurs more often in sports that include many turning and stopping motions, such as football and basketball.[2] The mechanism of injury is considered to be adduction and supination in the forefoot caused by athletic movements.[3–5] Fujita et al. reported in a previous study of the inside pivot leg during turning motion in football players that an increase in lateral foot plantar pressure is the factor generating stress fracture of the fifth metatarsal; moreover, players with higher toe grip strength exhibited lower lateral foot plantar pressure.[6] An increase in lateral foot plantar pressure puts a greater load on the lateral foot. In this case, the center of pressure (COP) is regarded as shifted laterally.

An earlier study that investigated the physical properties of college football players with stress fracture of the fifth metatarsal established that the group with stress fracture of the fifth metatarsal tended to have weaker toe grip strength.[7] Furthermore, the occurrence of ankle pain decreased on improvement of the toe grip strength in basketball players.[8] Moreover, it has been demonstrated that improvement in the toe grip strength is effective for better balance and for achieving higher walking speeds in college students in general.[9] These facts suggest that improvement in the toe grip strength reduces the load on the lateral foot. However, the effect of improvement in the toe grip strength on the COP position in athletic movement remains unclear. The above-described studies[4,6,7] mainly investigated football players. Here, our originally study investigates the effects of toe grip strengthening exercises on basketball players and non-athletes.

According to several studies, including that of Handa et

Received: November 2, 2017, Accepted: March 25, 2018, Published online: April 14, 2018
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**Fig. 1.** Reach balance training.

al.,[10–14] there is significant correlation between the reaching distance of the arm and the toe grip strength in forward reaching movements. Schlenstedt et al.[15] reported that the distance of the COP shift in the front–back direction decreased significantly after single-leg balance exercise. Therefore, we can expect that single-leg reach balance training will improve the toe grip strength and stabilize the COP position.

The main purpose of the current study was to clarify loading on the foot in athletic movements in basketball players. Because basketball players are especially familiar with the movements studied and because they suffer from the risk of fifth metatarsal fatigue fracture, these investigations could elucidate which movements put most stress on the foot and could yield fruitful results for athletes in general. Another aim was to determine the effects of reach balance training (RB-T), which is an exercise aimed at improving toe grip strength, in basketball players and non-athletes. The maximum vertical ground reaction force ($F_z$) during athletic movements (i.e., the loading on the foot) and the COP position at the maximum $F_z$ were measured. Changes were investigated by assessing differences between values obtained before and after intervention, assuming that the load on the lateral foot in the direction of supination increases with the distance of the COP position lateral to the center of the foot.

## MATERIALS AND METHODS

### Participants

The athlete participants were 11 male college basketball players (BT group: age 19.9±0.7 years, height 179.3±4.8 cm, weight 75.9±8.1 kg) who belong to league 1 of the Kanto Collegiate Basketball Federation. The non-athlete participants were 22 ordinary male college students; 12 were assigned randomly to the training group (age 21.6±0.5 years, height 173.3±5.8 cm, weight 62.6±5.0 kg) (T group), and 10 were assigned randomly to the control group (age 21.9±0.6 years, height 169.0±7.1 cm, weight 60.9±7.1 kg) (C group). Handedness was inquired of each participant, and the leg on the same side as the dominant arm was designated the dominant leg; that on the other side was designated the nondominant leg. Participants were informed of the objectives, methods, and the anticipated hazards and inconveniences related to the experiment. Each participant gave written consent thereafter. Consent was obtained from guardians of participants who were minors. Participants who became injured or suffered ill health during the intervention period were excluded. This study was undertaken after obtaining approval from the research ethics committee of the affiliated institution (IN 28–56).

### Methods

The BT group and the T group performed RB-T (**Fig. 1**) on both sides 20 times/day for 2 weeks. RB-T was started in

Fig. 2. Foot marker locations.

