

Original Research

The effects of different types of warm-up exercises on golf performance

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Abstract

Background and objective: Most studies of golf warm-up exercises have focused on the differences between static and dynamic stretching, while relatively few have compared them to post-activation potentiation (PAP) warm-up exercises. The current study aimed to verify the effects of different types of warm-up exercises on golf performance, with the goal of identifying an optimal strategy.

Methods: A total of 30 elite golf players in their 20s and 30s were randomly assigned to three different groups of 10 participants each: the dynamic warm-up (DWU) group, the PAP group, and the swing warm-up (SWU) group. Driving distance, six-iron carry, club head speed, ball speed, smash factor, and accuracy were measured before and after each warm-up exercise.

Results: Driving distance increased by 2.65% in the DWU group ($P < 0.001$) and 2.21% in the PAP group ($P < 0.01$). Carry also significantly increased by 2.30% in the DWU group ($P < 0.01$) and 2.10% in the PAP group ($P < 0.01$). The PAP group exhibited a six-iron carry increase of 3.35% ($P < 0.001$) and a ball speed increase of 1.86% ($P < 0.05$). In terms of accuracy, the rate of errors decreased by 47.49% in the DWU group ($P < 0.01$).

Conclusion: Among the golf-specific warm-up exercises investigated, DWU was identified as the most efficient exercise for improving total distance and accuracy. Such improvements can be attributed to increased mobility, as well as enhancements in swing size and the efficiency of the neuromuscular system. Thus, our results suggest that golf players should perform DWU exercises to improve their golf performance.

Keywords

Golf-specific warm-up; Post-activation potentiation; Drive performance; Iron performance

1. Introduction

In sports, warm-up exercises prepare the body prior to competing or training in order to improve performance and prevent injury [1]. The main purposes of warm-up exercises are to increase the temperature of muscle tissues, increase the sensitivity of the nervous system, and facilitate muscle contraction, reaction time, and blood flow. Together, these functions allow the athlete to perform more stable and harmonious actions [2]. Warm-ups influence

subsequent exercise performance by increasing adenosine triphosphate turnover, muscle cross-bridge cycling rate, and oxygen uptake kinetics, which in turn enhance muscular function [3]. Therefore, appropriate warm-up exercises are strongly associated with player performance [4].

The golf swing is a highly controlled multi-part, closed-chain, rotary motion that requires muscle strength, power, flexibility, and balance [5]. Therefore, the warm-up program should include activation of the major rotator cuff and core stability muscles, appropriate exercise patterns, and dynam-

ics. Static stretching is commonly used in sports to ensure flexibility and prevent injury. Because securing mobility during a full swing has been recognized as an extremely important factor, many golf players incorporate static stretching into their training [6]. However, recent studies demonstrated negative or no effect of static stretching on performance, as it decreases muscle strength, power, and speed during sports or physical activity [7–9]. Rosenbaum and Hennig [10] argued that static stretching leads to this rapid functional decline by inducing slackness in the tendons, in turn affecting the coordinated function of the muscle-tendon unit (MTU). In addition, previous studies indicated that decreases in neuromuscular sensitivity and neural inhibition also contribute to reduced force production. Static stretching increases muscle length and thus, increases flexibility. However, stiffness decreases, resulting in decreased muscle strength [11, 12]. Accordingly, previous research indicates that dynamic warm-up exercises can improve muscle function by preserving the stiffness of the MTU, when compared to warm-up exercises involving static stretching [13, 14].

High-load dynamic warm-up exercises are particularly effective for power and muscle exertion, and several prior studies provide evidence that the use of muscle post-activation potentiation (PAP) increases muscle strength and improves performance [15–17]. PAP is based on the concept that the contractile history of a muscle influences subsequent muscle contraction. Therefore, the force exerted by a muscle can be increased based on its previous contraction [18].

