Effects of core and non-dominant arm strength training on drive distance in elite golfers.

Dong Jun Sung

Seung Jun Park

SoJung Kim
Rowan University, kims@rowan.edu

Moon Seok Kwon

Young-Tae Lim

Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science 5 (2016) 219–225

www.jshs.org.cn

Original article

Effects of core and non-dominant arm strength training on drive distance in elite golfers

Dong Jun Sung [a], Seung Jun Park [a], Sojung Kim [b], Moon Seok Kwon [a], Young-Tae Lim [a,*]

[a] Division of Sport Science, Konkuk University, Chungju, Chungbuk 380-701, Republic of Korea

[b] College of Physical Education, Kyung Hee University, Suwon, Gyeonggi 446-701, Republic of Korea

Received 29 May 2014; revised 25 August 2014; accepted 15 December 2014

Available online 23 April 2015

Abstract

Background: Various training schemes have sought to improve golf-related athletic ability. In the golf swing motion, the muscle strengths of the core and arms play important roles, where a difference typically exists in the power of arm muscles between the dominant and non-dominant sides. The purposes of this study were to determine the effects of exercises strengthening the core and non-dominant arm muscles of elite golf players (handicap < 3) on the increase in drive distance, and to present a corresponding training scheme aimed at improving golf performance ability.

Methods: Sixty elite golfers were randomized into the control group (CG, $n = 20$), core exercise group (CEG, $n = 20$), and group receiving a combination of muscle strengthening exercises of the non-dominant arm and the core (NCEG, $n = 20$). The 3 groups conducted the corresponding exercises for 8 weeks, after which the changes in drive distances and isokinetic strength were measured.

Results: Significant differences in the overall improvement of drive distance were observed among the groups ($p < 0.001$). Enhancement of the drive distance of NCEG was greater than both CG ($p < 0.001$) and CEG ($p = 0.001$). Except for trunk flexion, all variables of the measurements of isokinetic strength for NCEG also showed the highest values compared to the other groups. Examination of the correlation between drive distance and isokinetic strength revealed significant correlations of all variables except trunk flexion, wrist extension, and elbow extension.

Conclusion: The combination of core and non-dominant arm strength exercises can provide a more effective specialized training program than core alone training for golfers to increase their drive distances.

Keywords: Core exercise; Drive distance; Elite golfer; Isokinetic strength; Non-dominant arm strength exercise

1. Introduction

Over 35 million people enjoy playing golf, and this game has been gaining popularity globally.[1] Scientific approaches to improving the golf ability have recently focused on physical strength, in contrast to the past where consistent accuracy and putting techniques were regarded as having more significance.[2] This shifting of the focus has been occurring in recent years due to lengthening of the course yardage. For this reason, golfers require more physical strength to endure the extended time of a typical round, and to provide explosive swing power to cover longer distances, which can be intensified by a widened range of motion (ROM).[3]

Specialized training programs such as plyometrics training,[4] golf specific muscle power training,[5,6] or core training[7,8] have been applied to golfers with positive outcomes. The trunk of a golfer is the most vulnerable part to injury,[9] typically attributable to bad posture and improper swing mechanism, or weakened trunk muscle strength due to exercise deficiency. Strengthening of the core muscles could protect against injury while also improving golfing ability.

Core muscles are defined as the essential peripheral muscles of the spine and abdomen required for stabilizing the backbone, and for maintaining the balance of the pelvis.[10] In

Peer review under responsibility of Shanghai University of Sport.

* Corresponding author.

E-mail address: ytlim@kku.ac.kr (Y.-T. Lim)

http://dx.doi.org/10.1016/j.jshs.2014.12.006

a study applying core muscle training to golfers for 12 weeks, the flexibility, core muscle strength, and performance of drives were improved.[7] The club head speed was also found to increase after the application of training for 11 weeks.[11] The reason for the benefits can be understood by examining the mobilization of core muscles in the swing span of the club. The rectus abdominus muscle in the stance position, the external oblique muscle for the back swing, and the external oblique and rectus abdominus muscles for creating power for the down swing all play important roles for each segment of the swing.[12]

