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Acute Effects of Different Warm-Up Protocols on Junior Golfers' Drive Performance

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ABSTRACT

There is a paucity of evidence assessing the efficacy of warm-up interventions with junior golfers. This study assessed the acute effects of warm-up protocols on junior golfers' driving performance. In a randomised, repeated, counter-balanced design, fifteen junior golfers (age=14.77 years ± 2.08; hcp=7.57±6.53) undertook control, dynamic and RAMP (i.e. raise, activate, mobilise, potentiate) warm-up conditions, before club and ball metrics were recorded using a Trackman 4 launch monitor. Repeated measures ANOVAs found significant increases (p<0.05) in club head speed (CHS) (η_p^2=.142), and significant decreases in launch angle (η_p^2=.060), max height (η_p^2=.436) and dispersion (η_p^2=.126) for both conditions compared to control, indicative of a more penetrative ball flight and improved accuracy, however, significant differences between dynamic and RAMP conditions were not observed. Despite increased CHS, golfers were unable to translate this to increased ball speed, thus impacting upon distances achieved. In conclusion, both dynamic and RAMP warm-ups can have acute benefits on measures of golf drive performance in junior golfers. It is recommended that golfers work with Professional Golfers' Association golf coaches and strength and conditioning coaches to assess all impact factor and ball flight metrics when aiming to integrate improvements to on course performance. Future research should also attempt to assess the translation of increased golf driving performance to strokes gained on the golf course with junior golfers.

Keywords: golf, golf swing, warm-up, RAMP, dynamic stretching, club head speed

INTRODUCTION

The impact of warming-up as physical preparation for sports performance is unequivocal, with a plethora of previous literature demonstrating that warm-ups can improve performance whilst reducing injury risk in various populations (Ehlert and Wilson, 2019; Faigenbaum et al., 2005; McCrary et al., 2015; Silva et al., 2018). Physiological changes include increased body temperature, improved metabolic pathways, readiness of neural pathways and also improved psychological preparation, all correlating to potentially improved performance (McGowan et al., 2015). The positive effects of warm-ups have been demonstrated in adult golf, with Ehlert and Wilson's (2019) systematic review establishing that an effective warm-up had beneficial effects on golf performance metrics, such as club head speed (CHS), carry distance and total distance.

Despite the growing evidence supporting the potential benefits, emerging evidence suggests golfers do not regularly undertake a warm-up (Ehlert and Wilson, 2019). Fradkin et al. (2007) outlined up to 80% of players did not consistently engage in warm-up behaviours, with this trend more prevalent as handicap increases (Gosheger et al., 2003). Alongside inconsistent adherence to warming-up, warm-up practice varies considerably (e.g. strategies and protocols employed, as well as use before a range session vs practice vs tournament; Wells and Langdown, 2020). A range of golf specific warm-up protocols have been investigated with adult populations. Examples include air swinging with weighted clubs, dynamic stretching, overspeed, potentiation and whole-body vibration showing slight improvements on key variables of drive performance (Bliss et al., 2021; Bunker et al., 2011; Langdown et al., 2019; Park et al., 2021, Read et al., 2013). However, despite the positive impact warm-up practice has had on golf performance, best practice has yet to be identified, particularly in junior golfers.

Currently, the evidence related to warm-up practices and performance outcomes in junior golfers is minimal, with Coughlan et al. (2018) currently the only known study in this demographic and subject area. Twenty-one junior golfers (male n=8, female n=13) completed three warm-up protocols (control, club only, dynamic and club) in a counterbalanced study design. Coughlan et al. (2018) found significant increases in CHS and an increase of 40% in perceived quality of shots as a result of the combined dynamic and club warm-up. However, despite the observed significant increase in CHS, Coughlan et al. (2018) acknowledge the 95% confidence interval was 0.545 to 1.520mph, suggesting minimal meaningful change to on course performance.

Whilst the Coughlan et al. (2018) study was the first of its kind, similarly to the majority of literature based around adult golfers, the intervention did not utilise a raise, activate, mobilise, and potentiate (RAMP) protocol. Jeffreys (2006) suggests that a RAMP warm-up protocol is preferable to optimise sporting performance. A RAMP warm-up is a sequential protocol that raises the heart rate and body temperature, mobilises the muscles and joints, with the final the potentiation aspect preparing the muscles through the undertaking of explosive representative movements. Bliss et al. (2021) compared two RAMP protocols in elite collegiate golfers: one which had a bodyweight potentiation method, and another that used a speed stick potentiation method. The results showed both RAMP protocols improved golf drive performance, with similar results observed between the two protocols.