However, high-intensity or long warm-up exercises are associated with the accumulation of fatigue, which decreases function [19]. Therefore, given these discrepancies, further clarification of their effects is necessary. In addition, most studies of golf warm-up exercises have focused on the differences between static and dynamic stretching [6, 20, 21], while relatively few have compared them to PAP warm-up exercises. Furthermore, prior studies demonstrate that limited warm-up exercises may not be suitable for injury prevention or performance improvement [22]. Most warm-up exercises are selected based on the experiences of coaches, players, and seniors, without empirical evidence. The main factor affecting golf performance is the rotational power of the upper limb and trunk. Given that increases in such power can lead to improvements in driving distance, ball speed, and club head speed, golf players would likely benefit from a golf-specific warm-up program [23]. Therefore, in the present study, we aimed to design a warm-up program that considers the characteristics specific to golf and to evaluate its impact on performance.

2. Methods

2.1 Participants

The study included 30 elite male golf players in their 20s and 30s who met the following inclusion criteria: registration with the Korea Golf Association (KGA) and the Korea Professional Golf Association (KPGA), no history of musculoskeletal pain or disease within the last 6 months, absence of

restrictions on participating in warm-up exercises or training, and performance of resistance exercises more than three times a week. The participants were all low handicap golfers and players of the same level. Participants were randomly assigned to three different groups of 10 participants each. The three groups included: the dynamic warm-up (DWU) group, the post-activation potentiation warm-up (PAP) group, and the swing warm-up (SWU) group (Table 1). The design of this study is shown in Fig. 1. This study was conducted after review and approval by the Institutional Review Board of Korea National Sport University (1263-201911-HR-067-01: 20191112-84). The participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

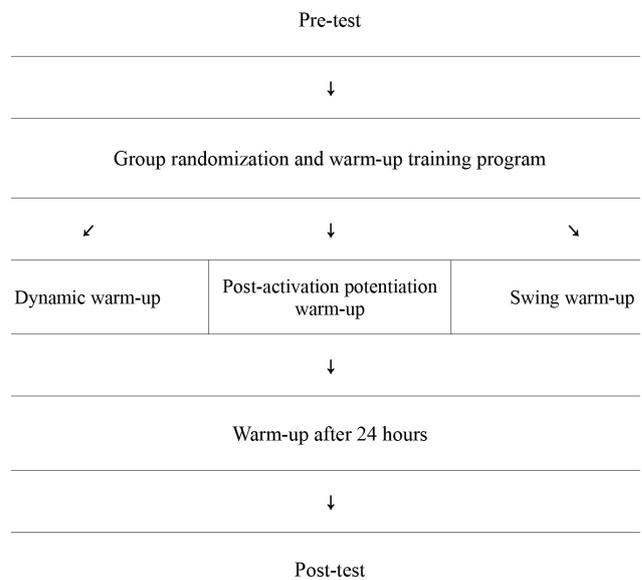


FIG. 1. Procedure of measurement.

2.2 Measurement tools and methods

2.2.1 Golf performance

All measurements were collected before and immediately after the warm-up exercises, and measurements were obtained 24 hours apart. We used TrackMan Pro (TrackMan, Scottsdale, AZ, USA) to analyze players' golf performance [24]. For each player, distance was measured using the driver and six-iron before and after the warm-up exercises. Players used the same club and ball during the measurement period. Measurement equipment was installed near the tee, and each player performed a driver swing and iron swing five times. The mean score was calculated to evaluate their shot performance. Between each attempt, the players self-reported their shot quality scores on a scale of 0 to 10, with 0 being the worst shot and 10 being the best shot [25, 26]. The shot with the lowest score was excluded from the measurement values. Between each shot, 1 minute of rest was provided to avoid fatigue from continuously swinging. The following measurement data were obtained: driving distance,

TABLE 1. Participant characteristics (n = 30).