Another important contributor to the swing motion is the non-dominant arm. The non-dominant arm controls the club, from the back swing to the down swing.[13] In the back and down swing aspects, including gripping the club, the roles of the extensor carpi ulnaris, flexor carpi ulnaris, and posterior deltoid in the non-dominant arm are as important as the muscles in the dominant arm.[12] In addition, the non-dominant arm complex is also influential in generating power in the swing,[14] as the forearm could lead the flexor burst in the acceleration section of the swing.[15]

Despite these important roles of the non-dominant arm, specialized strength training for this arm is uncommon. The muscle force of the dominant arm is reportedly about 10% greater than the non-dominant arm.[16,17] However, studies have lacked findings on the influence of strengthening muscles of the non-dominant arm (typically the left one in a right handed golfer) on swing performance. Golfers who utilize the dextral arm muscles are typically unskilled in the use of sinistral arm muscles; strengthening of the non-dominant upper limb to balance the power between both arms is required.[18]

The combination of accuracy and drive distance is important in modern golf ability.[13,19] Golf relies on a successful drive,[20] and the drive distance is highly correlated with the scores of elite golfers.[21] Numerous studies have reported the effects of various training methods on drive distance,[4–7] but the effects of strengthening training of the non-dominant arm on golf ability remain unclear. Therefore, this study examined the influence of such strength training on drive distance and assessed the correlation between strength and drive distance. We hypothesized that a combination of core and non-dominant training would increase drive distance, and that there would be a positive correlation between isokinetic strength of the non-dominant arm and drive distance.

2. Materials and methods

2.1. Participants

The sample size was determined to have a set effect size, error, and power value of 0.42,[22,23] 0.05, and 0.8, respectively, to use the F-value through power analysis (G-power program 3.1.3, Kiel, Germany).[24] Sixty golfers participated in this study, all of whom were right handed male Korean elite golfers with careers of over 5 years and handicaps of less than 3, who also periodically participated in tournaments. They were free from any musculoskeletal system disorders and had never participated in resistance training to improve their golfing abilities, apart from regular training. This study was approved by the Konkuk University Research Ethics Committee. After agreeing to participate, the participants were informed about the procedures and aims of the study and signed a written informed consent.

The 60 participants were randomly assigned to a control group (CG, n = 20), a core muscle exercise group (CEG, n = 20), and a group with combined strengthening exercises of the non-dominant arm (in this study, the left arm) and core muscles (NCEG, n = 20). All participants visited the biomechanics laboratory at Konkuk University for measurement of body composition (InBody 4.0; Biospace, Seoul, Korea).

2.2. Exercise program

The 60 participants completed the entire 8 weeks of the study program, and all participants in the CEG and NCEG attended an 8-week training program without withdrawal.

The CG did not receive any specific intervention other than conventional golf swing training. The CEG only performed core exercise, which was carried out for 60 min per day, 3 times a week, for 8 weeks. An initial core muscle exercise program aimed to achieve basic balance and muscle force during the first 4 weeks, after which it was configured to secure dynamic balance by active improvement in muscle strength, aiming for the combination of dynamic balance and strength for the remaining 4 weeks (Fig. 1 and Table 1). The NCEG performed non-dominant arm exercise in addition to the core exercise. The non-dominant arm strength exercise program for NCEG consisted of 6 exercises which were highly relevant to the golf swing motion to improve the function of the forearm, biceps, and shoulder. The NCEG carried out exercise 60 min per session, 6 times a week, for 8 weeks. Core and non-dominant arm strength exercises were applied alternately each day.

A 10-min stretching session was included in all exercise programs as a warm-up and at the close of each exercise session. Before application of the exercise programs, all participants were tested to measure the maximum muscle force for each weight training exercise, and the corresponding exercise intensities were assigned to each participant based on the test results. The 1 repetition maximum (1RM) was measured again 3 weeks after starting of the exercise programs to adjust the exercise loads to accommodate for respective strength gains, as described previously.[25]

2.3. Measurement of drive distance

Drive distance was measured using a radar-based detecting device, Flight Scope KUDU (EDH, Orlando, FL, USA), with data collected from measurements within the range of ±15 m (the right and the left deviation) for balls hit with correct club impacts (Smash factor ≥1.47). Performance of the Flight Scope KUDU was comparable to the laser-based rangefinder. Average error and standard deviation of the Flight Scope KUDU was 0.50 m and 2.02 m, respectively. The drive distances of participants were measured 5 times using their