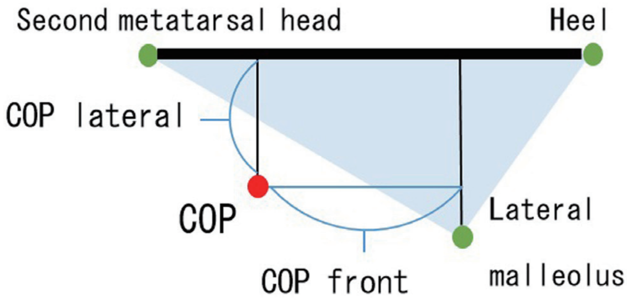


Fig. 3. Definitions of COP lateral distance and COP front distance.

the single-leg standing position, and then the contralateral leg of the supporting leg was stretched backward maximally while the arm was extended forward maximally. For the BT group, RB-T was performed in addition to normal practice and training. Participants who could not perform RB-T four or more days a week over the 2-week study period were excluded.

## Measurement Methods

The following parameters were measured before and after RB-T intervention: $F_z$, the COP lateral distance and front distance during movements, and the toe grip strength. For motion analyses, a three-dimensional motion analyzer (Vicon Nexus; Vicon Motion Systems) was used. Reflection markers were applied to 35 sites over the body according to the plug in gait model; their locations were measured at a sampling frequency of 100 Hz using five cameras. For $F_z$ measurement, two ground reaction force meters (BP400600; Advanced Medical Technology Inc.) were used at a sampling frequency of 1000 Hz.

The four movements performed barefoot to measure the maximum $F_z$ (standardized by body weight) were turning, take-off, single-leg front landing, and single-leg lateral landing. Each movement was measured four times, and the mean of three runs (excluding the first run) was calculated. For turning, the maximum $F_z$ was measured separately for the outside leg and the inside leg. Single-leg front landing and single-leg lateral landing were achieved on landing after jumping in the forward direction and the right direction with maximal effort, but allowing the participant to stand still for 1 s or longer after landing.

For the COP lateral distance, the minimum distance was calculated between the COP and the line through the second metatarsal head and the rear tuberosity of the heel using the marker position on the horizontal surface (**Figs. 2, 3**). The COP position was measured using the ground reaction force meter. An outward shift in COP was designated as positive (+), and an inward shift as negative (–). In addition, the COP front distance was measured as the distance from the COP to the perpendicular from the marker at the lateral malleolus to the line through the second metatarsal head and the heel (**Fig. 3**). The COP lateral distance and the COP front distance were measured at the time of maximum $F_z$. If $F_z$ was bimodal, the COP distance was recorded at the maximum $F_z$ within 40 ms after grounding (**Fig. 4**).

The toe grip strength was measured three times using a toe grip strength meter (TKK3364; Takei Scientific Instruments Co. Ltd.) and the mean was calculated.

## Analysis Methods

The maximum normalized $F_z$ was obtained for five conditions: take-off, single-leg front landing, single-leg lateral landing, and the outside and inside leg in turning. The means measured before and after intervention were compared using one-way analysis of variance (ANOVA). Subsequent multiple comparisons were carried out using the Bonferroni test. For the toe grip strength, the means of three measurements on both legs before and after intervention were compared. For the toe grip strength, the COP lateral distance, and the COP front distance, the effects were compared using two-way ANOVA for the three groups, comparing values obtained before and after the intervention. The level of significance was set at 5% for all analyses. SPSS Statistics software (ver.22.0; IBM Corp.) was used for the statistical analyses.