In light of the paucity of evidence examining warm-up interventions in junior golf populations, the aim of this study was to investigate the impact of golf specific warm-ups, namely a RAMP protocol and a dynamic (DYN) protocol, on golf drive metrics in junior golfers.

METHODS

Participants

Fifteen junior golfers (male n=13 and female n=2) were recruited through convenience sampling from a local development squad. Subject handicap (hcp; 7.57 ± 6.53), age (14.77 years ± 2.08), height (167.77cm ± 11.25) and weight (61.15kg ± 15.54). During the study, two participants withdrew, one through injury and one through non-engagement leaving 13 for analysis. Participant handicap was recorded at the start of the study using the World Handicap System (WHS). Standard protocols were used for measuring height (cm), weight (kg), body mass index (kg/m^2), as used by Gorber et al. (2007). Prior to any involvement in the study, the participant's parents or guardians were provided with detailed participant information, the participants were screened using a standardised PAR-Q and provided informed consent. The study was approved by the University Centre Middlesbrough's Research Ethics Committee.

Experimental Protocol

Testing took place using a private and covered driving range in the off season (November, 2022), using a standard range mat and tee set up. A Trackman 4 launch monitor (Trackman, Denmark) and premium Srixon range balls (Srixon, Japan) were used for data collection purposes with full ball flight available for tracking out onto the range. Alongside device calibration, any obviously sub optimal balls were removed from the basket by a PGA professional. Additionally, each participant used their own, custom fitted driver for all repeated conditions.

The conditions were completed in a repeated, crossover design with participants randomly assigned to groups across three separate days of testing. Testing ran over a three-week period, with each condition completed seven days apart to ensure no influence of previous protocols. All groups completed the control condition in week one. Familiarisation of the subsequent week's warm-up condition (dynamic or RAMP) was conducted by a qualified S&C coach upon completion of the data collection process on that day.

For each condition, a coaching cue previously utilised by Langdown et al. (2019), was employed, with golfers instructed to 'imagine they were playing their drive on a straight par 5 in a tournament and aiming for maximal distance, while maintaining accuracy towards the target'. The Trackman 4 was calibrated to the same target, and this was verbally reinforced at the start of each condition. Prior to each shot, participants could complete a self-defined number of practice swings or follow a pre-established shot routine, providing it was consistently applied.

To reduce the impact of external factors impacting the dataset, participants were asked to avoid any exercise in the 24 hours prior, although prescheduled activity such as PE in school was permitted. Participants were also required to refrain from caffeine ingestion in the 24 hours prior to the data collection window.

Number of drives per condition

For each condition golfers were asked to play 15 drives in line with the coaching cue. A reduction strategy was implemented to filter the shots based on the following a-priori thresholds:

- Shots with any missing Trackman data.
- Where smash factor was <1.35 shots were deemed as being mishit (equivalent to a 10% reduction in strike efficiency based on the 'ideal' of 1.5).
- Where golfer self-reported 'shot quality' ratings were ≤4, no matter what the Trackman data showed.

Furthermore, any additional shots in conditions were removed to ensure an equal number were analysed across the three conditions for each participant. This left a minimum of eight shots per participant, per condition and a mean of 10.23 ± 1.59 shots being analysed across the sample of golfers. While this contrasts with the Langdown et al. (2019) study in high performance adult golfers, this approach allowed for elimination of any outliers due to inconsistencies in drive performance (specifically for strike and ball variables) allowing the analysis to focus on the impact of warm-up conditions where a minimum standard of strike efficiency was achieved. Previous research has set this precedent: Myers et al. (2008) used a shot removal criterion in which five of ten shots were selected based on those with the highest ball velocity. Park et al. (2021) removed a single shot with the lowest self-reported score on a scale of 1-10. Bliss et al. (2021) employed box-and-whisker plots to remove any mishit shots, with values outside of 1.5 the lower bound removed, and Bliss et al. (2015) also applied the same strategy in addition to removing any '1' rated shots from a self-selected 1-5 scale.