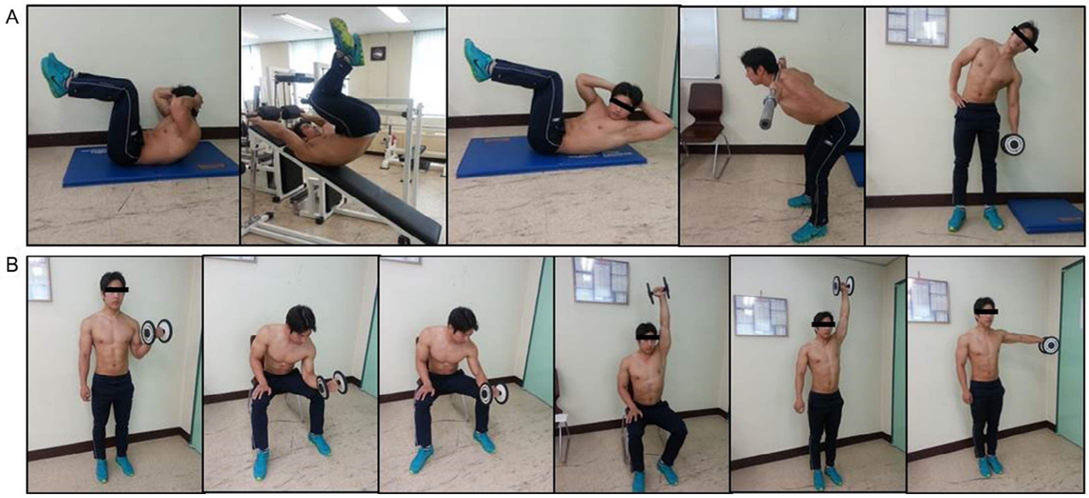

Fig. 1. Depiction of exercise programs employed in the present study. (A): Core exercise program. From the left, crunch – reverse crunch – trunk twist – good morning – dumbbell side bend. (B): Non-dominant arm strength training. From the left, dumbbell curl – wrist curl – reverse wrist curl – triceps extension – dumbbell press – side lateral raise.

Table 1
Core and non-dominant arm strengthening exercise programs.

Exercise program	Weeks 1–4 (load/sets × repetitions)	Weeks 5–8 (load/sets × repetitions)
Core exercise		
Crunch	3 × 12	3 × 15
Reverse crunch	3 × 12	3 × 15
Trunk twist	3 × 12	3 × 15
Good morning	3 × 12	3 × 15
Dumbbell side bend	60% 1RM/3 × 12	60% 1RM/3 × 15
Non-dominant arm strengthening exercise		
Dumbbell curl	60% 1RM/3 × 12	70% 1RM/3 × 15
Wrist curl	60% 1RM/3 × 12	70% 1RM/3 × 15
Reverse wrist curl	60% 1RM/3 × 12	70% 1RM/3 × 15
Triceps extension	60% 1RM/3 × 12	70% 1RM/3 × 15
Dumbbell press	60% 1RM/3 × 12	70% 1RM/3 × 15
Side lateral raise	60% 1RM/3 × 12	70% 1RM/3 × 15

Abbreviation: 1RM = 1 repetition maximum.

own clubs, and average values were obtained by excluding both the minimum and maximum measurements of drive distances.

2.4. Measurement of isokinetic strength

Isokinetic strength was measured using a commercial system (Biodex; Shirley, New York, NY, USA). Before each measurement, participants were given 2 chances to practice for becoming familiar with the protocol, and the purpose and procedure of each measurement were explained to the subjects to enable maximum effort. The measurement protocol was designed to measure the isokinetic strength of the wrist, elbow, trunk, and shoulder of the non-dominant arm, 5 times at 60°/s. For a proper comparison, the collected data of peak torques were normalized to peak torque/body mass (Nm/kg). Flexion/extension of the wrist, elbow, and trunk were performed at the transverse axis on the sagittal plane, and horizontal adduction/abduction of the shoulder was also performed on the vertical axis of the transverse plane in the diagonal direction.