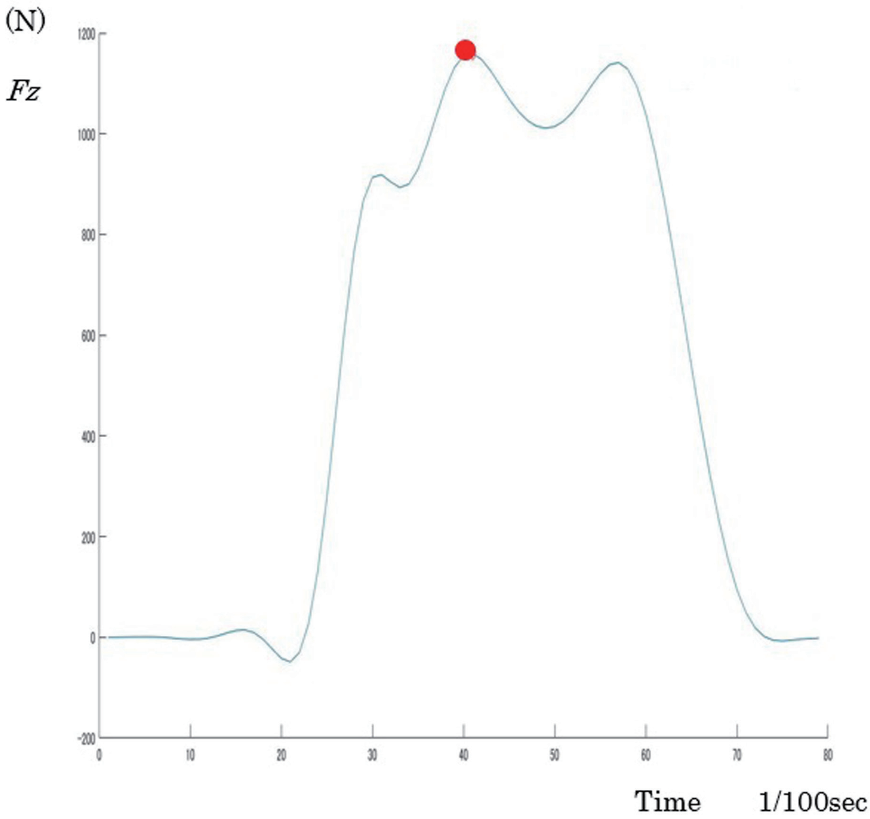


**Fig. 4.** The red dot indicates the point of maximum $F_z$.

## RESULTS

No participant was excluded from the BT group or the T group because of failure to complete training. The results of trials in which the single-leg standing position could not be maintained for 1 s or longer after landing were excluded.

**Figure 5** presents the mean maximum $F_z$ normalized by body weight for each motion. A significant main effect was found for each as a result of ANOVA among the five groups [F (2.768, 0.103)=153.823, MSe=0.103, P<0.01: Greenhouse–Geisser correction, partial $\eta^2$=0.77]. As a result of multiple comparisons, the normalized maximum $F_z$ was highest for take-off and decreased in the following order: single-leg front landing, single-leg lateral landing, and the outside leg and the inside leg in turning. No significant difference was found in the maximum normalized $F_z$ in the outside leg and the inside leg in turning.

**Figure 6** shows the toe grip strength before and after RB-T intervention in the BT group, T group, and C group. The mean toe grip strength was 16.6±3.5 kg before intervention and 17.8±4.8 kg after intervention in the BT group. In the T group, the values were 15.3±3.3 kg and 17.0±3.6 kg, respectively, and in the C group, the values were 11.7±2.7 kg and 11.5±2.5 kg, respectively. Two-way ANOVA revealed no significant interaction. A significant main effect was found before and after intervention [F (1, 61)=5.745, MSe=5.058, P=0.020: Greenhouse–Geisser correction, partial $\eta^2$=0.086]. A significant main effect was also found among the three groups [F (2, 61)=18.488, MSe=19.734, P<0.01, partial $\eta^2$=0.377]. Results of multiple comparisons showed that for toe grip strength, BT group > C group, T group > C group, and BT group = T group.