	Age (years)	Height (cm)	Weight (kg)	SMM (kg)	BMI (kg/m ²)	%BF (%)
DWU group (n = 10)	23.60 ± 0.77	175.37 ± 4.32	75.66 ± 10.28	34.86 ± 3.69	24.61 ± 3.42	18.35 ± 5.54
PAP group (n = 10)	25.80 ± 1.05	179.80 ± 3.12	86.41 ± 10.54	37.86 ± 2.48	26.69 ± 2.75	22.40 ± 6.23
SWU group (n = 10)	24.30 ± 0.84	176.60 ± 6.55	80.57 ± 14.84	36.27 ± 4.94	25.71 ± 3.67	19.99 ± 6.07

BMI, body mass index; DWU, dynamic warm-up; PAP, post-activation potentiation warm-up; SMM, skeletal muscle mass; SWU, swing warm-up; Values, mean ± standard deviation; %BF, percentage of body fat.

TABLE 2. Dynamic warm-up program.

Program	Sets × Reps	Target muscles
Scapular wall slides (Shoulder stabilization and mobility increase)	1 × 30 sec	Serratus anterior Rotator cuff
Leg swing (Lower limb range of motion increase)	1 × 5 each side	Hip flexor Hamstring
Stork turn (Power increase by separation of lower and upper limbs through gluteus rotation)	1 × 5 each side	Hips and legs Transverse abdominis Gluteus maximus
Lunge with twist (Combined motion that can stimulate lower limb muscles and improve trunk rotational mobility)	1 × 5 each side	Quadriceps/hamstrings Obliques
Opposite rotation and reach (Thoracic spine rotational mobility increase)	1 × 5 each side	Transverse abdominis Obliques Abdominals obliques
Wood chop with halo (Whole-body activation)	1 × 5 each side	Rotator cuff Gluteus

TABLE 3. Post-activation potentiation warm-up program.

Program	Sets	Reps	Rest time
Medicine ball slam (3 kg) (PAP effect on upper limb)	1	3	60 sec
Countermovement jump (Application of plyometric principle)	1	3	

carry, club head speed, ball speed, and accuracy divided by club speed. We also used the smash factor to reflect force transmissibility [12].

2.2.2 Warm-up protocol

For warm-up exercises, performing a combination of sports-specific exercises suitable for each type of physical activity (e.g., low-intensity aerobic exercise, stretching, and low-intensity resistance exercise) is recommended [27]. In addition, Jeffreys [28] proposed the RAMP method (Raise, Activate, Mobilize, Potentiation) as a three-step warm-up exercise. Optimal warm-up exercises have the following three qualities: First, they increase temperature, heart rate, respiration rate, and blood flow through low-intensity movement. Second, they have specific exercise patterns and activate certain muscle groups. Third, they are associated with PAP effects conferred through maximum-intensity exercise. Therefore, the warm-up exercise program used in this study included 10 minutes of light walking to increase heart rate and temperature, as well as an air swing that could easily reflect the exercise pattern that is characteristic of golf (Tables 2,3,4). The composition of the DWU program was based on the mechanism of the golf swing and the muscle activity reported in previous studies [20]. The PAP program involved plyometric motions based on the mechanism of the golf swing and the muscle activity reported in previous

studies [17].

2.2.3 Statistical analysis

The collected data were analyzed using SPSS (v. 21.0 IBM SPSS, New York, USA) for Windows. Descriptive statistics were calculated, including the mean and standard deviation. A two-way repeated-measures analysis of variance (ANOVA) was used to verify differences in dependent variables between the pre- and post-warm-up sessions (time, group). Paired *t*-tests were used to examine the significance of differences between the two sessions, and post hoc Bonferroni correction was applied when differences in groups or time × group interactions were deemed statistically significant. The corrected significance for this analysis was set at $P = 0.016$. An analysis of covariance (ANCOVA) was used when significant differences occurred as a result of homogeneity between groups in the preliminary data. The significance level for all analyses was set at $P < 0.05$. Normality was assessed using the Shapiro-Wilk test, and the normality condition was satisfied with $P = 0.05$ or higher in all three groups for all variables.

3. Results

3.1 Driver shot performance

Table 5 shows driver shot performance for each group before and after warm-up exercise. In the analysis of total distance

TABLE 4. Air swing warm-up program.