2.5. Statistical analysis

All descriptive data for the dependent variables are presented as mean ± SE. Group differences in baseline values for the dependent variables were determined by 1-way ANOVA. The drive distance and isokinetic strengths of the 3 groups were corrected to allow comparison by employing the pre-training values as covariates, and analysis was carried out by ANCOVA to compare the measured values obtained from post-examination. In cases where the “between-subjects factors” appeared to be significant, the differences between each group were further identified through the contrast test with the least significant difference. Correlations between distance and isokinetic strength were analyzed through the Pearson’s correlation coefficient test of the post-training data. All statistical procedures were performed using SPSS for Windows Version 19.0 (IBM Corp., Armork, NY, USA). The level of significance was set to $p < 0.05$.

3. Results

Table 2 shows the means ± SE for the baseline physical characteristics, drive distance, and body composition variables for each group. There were no significant differences between the groups for the physical characteristics or body composition variables at baseline ($p > 0.05$).

3.1. Change of drive distance

The differences in the drive distance according to the training applied are shown in Table 3.

Table 2
Physical characteristics and drive distance at the beginning of the study (mean ± SE).

Measures	Group			p value
	CG	CEG	NCEG	
Age (year)	24.0 ± 1.0	23.0 ± 0.5	23.2 ± 0.6	0.110
Height (cm)	177.1 ± 1.8	175.6 ± 1.1	174.8 ± 1.9	0.674
Weight (kg)	73.1 ± 4.2	74.7 ± 2.0	72.4 ± 1.8	0.078
BMI (kg/m^2)	24.4 ± 0.9	24.7 ± 0.6	23.2 ± 0.8	0.165
Drive distance (m)	221.26 ± 4.01	224.53 ± 8.89	215.69 ± 5.51	0.372

Abbreviations: CG = control group; CEG = core exercise group; NCEG = non-dominant arm + core exercise group.

Table 3
Drive distance before and after exercise intervention for 3 groups (m) (mean ± SE).

Group	Pre	Post	p value	Contrast test (p value)
CG	221.26 ± 4.01	222.16 ± 2.96	<0.001	a: b (<0.001)
CEG	224.53 ± 8.89	235.23 ± 4.82		a: c (<0.001)
NCEG	215.69 ± 5.51	239.16 ± 1.84		b: c (0.001)

Notes: a = CG, b = CEG, c = NCEG; p value was tested by ANCOVA; adjusted for pre-test value.
Abbreviations: CG = control group; CEG = core exercise group; NCEG = non-dominant arm + core exercise group.

The 8-week exercise intervention programs produced significant differences in drive distance between the groups ($p < 0.001$) (Table 3). The drive distance of NCEG was significantly longer (239.16 ± 1.84 m) than both CG (222.16 ± 2.96 m, $p < 0.001$) and CEG (235.23 ± 4.82, $p = 0.001$).

3.2. *Effects of exercise programs on isokinetic strength*

Isokinetic strength of the non-dominant arm and trunk were measured after application of the training programs (Table 4). Significant differences in the isokinetic strengths of wrist extension were observed between the 3 groups ($p < 0.001$). The peak torque of wrist extension was significantly greater for NCEG than CG ($p < 0.001$) and CEG ($p < 0.001$). Similar to the results of wrist extension, the peak torque of wrist flexion in NCEG had a significantly greater increase compared with the CG ($p < 0.001$) and CEG ($p < 0.001$).

The elbow extension among the 3 groups was also significantly different after 8 weeks ($p < 0.001$). Accordingly, a contrast test showed that peak torque of elbow extension was significantly higher for the NCEG than CG ($p < 0.001$) and CEG ($p = 0.005$). Similarly, elbow flexion of the NCEG also increased more than both the CG ($p < 0.001$) and CEG ($p < 0.001$). In addition, the elbow flexion of CEG was greater than that of CG ($p = 0.011$).

Concerning isokinetic strength of the shoulder after application of the training programs, significant differences in shoulder diagonal abduction were evident among the 3 groups ($p < 0.001$). The contrast test indicated that the isokinetic of shoulder diagonal abduction in the NCEG was significantly greater than in both the CG ($p < 0.001$) and CEG ($p < 0.001$). Similarly, shoulder diagonal adduction was also significantly different among the 3 groups ($p < 0.001$), with the NCEG expressing higher increase in the peak torque than both the CG ($p < 0.001$) and CEG ($p < 0.001$).

Table 4
The results of isokinetic strength of non-dominant arm and trunk (peak torque/body mass, Nm/kg) (mean ± SE).