Warm-up protocols

For the control condition, participants rested for a period equal to the duration of the other intervention conditions, with no ball striking or warm-up activities permitted during this time. The dynamic protocol used was that of Coughlan et al. (2018) (Table 1) and the RAMP protocol was designed by a qualified S&C coach utilising an evidence-based approach to the programme design (Table 2). Following each condition, participants hit 15 drives, and all shot data was recorded. One-minute rest was used between shots to allow for recovery.

Statistical Analysis

Repeated measures ANOVAs were used to test the three levels of independent variable: control, dynamic and RAMP for a variety of golf drive performance metrics, including the following variables:

Club variables:

Angle of attack, club path, club head speed (CHS), dynamic loft, face angle, swing direction, and swing plane.

Table 1. Dynamic warm-up protocol.

Exercise	Sets/Reps
Overhead Squats	1x10
Squat to Overhead Reach	1x10
Lunge and Side Bend	1x10 (5 each leg)
Lunge and Rotate	1x10 (5 each leg)
Standing Internal Hip Rotation	1x10 (5 each leg)
Single Leg Land and Rotate	1x10 (5 each leg)
Lateral Bound	1x10 (5 each leg)

Complete all the above twice

Table 2. RAMP warm-up protocol.

Section	Exercise	Sets/Reps	Rationale
Raise, Activate, Mobilise	Overhead Squat with Golf Club	1x10 *	Muscular recruitment of the bicep femoris, vastus lateralis and gluteus maximus and medius is observed during the swing, acceleration and follow through phases of a golf swing (McHardy and Pollard, 2005).
	Lunge (linear/ lateral/ reverse) with Thoracic Rotation	1x5 (each leg each way)	
	Hamstring Leg Swing	1x8 (each leg)	
	Open & Close Gate	1x8 (each leg)	The amount of work performed by the right hip has been found to be the second highest out of the regions of the body during a golf swing (17.2-20.5%). Increased mobility of the hips may support lower stress levels on the lumbar region (Bishop et al., 2022).
	Push-Up with Rotation	1x (each way)	Pectoralis major plays a significant role during the backswing, downswing and follow through alongside thoracic mobility requirements (McHardy and Pollard, 2005).
	Thread the Needle	1x6 (each way)	Increased thoracic mobility may support lower stress levels on the lumbar region (Bishop et al., 2022).
	World's Greatest Stretch	1x6 (each way)	
	Band Pull Apart	1x10 #	Subscapularis and infraspinatus are active during the golf swing (McHardy and Pollard, 2005).
	Monster Walk	1x20m #	During the acceleration phase, it has been reported that the lead and trail gluteal activation during the golf swing is 58% and 98-100% respectively (McHardy and Pollard, 2005). The use of a mini resistance band during monster walks significantly increases gluteal activation (Cambridge et al. 2012).
	Pallof Press	1x10 (each way) #	Trunk activation to support stability and force production during the downswing and follow through phases (McHardy and Pollard, 2005).
Potentiate	Countermovement Jump	1x5	Significant relationships between countermovement jump impulse and CHS have been reported within the literature (Wells et al., 2018).
	Rotational Countermovement Jump	1x6 (each way)	
	Explosive Push Up	1x6	Where medicine ball throws may not be logistically viable, an explosive push up requires no equipment and displays similar muscular activity and movement patterns.
	Explosive Woodchop	2x6 #	Golf drive performance improvements have been reported following the completion of the woodchop exercise (Tilley and Macfarlane, 2012).

*Note * uses a golf club and # uses a resistance band.*

Ball variables:

Ball speed (BS), carry distance (CD), launch angle (LA), launch direction (LD), maximum height of trajectory (height), side (i.e. dispersion using absolute values to combine both left and right values from target line), spin rate, total distance (TD).

Definitions of each club and ball variable and how they are measured / calculated can be found at (Hahn, n.d.).

Significance was set to $p<0.05$, with data presented as means +/- standard deviation. Data was tested for normality. No transformations were made where outliers had skewed the data due to central limit theorem (n = 132 shots for each variable and warm-up protocol were used in analysis) (Field, 2018). Where Mauchly's Test of Sphericity was violated, degrees of freedom were corrected with Greenhouse-Geisser estimates. When significant effects were observed post-hoc tests with a Bonferroni correction (post-hoc alpha level correction p=.0167) were used to identify where differences existed between measures with η_p^2(partial eta squared) used to demonstrate effect size ($\eta_p^2 \geq 0.0099$ = small; $\eta_p^2 \geq 0.0588$ = medium; $\eta_p^2 \geq 0.1379$ = large; as recommended by Richardson, (2011)).