Program	Shots	Reps	Club	Rest (s)
Practice swings (Reflecting golf specific movement patterns)	10	1	Superspeed (Green)	10
Practice swings	10	1	Superspeed (Blue)	10
Practice swings	10	1	Superspeed (Red)	10
Full-swing shots	5	1	Six-iron	10
Full-swing shots	5	1	driver	10

TABLE 5. Changes in driver shot performance.

	Group	Pre	Post	Change (%)	Sig.	
Total distance (m)	DWU	259.26 ± 8.54	266.15 ± 10.01	2.65***	Time	0.001**
	PAP	257.98 ± 8.63	263.69 ± 7.53	2.21**	Time × Group	0.010*
	SWU	260.8 ± 11.49	260.63 ± 12.38	0.06	Group	0.873
Carry (m)	DWU	238.11 ± 7.27	243.6 ± 8.89	2.30**	Time	0.001**
	PAP	237.84 ± 8.12	242.84 ± 9.29	2.10**	Time × Group	0.099
	SWU	234.93 ± 12.54	236.33 ± 13.90	0.59	Group	0.450
Club head speed (m/s)	DWU	48.76 ± 1.47	48.61 ± 1.45	-0.31	Time	0.347
	PAP	48.24 ± 1.28	48.75 ± 1.20	1.06	Time × Group	0.270
	SWU	48.04 ± 2.48	48.15 ± 2.42	0.23	Group	0.739
Ball speed (m/s)	DWU	71.46 ± 2.04	71.30 ± 2.07	-0.23	Time	0.521
	PAP	70.70 ± 1.76	71.36 ± 1.35	0.92	Time × Group	0.338
	SWU	70.45 ± 3.32	70.43 ± 3.55	-0.03	Group	0.676
Smash factor	DWU	1.47 ± 0.01	1.47 ± 0.02	0.00	Time	0.689
	PAP	1.47 ± 0.01	1.47 ± 0.02	-0.13	Time × Group	0.920
	SWU	1.47 ± 0.02	1.46 ± 0.02	-0.13	Group	0.984
Accuracy (m)	DWU	13.63 ± 4.32	12.16 ± 3.17	-10.78	Time	0.199
	PAP	14.37 ± 7.19	13.16 ± 4.66	-8.42	Time × Group	0.987
	SWU	16.29 ± 9.61	15.19 ± 5.24	-6.72	Group	0.503

DWU, dynamic warm-up; PAP, Post-activation potentiation warm-up; SWU, swing warm-up.

Values are presented as the mean ± standard deviation; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; tested by paired t -tests and repeated analysis of variance.

(m) we observed a significant effect of measurement time ($P < 0.001$), as well as a time × group interaction ($P = 0.010$). Post hoc analysis revealed that the total distance significantly increased by 2.65% in the DWU group (post: 266.15 ± 10.01; pre: 259.26 ± 8.54; $P < 0.001$) and by 2.21% in the PAP group (post: 257.98 ± 8.63; pre: 263.69 ± 7.53; $P < 0.01$). In the analysis of carry (m) we observed a significant effect of measurement time ($P < 0.001$). Post hoc analysis revealed that carry significantly increased by 2.3% in the DWU group (post: 238.11 ± 7.27; pre: 243.6 ± 8.89; $P < 0.01$) and by 2.1% in the PAP group (post: 237.84 ± 8.12; pre: 242.84 ± 9.29; $P < 0.01$).

3.2 Six-iron shot performance

Table 6 shows six-iron shot performance in each group before and after the warm-up exercises. In the analysis of carry (m) we observed a significant effect of measurement time ($P = 0.007$) as well as a significant time × group interaction ($P = 0.016$). Post hoc analysis revealed that carry significantly increased by 3.35% in the PAP group (post: 154.50 ± 9.26; pre: 159.68 ± 8.90; $P < 0.01$). In the analysis of total accuracy (m), we observed a significant effect of measurement time ($P = 0.005$), with differences between groups ($P = 0.010$). Post hoc analysis revealed that the error range had significantly decreased by 47.49% in the PAP group (post: 8.97 ± 2.62;

pre: 4.71 ± 1.50; $P < 0.01$). We also included pre-warm-up ball speed as a covariate. As shown in Table 6, there was no significant difference in ball speed between the pre- and post-warm-up sessions ($P = 0.383$). However, ball speed before warm-up had a significant effect on the outcome after warm-up ($P < 0.001$) and the post hoc analysis revealed a significant increase in ball speed (1.86%) in the PAP group (post: 54.56 ± 1.56; pre: 53.56 ± 1.72; $P < 0.05$).