Site	Group	Pre	Post	p value	Contrast test (p value)
Wrist extension	CG	15.77 ± 1.23	16.63 ± 1.25	<0.001	a: c (<0.001)
	CEG	13.76 ± 1.65	15.40 ± 1.69		b: c (<0.001)
	NCEG	11.29 ± 1.03	25.18 ± 1.77		
Wrist flexion	CG	47.65 ± 3.21	48.58 ± 4.12	<0.001	a: c (<0.001)
	CEG	38.50 ± 3.24	44.01 ± 2.11		b: c (<0.001)
	NCEG	25.20 ± 2.32	66.84 ± 2.63		
Elbow extension	CG	122.61 ± 5.70	116.12 ± 7.02	<0.001	a: c (<0.001)
	CEG	122.29 ± 6.17	145.5 ± 5.57		b: c (0.005)
	NCEG	124.92 ± 2.81	153.38 ± 4.14		
Elbow flexion	CG	92.60 ± 3.67	85.13 ± 3.49	<0.001	a: b (0.011)
	CEG	96.34 ± 3.52	100.43 ± 3.31		a: c (<0.001)
	NCEG	100.83 ± 4.12	122.05 ± 4.89		b: c (<0.001)
Shoulder diagonal abduction	CG	147.77 ± 14.19	150.45 ± 12.53	<0.001	a: c (<0.001)
	CEG	150.11 ± 6.43	149.37 ± 7.54		b: c (<0.001)
	NCEG	133.60 ± 7.05	189.86 ± 9.85		
Shoulder diagonal adduction	CG	172.83 ± 7.34	180.77 ± 8.17	<0.001	a: b (0.034)
	CEG	230.37 ± 6.82	257.39 ± 10.13		a: c (<0.001)
	NCEG	231.73 ± 8.02	312.04 ± 14.01		b: c (<0.001)
Trunk extension	CG	743.47 ± 43.33	719.69 ± 43.70	<0.001	a: c (<0.001)
	CEG	655.94 ± 5.51	759.78 ± 49.08		b: c (0.006)
	NCEG	652.37 ± 29.93	900.14 ± 43.20		
Trunk flexion	CG	467.35 ± 27.55	421.49 ± 38.73	<0.001	a: b (<0.001)
	CEG	453.48 ± 24.53	561.39 ± 19.89		a: c (<0.001)
	NCEG	454.39 ± 19.37	535.92 ± 22.91		

Notes: a = CG, b = CEG, c = NCEG; p value was tested by ANCOVA; adjusted for pre-test value.
Abbreviations: CG = control group; CEG = core exercise group; NCEG = non-dominant arm + core exercise group.

Table 5
Correlation between drive distance and isokinetic strength.

Parameter	WFPQ	EFPQ	SDPQ	TFPQ	WEPQ	EEPQ	SBPQ	TEPQ
r	0.645	0.423	0.539	0.196	0.105	0.239	0.284	0.617
p value	0.001	0.003	0.002	0.171	0.860	0.111	0.010	0.005

Note: All isokinetic factors were using peak torque/body mass.
Abbreviations: WFPQ = wrist flexion peak torque; EFPQ = elbow flexion peak torque; SDPQ = shoulder diagonal adduction peak torque; TFPQ = trunk flexion peak torque; WEPQ = wrist extension peak torque; EEPQ = elbow extension peak torque; SBPQ = shoulder abduction peak torque; TEPQ = trunk extension peak torque.

Finally, changes in trunk isokinetic strengths were also observed. Significant differences appeared in both trunk extension and flexion among all groups ($p < 0.001$). Contrast test showed that the trunk extension of the NCEG increased more than both CG ($p < 0.001$) and CEG ($p = 0.006$), while trunk flexion was also higher in the NCEG than CG ($p < 0.001$). While improvement of trunk flexion was higher in the CEG than CG ($p < 0.001$), no significant difference was observed between the CEG and NCEG.

3.3. *Correlation between drive distance and isokinetic strength*

Pearson's correlation test was used to confirm whether isokinetic strength was related to drive distance. As can be seen in Table 5, positive correlations between drive distance and isokinetic strengths were observed, including wrist flexion ($r = 0.645$, $p = 0.001$), elbow flexion ($r = 0.423$, $p = 0.003$), shoulder diagonal adduction ($r = 0.539$, $p = 0.002$), shoulder abduction ($r = 0.284$, $p = 0.010$), and trunk extension ($r = 0.617$, $p = 0.005$) peak torque/body mass. Wrist flexion strength showed the highest correlation with drive distance.