RESULTS

Club variables

Angle of attack

Angle of attack violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. A significant and small effect of warm-up on angle of attack was found (F(1.91,249.56) = 6.53, *p* = .002, η_p^2=.047). Post-hoc test showed a decrease in angle of attack (a slightly steeper angle of attack), from control (Angle of Attack = .73 ± 2.97°) to both dynamic (Angle of Attack = .31 ± 3.21°; *p* = .036) and RAMP (Angle of Attack = .17 ± 3.52°; *p* = .005), but no difference between dynamic and RAMP (*p* = .939) protocols was observed.

Club path

No significant difference was found between conditions for club path (F(2,262) = .91, *p*=.733, η_p^2=.002). See table 3 for values.

Club head speed

The results of a repeated measures ANOVA show a significant and large effect for CHS (F(2,262) = 21.60, *p*<.001, η_p^2=.142). Post hoc Bonferroni analyses demonstrated that when compared to the control condition (CHS = 93.24 ± 12.21 mph), both dynamic (CHS = 94.01 ± 11.86 mph; *p* <.001) and RAMP (CHS = 94.23 ± 11.87 mph; *p* <.001) showed significant increases CHS. There was no statistically significant difference between dynamic and RAMP conditions (*p* = .419).

Dynamic loft

A significant and medium main effect of warm-up on swing plane was found (F(2,262) = 8.14, *p* <.001, η_p^2=.059). Post hoc Bonferroni analyses demonstrated that when compared to the control condition (Dynamic Loft = 15.60 ± 2.52°), RAMP showed a significantly decreased dynamic loft (Dynamic Loft = 14.41 ± 3.05°; *p* <.001). There was no significant difference between control and dynamic (Dynamic Loft = 14.97 ± 3.00°; *p* = .062) or between dynamic and RAMP (*p* = .254).

Face angle

No significant difference was found between conditions for face angle (F(2,262) = 2.16, *p* =.118, η_p^2=.016). See table 3 for values.

Swing direction

Swing direction violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. No significant difference was found between conditions for swing direction (F(1.88,246.64) = .38, *p* =.671, η_p^2=.003). See table 3 for values.

Swing plane

A significant and small main effect of warm-up on swing plane was found (F(2,262) = 4.08, *p* = .018, η_p^2=.030). Post hoc Bonferroni analyses demonstrated that when compared to the control condition (Swing Plane = 43.45 ± 3.91°), RAMP showed a significantly increased plane (Swing Plane = 44.48 ± 3.95°; *p* = .014). There was no significant difference between control and dynamic (Swing Plane = 43.74 ± 3.60°; *p* = 1.000) or between dynamic and RAMP (*p* = .191).

Ball variables

Ball speed

BS violated Mauchly's Test of Sphericity (ε=.009) and therefore the F value was re-calculated. No significant improvement was found between conditions for carry distance (F(1.87,245.01) = 1.82, *p* =.167, η_p^2=.014). See table 3 for values.

Carry distance

Carry distance violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. No significant improvement was found between conditions for carry distance (F(1.74,227.29) = 2.64, p=.081, η_p^2=.020). See table 3 for values.

Dispersion (side – absolute)

Dispersion violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. A significant and medium effect of warm-up on dispersion was found (F(1.38,181.34) = 18.64, *p*<.001, η_p^2=.126). Post-hoc test showed a decrease in dispersion from control (Dispersion = 22.9 ± 22.47 yards) to both dynamic (Dispersion = 13.86 ± 9.54 yards; *p* <.001) and RAMP (Dispersion = 13.05 ± 8.00 yards; *p* <.001) protocols, but no difference between dynamic and RAMP (*p* = .1.000) protocols was observed.

Launch angle

Launch angle violated Mauchly's Test of Sphericity (ε=.021) and therefore the F value was re-calculated. A significant and medium effect of warm-up on launch angle was found ($F(1.89,247.67) = 8.37$, $p<.001$, $\eta_p^2=.060$). Post-hoc test showed a decrease in launch angle from control (LA = 13.49 ± 2.37°) to both the dynamic (LA = 12.83 ± 2.92°; $p = .038$) and RAMP (LA = 12.30 ± 2.93°; $p <.001$) protocol. No differences between dynamic and RAMP ($p = .311$) were observed.