4. Discussion

The golf swing requires coordination, balance, flexibility, and strength in the movement of each body part [29], which help to increase ball swing consistency [30], maximum club head speed [31], and distance [32]. While the impact of warm-up exercises on physical strength and performance has been investigated among players of various sports, studies involving golf players are lacking. This is because golf has traditionally been perceived as a skill-oriented activity rather than a physical sport. Therefore, in the present study, we aimed to develop a golf-specific warm-up program for improving performance based on the characteristics of the golf swing. Our findings indicate that total driving distance and carry significantly increased in the DWU and PAP groups. However, none of the warm-up exercises exerted a statisti-

TABLE 6. Changes in six-iron shot performance.

	Group	Pre	Post	Change (%)		Sig.
Carry (m)	DWU	158.35 ± 6.55	158.52 ± 7.50	0.10	Time	0.007**
	PAP	154.50 ± 9.26	159.68 ± 8.90	3.35***	Time × Group	0.016*
	SWU	157.48 ± 4.47	158.33 ± 5.89	0.53	Group	0.912
Club head speed (m/s)	DWU	40.69 ± 1.39	40.54 ± 1.11	-0.35	Corrected model	0.000***
	PAP	39.85 ± 0.63	40.19 ± 0.84	0.85	Covariate	0.000***
	SWU	39.12 ± 1.15	39.09 ± 1.14	-0.05	Group	0.171
Ball speed (m/s)	DWU	55.34 ± 1.89	55.54 ± 2.46	0.36	Corrected model	0.000***
	PAP	53.56 ± 1.72	54.56 ± 1.56	1.86*	Covariate	0.000***
	SWU	53.51 ± 0.64	53.80 ± 0.96	0.54	Group	0.383
Smash factor	DWU	1.36 ± 0.04	1.37 ± 0.04	0.44	Time	0.253
	PAP	1.35 ± 0.04	1.36 ± 0.03	0.74	Time × Group	0.965
	SWU	1.37 ± 0.04	1.38 ± 0.04	0.51*	Group	0.312
Accuracy (m)	DWU	8.97 ± 2.62	4.71 ± 1.50	-47.49**	Time	0.005**
	PAP	6.91 ± 2.43	7.06 ± 1.54	2.17	Time × Group	0.052
	SWU	10.17 ± 3.74	7.91 ± 3.38	-22.22	Group	0.022*

DWU, dynamic warm-up; PAP, Post-activation potentiation warm-up; SWU, swing warm-up.

Values are presented as the mean ± standard deviation; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; tested by paired t -tests, repeated analysis of variance, or analysis of covariance was used when significant differences occurred as a result of homogeneity between groups.

cally significant effect on driver club head speed, ball speed, driver smash factor, or driver accuracy.

In a study that explored performance factors in the PGA Tour between 2003 and 2010 more than eight million shots were analyzed, and the authors reported that the long game was the major factor in determining score differences among PGA Tour golf players [33]. In accordance with these findings, our results indicate that both DWU and PAP exercises are effective in improving distance. In addition, the overall results indicate that DWU exercises may decrease club head speed and ball speed. These decreases in speed may be due to slackness in the muscles and joints caused by stretching activities. However, DWU also enhances the swing arc by promoting mobility, thus increasing distance by promoting an accurate impact at the sweet spot of a golf club. In terms of accuracy, the DWU exercises seem to have made the swing more effective, given the reduced error distance from the target (both to the left and right). These results are consistent with those of previous studies reporting that DWU exercises are effective in increasing distance by improving club head speed and accuracy [34], suggesting that higher-load DWUs most effectively augment performance by increasing intramuscular Ca^{2+} levels and cross-bridge cycling [35]. In contrast, although PAP exercises improved distance, they tended to be associated with relatively poor accuracy. This phenomenon may be related to changes in the sensitivity of the nervous system and proprioceptive senses due to muscle fatigue as the rate of muscle contraction increases. Prior studies that examined PAP predominantly focused on increasing swing speed through strength augmentation [17, 36]. As such, there is a lack of research regarding the effects of PAP on accuracy and precision. Therefore, these research results are expected to be valuable in terms of applying PAP warm-up exercises to any type of sport that requires both physical strength and precision.