4. Discussion

To the best of our knowledge, this is the first study to find a relationship between drive distance, the isokinetic strength of the non-dominant arm, and core muscle strengthening. We also provided a specialized training program for golfers to improve their golfing ability by identifying the correlation between drive distance and isokinetic strength.

In the present study, the exercise programs employed were effective for improving the drive distance, with the group which undertook combined strengthening exercises for core and non-dominant arm (NCEG) showing the highest impact by an improvement of ~9.8% over that observed in the pre-training conditions (CG, ~0.4%; CEG, ~5%). Such an improvement in drive distance was attributable to the marked enhancement in isokinetic strength of the participants in the NCEG, wherein wrist flexion, elbow flexion, shoulder abduction/adduction, and trunk extension were all significantly correlated with drive distance.

Many golfers may believe that resistance training has a negative influence on flexibility, which would cause deterioration of their swing ability.[4] However, ROM can be improved by applying a flexibility program integrated with a resistance program.[19] Golfing ability should be partly determined by the capability of power creation generated from a wide ROM of the golfers.[13,26,27] For this reason, many studies have applied such exercise programs to golfers for improving their physical strength. Muscle strengths of the legs, upper torso, and arm are all related to golf ability,[3,27] and have been correlated with swing speed. It is important to note that an improvement in muscle strength would have a positive influence on both drive distance and overall swing performance. Single resistance exercise programs or general composite exercise programs that includes endurance, flexibility, and/or balance training have been commonly applied to golfers.[4,6,20,26] Despite differences in the methods of application, the approaches appear to be beneficial concerning enhanced muscle strength and playing ability.[21] Therefore, enhancement of muscle strength by various training methods lead to improvement of golfing ability.

A study involving golfers with a handicap of less than 14 suggested that the muscle strength-related items, such as right wrist palmar flexion and left shoulder horizontal extension strength, are correlated with drive distance.[26] Another study reported correlations between the function of physical elements and the drive distances of male and female golfers with average handicap values of 10.[3] A significant correlation between vertical jump and drive distance in female golfers, and correlations of vertical jump, pull-up, and push-up performances with the drive distance of male golfers have also been identified. Thus, the relationship between physical strength and performance of the golf swing, including drive distance, is apparent. Similar to previous studies, this study demonstrated that a positive correlation exists between muscle strength and drive distance. This result suggests that strength training for improvement of the drive distance is essential.

In an interventional study, a strength training program was applied to 42 subjects for 8 weeks. Subsequent increases of the drive distance without reduced accuracy were reported.[28] It was also reported that the application of an exercise program of elastic resistance tubing for 10 weeks, which intended to improve the muscle strength of the right torso, induced significant increases in club head speed by 5.5%, carry distance by 7.7%, ball speed by 5%, and total distance by 6.8%.[6] Thus, the enhancement of muscle strength or muscle-associated components seems to have a positive influence on the improvement of drive distance. Fletcher and Hartwell[4] reported that club head speed and drive distance were improved after the application of an 8-week composite exercise program. The program consisted of right torso exercise, plyometrics, and stretching for elite male golfers (average handicap 5.5), and concluded that the improvements observed were attributable to enhanced muscle force.[4] Core and rotational stability training for 9 weeks produced increase of the club head speed by 3.8% compared to general resistance training, which produced increases of 1.2%.[11] The increase of club head speed was also reported for female subjects who participated in an 11-week program of right torso muscle exercise, flexibility, and medicine ball use.[27] In our study, strengthening of the core muscles improved drive distance, indicating that the core muscles play an important role in enhancement of drive distance.

In the present study, the NCEG demonstrated the most apparent improvement in drive distance. Moreover, the isokinetic strength such as wrist flexion, elbow flexion, shoulder diagonal abduction/adduction, and trunk extension all had a positive correlation with drive distance. These results implied that the composite enhancement of muscle force in the non-dominant arm and core muscles could improve the drive distances of golfers. In contrast, another study did not find a correlation between drive distance and enhanced isometric strength following a 7-week exercise program for average golfers (17 handicap) aged 32–84 years.[29] This could indicate that the measurement of isometric strength might not be compatible with appraisal of the complex motion of the golf swing. Combined exercise may be a more successful approach to improve drive distance.