**Table 1** presents the mean COP lateral distance at the maximum $F_z$ for each motion. Using two-way ANOVA for the dominant leg and the non-dominant leg for the three groups before and after RB-T intervention, a decrease in the mean COP lateral distance was found in turning in the dominant leg: 7.2±3.1 mm before intervention and 5.0±2.8 mm after intervention in the BT group, and 7.6±4.6 mm before intervention and 5.2±3.5 mm after intervention in the T group. However, no significant interaction was found and no main effect was found from examination of data before and

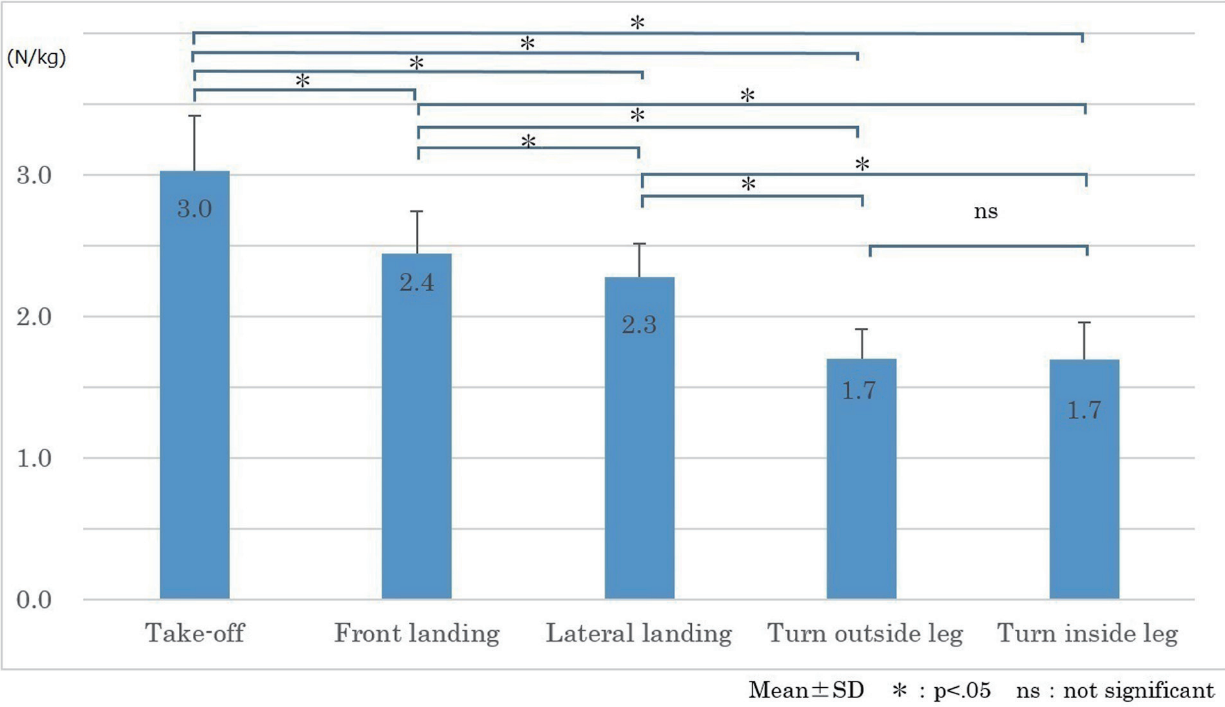


**Fig. 5.** Maximum $F_z$ normalized by body weight during each motion.

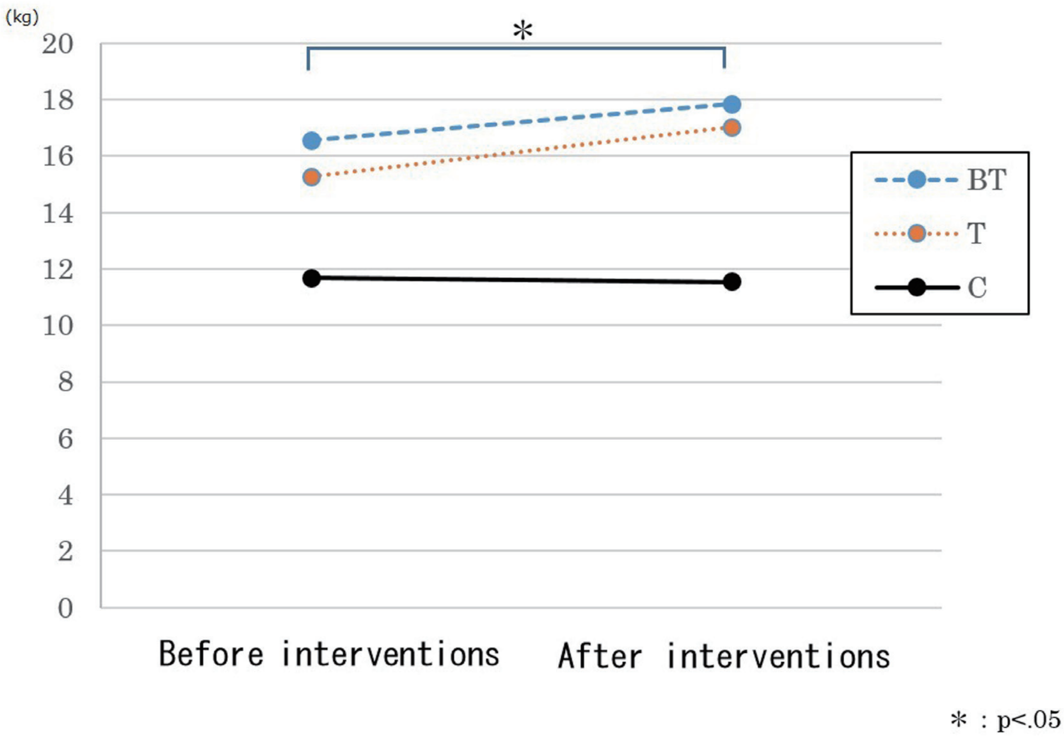


**Fig. 6.** Comparison of the toe grip strength before and after RB-T for the three groups.

after intervention or among the three groups [F (2, 29)=2.921, MSe=20.318, P=0.543, partial $\eta^2$=0.168].

For take-off, the COP lateral distance showed an increasing trend in both the dominant leg and the non-dominant leg in the BT group, although it decreased in the non-dominant leg of the T group from 3.7±8.8 mm before intervention to 0.8±10.3 mm after intervention. However, no significant interaction was found. No main effect was found for data obtained before and after intervention or among three groups [F (2, 29)=0.569, MSe=93.016, P=0.572, partial $\eta^2$=0.173]. No significant interaction was found for either leg during single-leg front landing or for either leg during single-leg lateral landing.

**Table 2** gives the mean COP front distance at the maximum $F_z$ for each motion. For both the dominant leg and the non-dominant leg, no significant interaction was found for any of the four motions among data obtained before and after intervention in the BT group, T group, or C group. No main effect was found for data obtained before and after intervention or among the three groups. For turning, the COP front distance showed a decreasing trend for both legs in the BT group and in the non-dominant leg in the T group [dominant leg: F (2, 28)=0.390, MSe=223.736, P=0.681, partial $\eta^2$=0.27; non-dominant leg: F (2, 27)=2.681, MSe=53.241, P =0.475, partial $\eta^2$=0.054]. For take-off, a decreasing trend was apparent after intervention compared to that before intervention for both legs in the BT group [dominant leg: F (2, 27)=2.681, MSe=99.754, P=0.870, partial $\eta^2$=0.166; non-dominant leg: F (2, 27)=2.681, MSe=53.241, P =0.475, partial $\eta^2$=0.054]. For single-leg lateral landing, a decreasing trend was observed only in the dominant leg in the T group [F (2, 29)=1.079, MSe=155.203, P=0.353, partial $\eta^2$=0.069].