Increases in club head speed were highest among the PAP

group, consistent with the findings of a previous study [17]. This large increase appears to result from an improved rate of force development (RFD), which in turn results from prioritizing the activation of type II muscle fibers via the PAP warm-up [37]. PAP thus exerts a positive effect on force production by strengthening and activating the MTU [38]. According to Tsai *et al.* [39], increased hip strength affects driving distance and one can assume that PAP warm-up exercises increased distance and club head speed through the countermovement jump in our study. Our analyses identified significant increases in six-iron distance and ball speed among the PAP group. We also observed a significant difference in six-iron club head speed between the DWU and SWU groups; however, there were no significant differences in the six-iron smash factor. Six-iron accuracy results were similar to those for driver accuracy, whereby the left and right error margins were significantly reduced after the warm-up exercise in the DWU group.

A previous study compared the effects of a weightlifting warm-up exercise using a barbell with the effects of a functional warm-up exercise using a resistive elastic band and revealed that the functional warm-up was more effective in improving golf performance [12]. These findings are consistent with the results of the previous study. However, despite the increase in distance and club head speed in the PAP group, DWU exercises were more effective in improving accuracy, suggesting they are the most efficient warm-up exercises. In addition, given that accuracy is a more important factor for iron shots than distance, it would be more beneficial to perform a DWU exercise. Understanding these influential factors may aid in designing an optimal exercise program for improving golf performance.

Increasing the range of motion is essential for performing the optimal swing mechanism [40]. Increased mobility has a positive effect on clubhead speed and distance [41]. In a previous study that analyzed changes in ROM according to

the warm-up exercise type, when dynamic stretching was performed a significant increase in range of motion was detected [42]. Our results suggest that the improvement in golf performance in the DWU group was due to an increase in the turning radius of the swing due to the increase in the range of motion caused by the dynamic warm-up between the shoulder and the trunk.

5. Conclusions

Our findings indicated that DWU exercises exert a positive impact on golf performance by increasing driving distance and improving accuracy via increases in swing efficiency. For iron shots, DWU exercises also appear to improve distance and accuracy. Consistent with the results of previous studies, our analysis also revealed that PAP warm-up exercises effectively increased distance and club head speed. However, further consideration is required to determine the accuracy of the swing and mobility of the body. According to a previous study, PAP warm-up exercises may be associated with difficulty in recovering from fatigue without at least 1 year of weight training [43]. Since this study involved only elite athletes, future studies should create an exercise program tailored to individual characteristics (gender, age, professional experience, training experience, goals) to explore the efficacy of PAP in terms of both performance and injury prevention.

Abbreviations

DWU, dynamic warm-up; KGA, Korea Golf Association; KPGA, Korea Professional Golf Association; MTU, Muscle-tendon unit; PAP, Post-activation potentiation; RFD, rate of force development; WU, swing warm-up.

Author contributions

Study design, DSP, ISK, and JHY. Study conduct, DSP, ISK, and JHY. Data collection, DSP, ISK, and JHY. Data analysis, DSP and ISK. Data interpretation, ISK and JHY. Drafting manuscript, DSP. Revising manuscript content, ISK and JHY.

Ethics approval and consent to participate

This study was conducted after review and approval by the Institutional Review Board of Korea National Sport University (1263-201911-HR-067-01: 20191112-84). The participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

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Conflict of interest

The authors declare no conflict of interest.

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