Training and strengthening of the core muscles is imperative in the majority of sports to obtain optimal performance and prevent injuries.[8] This also applies to the game of golf, wherein the core muscles have been known to control the movement of the body during the swing, to impact and adjust the cooperation of physical stabilization.[30] The abdomen and lower back are typically recognized as the power zone, and are the essential region for creating power. Additionally, muscles around the lumbar region play a role in neuromuscular control to maintain stabilization of physical function.[31] In this manner, the core muscles play an important role in the creation of power and for stabilizing the body while performing exercise. In golf, the mobilization of core muscles is apparent when examining the results of electromyographic analysis performed during each segment of the swing.[32] The results also suggest that training of the core muscles would influence enhancement of the overall swing performance.

Similar to results of this study, a study on the application of core exercises for 12 weeks revealed improvements in drive performance, core muscle strength, and flexibility of female golf players,[7] demonstrating the effectiveness of core exercise programs for increasing drive distance.

Although there is a body of evidence pointing to the benefits of muscle strengthening, no previous studies have yet addressed the strength of the non-dominant arm relative to golf performance. A non-dominant arm strengthening exercise program was employed herein based on the results of a study which revealed the muscle force of the dominant arm to be 10% stronger than the non-dominant one.[16,17] Those who participated in the non-dominant arm strengthening exercise program showed dramatic increase in drive distance. Based on these results, we suggest that the combined employment of a non-dominant arm strength exercise program would be more effective for improving the drive distance of golfers. In addition, while one-side exercise might be unfavorable, improving deficient muscle strength between the two arms could also be an effective training method. Our results may help in the design of a specialized exercise program applicable to golfers, especially those desiring to increase their drive distance.

Herein, wrist flexion, elbow flexion, shoulder abduction/adduction, and trunk extension showed positive correlations with drive distance. Improvement in the isokinetic strengths of such joints may have contributed to power accumulation in the segment from the backswing to the impact, which could increase drive distance.

Overall, core muscle and non-dominant arm strength exercise programs for elite golfers identified apparent improvement of the drive distance and isokinetic strength in the NCEG. It can be concluded that strengthening exercises of both the core muscles and the non-dominant arm would provide an effective specialized training program for elite or professional golfers. Golfers with high-handicaps, or those enjoying golf as their hobby on weekends, could also employ such a training program if they wish to improve their performance.

Several limitations of this study should be noted. A major limitation of the present study is that an indirect technique was used to measure the drive distance, with employment of a radar-based device. In addition, an unequal training volume was applied between the CEG (3 times/week) and NCEG (6 times/week). Besides, the participants in this study were elite golfers, so further study is needed to investigate the effects of such exercise on the drive distance for amateur golfers.

Acknowledgment

This work was supported by Konkuk University in 2015.

Authors' contributions

DJS, YTL, and SJP conceived of and designed the study; SK and MSK performed the statistical analysis; DJS and YTL contributed to the writing of the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

References

1. Farrally MR, Cochran AJ, Crew DJ. Golf science research at the beginning of the twenty-first century. *J Sports Sci* 2003;**21**:753–65.
2. Keogh JW, Marnewick MC, Maulder PS, Nortje JP, Hume PA, Bradshaw EJ. Are anthropometric, flexibility, muscular strength and endurance variables related the club head velocity in low- and high-handicap golfers? *J Strength Cond Res* 2009;**23**:1841–50.
3. Wells GD, Elmi M, Thomas S. Physiological correlates of golf performance. *J Strength Cond Res* 2009;**23**:741–50.
4. Fletcher IM, Hartwell M. Effect of an 8-week combined weights and plyometrics training program on golf drive performance. *J Strength Cond Res* 2004;**18**:59–62.
5. Alvarez M, Sedano S, Cuadrado G, Redondo JC. Effects of an 18-week strength training program on low-handicap golfers' performance. *J Strength Cond Res* 2012;**26**:1110–21.
6. Lephart SM, Smoliga JM, Myers JB, Sell TC, Tsai YS. An eight-week golf specific exercise program improves physical characteristics, swing mechanics, and golf performance in recreational golfers. *J Strength Cond Res* 2007;**21**:860–9.
7. Kim KJ. Effects of core muscle strengthening training on flexibility, muscular strength and driver shot performance in female professional golfers. *Int J Appl Sport Sci* 2010;**22**:117–27.
8. McGill S. Core training: evidence translation to better performance and injury prevention. *Strength Cond J* 2010;**32**:33–46.
9. McHardy A, Pollard H, Luo K. One-year follow-up study on golf injuries in Australian amateur golfers. *Am J Sports Med* 2007;**35**:1354–60.