## DISCUSSION

We found that the mean normalized maximum $F_z$ in athletic movements was highest during take-off and decreased in the following order: front landing, lateral landing, and turning. During take-off, the loading on the foot was about three times the body weight. Guettler et al.[16] reported that the plantar pressure of basketball players wearing shoes was about five times the body weight for single-leg landing. This discrepancy could be explained by the difference between subjects wearing shoes and being barefoot. In football players, the critical factor for stress fracture of the fifth metatarsal is reportedly the weight bearing outward shift of the inside leg during turning.[6] However, in the current study, no significant difference was found between the inside and outside legs in basketball players. This finding suggests that similar loading would occur in both legs during turning.

After RB-T intervention, the toe grip strength tended to increase in the BT group and the T group, but not in the C group. RB-T is the motion of arms reaching forward while balancing on a single leg. Correlation has been observed between the forward reaching distance of the arm and the toe grip strength.[10–14] In RB-T, which requires posture control on a single leg to avoid falling, it is necessary to reach out the arm and the leg while always controlling the COP position within the base of support of the foot. It is considered that repeatedly performing this motion is effective for improving the neurogenic muscle strength of toe flexors. However, it is expected that when RB-T is performed but the toe grip strength is not used properly, the COP position will be poorly controlled and the COP will move laterally. This is regarded as one reason why the COP lateral distance did not decrease uniformly in the current study. Additionally, previous reports show that the effect of exercise therapy to improve toe grip strength was observed after not less than 3 weeks in a study in which towel gathering (10 min) was performed four times per week,[17] after 4 weeks of combined training at least six times per week,[9] and after 6 weeks of combined training three times per week (performed 18 times).[18] It is likely, therefore, that the effect of RB-T in improving toe grip strength would be demonstrated more clearly by extending the intervention period to at least 3 weeks or by increasing the number of training iterations.

After intervention, the COP lateral distance tended to decrease in turning of the dominant leg in the BT group and the T group. This effect likely resulted from RB-T improving the toe grip strength, which changed the COP position inward at the point of maximum $F_z$ during turning. This agrees with previous studies that demonstrate a decreased moment of supination by the centering of the COP position.[19,20] The COP front distance similarly showed a decreasing tendency during take-off in the BT group, but not in the T group. This could be because the BT group was familiar with the movement adopted in the study and so the effect was evident in 2 weeks. For the T group, the RB-T training was sufficient to see an improvement in the toe grip strength, but not to see a movement in the COP front distance. According to Tsuyuguchi et al.,[8] "centipede walking," or pulling at the floor with the toes in the standing position, is considered to be effective training for rehabilitation. "Centipede walking" with active exercise for 2 months helped to improve the toe grip strength and the time of closed-eye single-leg standing. Handa et al.[10] and Fransz et al.[21] suggested that toe grip strength has a stronger

**Table 1.** COP lateral distance in millimeters for different motions

| | BT group | | | | T group | | | | C group | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dominant leg | | Non-dominant leg | | Dominant leg | | Non-dominant leg | | Dominant leg | | Non-dominant leg | |
| | pre | post | pre | post | pre | post | pre | post | pre | post | pre | post |
| Turning | 7.2±3.1 | 5.0±2.8 | 7.2±3.0 | 9.1±6.4 | 7.6±4.6 | 5.2±3.5 | 6.7±4.4 | 8.8±3.8 | 6.8±4.7 | 8.4±4.0 | 10.0±5.4 | 8.1±3.5 |
| Take-off | 7.7±5.8 | 9.4±6.7 | 3.4±5.0 | 4.0±6.6 | 6.8±8.1 | 8.9±6.7 | 3.7±8.6 | 0.8±10.3 | 2.2±4.8 | 2.7±6.1 | -0.5±5.4 | 1.5±5.3 |
| Single-leg front landing | 6.0±5.7 | 9.0±3.0 | 1.3±3.4 | 1.0±6.5 | 5.7±9.7 | 8.8±4.0 | 4.5±9.5 | 3.6±6.9 | 4.6±4.4 | 8.1±4.8 | 0.1±7.5 | 3.1±4.8 |
| Single-leg lateral landing | 5.5±7.0 | 3.2±11.4 | 1.0±3.7 | -1.0±7.3 | 6.5±9.3 | 7.2±4.2 | 5.3±6.1 | 2.7±6.6 | 3.8±4.7 | 3.6±6.7 | 1.8±5.2 | -0.8±6.4 |

Data are mean±SD.