10. Akothota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. *Curr Sports Med Rep* 2008;**7**:39–44.
11. Seiler S, Skaanes P, Kirkesola G, Katch F. Effects of sling exercise training on maximal club head velocity in junior golfers. *Med Sci Sports Exerc* 2006;**38**(Suppl. 5):S286.
12. Maddalozzo GF. An anatomical and biomechanical analysis of the full golf swing. *NSCA J* 1987;**9**:74–9.
13. Hume P, Keogh J, Reid D. The role of biomechanics in maximizing distance and accuracy of golf shot. *Sports Med* 2005;**35**:429–49.
14. Pink M, Jobe FW, Perry J. Electromyographic analysis of the shoulder during the golf swing. *Am J Sports Med* 1990;**18**:137–40.
15. Glazebrook MA, Curwing S, Islam MN, Kozey J, Stanish WD. Medical epicondylitis. An electromyographic analysis and an investigation of intervention strategies. *Am J Sports Med* 1994;**22**:674–9.
16. Betchol CO. Grip test: the use of a dynamometer with adjustable handle spacing. *J Bone Jt Surg AM* 1954;**36**:820–4.
17. Gedela RK, Kirby A, Huhtala H. Does the dominant hand possess 10% greater grip strength that the non dominant hand? *Indian J Physiother* 2008;**45**:116–21.
18. Horn J. *Golf is a woman's game*. St. Avon: Adams Media; 1977.p.126.
19. Hetu FE, Christie CA, Faigenbaum AD. Effects of conditioning on physical fitness and club head speed in mature golfers. *Percept Mot Skills* 1998;**86**:811–5.
20. Thompson CJ, Cobb KM, Blackwell J. Functional training improves club head speed and functional fitness in older golfers. *J Strength Cond Res* 2007;**21**:131–7.
21. Torres-Ronda L, Sanchez-Medina L, Gonzalez-Badillo JJ. Muscle strength and golf performance: a critical review. *J Sports Sci Med* 2011;**10**:9–18.
22. Griffiths KM, Farrer L, Christensen H. The efficacy of internet interventions for depression and anxiety disorders: a review of randomized controlled trials. *Med J Aust* 2010;**192**:S4–11.
23. Pérez-Turpin JA, Zmijewski P, Jimenez-Olmedo JM, Jové-Tossi MA, Martínez-Carbonell A, Suárez-Llorca C, et al. Effects of whole body vibration on strength and jumping performance in volleyball and beach volleyball players. *Biol Sport* 2014;**31**:239–45.
24. Cohen J. *Statistical power analysis for the behavioral science*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.p.386–406.
25. Kraemer WJ, Fry AC. Strength testing: development and evaluation of methodology. In: Maud P, Foster C, editors. *Physiological assessment of humane fitness*. Champaign, IL: Human Kinetics; 1995.p.250.
26. Wallace ES, Otto SR, Nevill A. Ball launch conditions for skilled golfers using drivers of different lengths in an indoor testing facility. *J Sport Sci* 2007;**25**:731–7.
27. Doan BK, Newton RU, Kwon YH, Kraemer WJ. Effects of physical conditioning on intercollegiate golfer performance. *J Strength Cond Res* 2006;**20**:62–72.
28. Landford EE. *The effect of strength training on distance and accuracy in golf*. Provo, UT: Brigham Young University; 1976. [Dissertation].
29. Reyes M. Maximal static contraction strengthening exercises and driving distance. Science and golf IV. In: Thain E, editor. *Proceedings of 2002 World scientific congress of golf*. London: Routledge; 2002.p.45–53.
30. Omkar SN, Vishwas S, Tech B. Yoga techniques as a means of core stability training. *J Bodyw Mov Ther* 2009;**13**:98–103.
31. Akuthota V, Nadler SF. Core strengthening. *Arch Phys Med Rehabil* 2004;**85**:86–92.
32. McHardy A, Pollard H. Muscle activity during the golf swing. *Br J Sports Med* 2005;**39**:799–804.