**Table 2.** COP front distance in millimeters for different motions

| | BT group | | | | T group | | | | C group | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dominant leg | | Non-dominant leg | | Dominant leg | | Non-dominant leg | | Dominant leg | | Non-dominant leg | |
| | pre | post | pre | post | pre | post | pre | post | pre | post | pre | post |
| Turning | 114.9±17.7 | 109.8±14.2 | 110.8±14.0 | 104.9±19.1 | 101.7±23.8 | 104.0±16.2 | 111.7±30.0 | 95.1±29.7 | 103.5±14.6 | 105.0±9.8 | 103.8±13.3 | 97.9±14.7 |
| Take-off | 127.0±16.6 | 124.2±15.3 | 121.3±7.7 | 118.6±10.4 | 113.7±20.2 | 125.3±17.4 | 116.8±20.2 | 119.3±16.8 | 128.4±5.7 | 132.5±7.1 | 121.8±7.0 | 123.2±9.5 |
| Single-leg front landing | 115.5±15.7 | 115.1±17.8 | 110.2±15.3 | 111.6±16.8 | 101.3±25.7 | 103.0±21.2 | 106.8±24.4 | 104.3±18.5 | 99.0±9.7 | 96.9±14.3 | 94.8±22.1 | 90.3±20.3 |
| Single-leg lateral landing | 90.1±11.0 | 92.6±12.1 | 81.5±16.6 | 80.4±13.8 | 96.0±23.8 | 89.2±13.8 | 78.9±25.5 | 83.8±17.8 | 86.6±14.7 | 89.7±14.7 | 87.5±15.6 | 92.0±15.7 |

Data are mean±SD.

influence on situations in which kinetic balancing capacity is needed than on passive standing. RB-T was also suggested to be effective not only for the improvement of muscle strength but also for improving the kinetic balancing function and the centering of the COP.

Limitations of this study prevented us from concluding simply that the COP distance was changed by the effects of RB-T alone because the BT group in this study performed normal athletic practice and training. The effects of RB-T would probably be confirmed more clearly by broadening measurements to include the shift of the center of gravity during performance of RB-T or 3D analysis of the COP position. RB-T seems to contain many possibilities. It should be possible to generalize these observations by investigating other sports and, consequently, to make proposals to help protect athletes from injury.

## CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

## REFERENCES

1. Fernández Fairen M, Guillen J, Busto JM, Roura J: Fractures of the fifth metatarsal in basketball players. Knee Surg Sports Traumatol Arthrosc 1999;7:373–377. DOI:10.1007/s001670050183, PMID:10639656
2. Kokubo T, Hashimoto T: Treatment of the fifth metatarsal proximal fractures [in Japanese]. Jpn J Orthop Sports Med 2015;35:3–10.
3. Kavanaugh JH, Brower TD, Mann RV: The Jones fracture revisited. J Bone Joint Surg Am 1978;60:776–782. DOI:10.2106/00004623-197860060-00008, PMID:701310
4. Fujitaka K, Otuki S, Kishimoto K, Hashimoto M, Okubo M, Kumai T, Tanaka Y: Motion analysis of soccer players with stress fracture of the fifth metatarsal [in Japanese]. Jpn J clinical. Sports Med 2014;22:331–334.
5. Obara K, Sasaki K, Matsuno T: Motion analysis of a volleyball player with the fifth metatarsal stress fracture; a case report [in Japanese]. J East Jpn Orthop 2010;22:81–84.
6. Fujita Y, Sakuraba K, Kubota A, Fujita S, Aoki K, Fukushi N: Relationship between toe muscle strength and plantar pressure distributions during turn in male high school soccer players [in Japanese]. Jpn J Orthop Sports Med 2015;35:47–51.
7. Fujitaka K, Otsuki S, Kishimoto K, Hashimoto M, Okubo M: Relationship between stress fracture of the 5th metatarsal and physical factors in college soccer players [in Japanese]. Jpn J Orthop Sports Med 2013;33:37–41.
8. Tsuyuguchi R, Seto T, Ootsuki S, Nakata H, Hamaguchi K, Tanaka S: The difference between training period with a detraining period of body balance, grip strength of the toes and the incidence of ankle pain in boy basketball players [in Japanese]. Jpn J clinical. Sports Med 2015;23:217–223.
9. Kaneko R, Fujisawa S, Sasaki M: Influence of toe flexer muscle strength training on floor reaction force during maximum speed walk [in Japanese]. Rigakuryoho Kagaku 2009;24:411–416. DOI:10.1589/rika.24.411
10. Handa S, Horiuchi K, Aoki K: A study on the measurement of toe grasping strength and effect of standing postural control [in Japanese]. Jpn J Ergonomics 2004;40:139–147. DOI:10.5100/jje.40.139
11. Kabe N, Kurosawa K, Nishida Y, Kishida A, Kobayashi S, Tanaka Y, Makizako H, Masuda Y, Watanabe M: The study of relationship between toe and dynamic postural control [in Japanese]. Rigakuryoho Kagaku 2002;17:199–204. DOI:10.1589/rika.17.199
12. Koda H, Fukumoto T: Correlations among toe flexor strength, anterior COP shift, and functional reach in elderly vs. young people [in Japanese]. Jpn J Clin Biomech 2014;35:285–289.
13. Tanaka Y, Suzuki Y, Haruna H, Hosoya S: Relationship between toe flexion strength and center of foot pressure by moving center of gravity in anteroposterior direction [in Japanese]. Bull Hokkaido Univ Sci 2016;42:85–90.
14. Soma M, Igarasi T, Kudou W, Nakae H, Abiko T: Influence of foot-gripping strength training to functional reach test and maximal step length, walking ability in healthy adults [in Japanese]. Jpn J Health Promot Phys Ther 2012;2:59–63. DOI:10.9759/hppt.2.59
15. Schlenstedt C, Arnold M, Mancini M, Deuschl G, Weisser B: The effect of unilateral balance training on postural control of the contralateral limb. J Sports Sci 2017;35:2265–2271. DOI:10.1080/02640414.2016.1265660, PMID:27935423
16. Guettler JH, Ruskan GJ, Bytomski JR, Brown CR, Richardson JK, Moorman CT 3rd: Fifth metatarsal stress fractures in elite basketball players: evaluation of forces acting on the fifth metatarsal. Am J Orthop 2006;35:532–536. PMID:17152977
17. Takei K, Murata S, Kai Y, Murata J: Effect of foot grip strength training [in Japanese]. Rigakuryoho Kagaku 2011;26:79–81. DOI:10.1589/rika.26.79

18. Fukuda I, Kobayashi R: The effect of toe-grip training in healthy young adults [in Japanese]. Phys Ther Jpn 2008;35:261–266.
19. Dayakidis MK, Boudolos K: Ground reaction force data in functional ankle instability during two cutting movements. Clin Biomech (Bristol, Avon) 2006;21:405–411. DOI:10.1016/j.clinbiomech.2005.11.010, PMID:16427165
20. Kawakami Y, Yonetani Y, Takao R, Ogasawara I, Mae T, Nakata K, Horibe S: Reproducibility of dynamic body balance measurement by center of foot pressure analysis immediately after single-leg hop landing. Kurume Med J 2016;62:41–46. DOI:10.2739/kurumemedj.MS65012, PMID:27237940
21. Fransz DP, Huurnink A, Kingma I, van Dieën JH: How does postural stability following a single leg drop jump landing task relate to postural stability during a single leg stance balance task? J Biomech 2014;47:3248–3253. DOI:10.1016/j.jbiomech.2014.06.019, PMID:25016486