Launch direction

Launch direction violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. A significant and medium effect of warm-up on launch direction was found ($F(1.27,165.78) = 8.36$, $p = .002$, $\eta_p^2=.060$). Post-hoc test showed a difference in launch direction from control (LD = -0.89 ± 3.01°) to the RAMP (LD = 1.70 ± 9.00°; $p = .007$) protocol and a significant difference between dynamic (LD = -0.54 ± 3.61°) and RAMP ($p = .015$). No significant difference between the control and dynamic ($p = .920$) protocols was observed.

Maximum height

Maximum height violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. A significant and large effect of warm-up on maximum height was found ($F(1.09,142.28) = 101.39$, $p <.001$, $\eta_p^2=.436$). Post-hoc test showed a decrease in maximum height from control (Max Height = 52.67 ± 35.49 ft) to both dynamic (Max Height = 25.08 ± 7.84 ft; $p <.001$) and RAMP (Max Height = 24.09 ± 8.70 ft; $p <.001$), but no difference between dynamic and RAMP ($p = .404$) protocols was observed.

Spin rate

No significant difference was found between conditions for spin rates ($F(2,262) = .21$, $p =.811$, $\eta_p^2=.002$). See table 3 for values.

Total distance

Total distance violated Mauchly's Test of Sphericity (ε<.001) and therefore the F value was re-calculated. No significant improvement was found between conditions for total distance ($F(1.77,232.49) = .91$, $p=.393$, $\eta_p^2=.007$). See table 3 for values.

Combined variable

Smash factor (efficiency of strike; ball speed / CHS)

Smash factor violated Mauchly's Test of Sphericity (ε<.023) and therefore the F value was re-calculated. A significant and small effect of warm-up on smash factor was found ($F(1.89,247.96) = 5.05$, $p =.008$, $\eta_p^2=.037$). Post-hoc test showed a decrease in smash factor from control (Smash Factor = 1.445 ± 0.036 au) to RAMP (Smash Factor = 1.435 ± 0.040 au; $p =.002$), but no differences between control and dynamic (Smash Factor = 1.441 ± 0.039 au; $p =.391$), or between dynamic and RAMP ($p = .378$) protocols.

Mishits

The total number of mishits in accordance with the criteria outlined in the method totalled 34. RAMP totalled 13 (1.00 ± 1.36), DYN totalled 13 (n mishits per participant = 1.00 ± 1.47) and control totalled 8 mishits (.62 ± .74). It should be noted that 53% of mishits can be attributed to two participants.

DISCUSSION

The aim of this study was to assess the acute impact of golf specific warm-up protocols (control, dynamic and RAMP) on golf drive metrics in junior golfers. Whilst the RAMP protocol is well advocated within the general strength and conditioning literature (Bliss et al., 2021; Jeffreys, 2006; Wells and Langdown, 2022), to the authors knowledge, this is the first study to utilise a golf specific RAMP protocol with junior golfers, and only the second study that has assessed the acute impact of warming-up with a sample from that population.

This study has shown completing a dynamic or RAMP warm-up before golf performance can have a positive and significant impact on key club and ball variables of a golf drive, when compared to control conditions. CHS increased significantly across the warm-up conditions. When compared to control, the dynamic and RAMP protocols significantly improved mean CHS by 0.77 mph and 0.99 mph respectively. This improvement following a warm-up is supported by Coughlan et al. (2018), who found a 1 mph increase in mean CHS following a dynamic warm-up protocol, when compared to control conditions with junior golfers. Despite the current study's findings of an increase in CHS, there was no change in ball speed between conditions,

Table 3. Drive Performance for each experimental condition.

	Condition	Control	Dynamic	RAMP	η_p^2	Observed power
Club variables	Angle of Attack (°)	.73 ± 2.97	.31 ± 3.21*	.17 c± 3.52*	.047	.895
	Club Path (°)	-1.03 ± 3.46	-1.20 ± 2.54	-1.13 ± 3.33	.002	.099
	Club head Speed (mph)	93.24 ± 12.21	94.01 ± 11.86*	94.23 ± 11.87*	.142	1.000
	Dynamic Loft (°)	15.60 ± 2.52	14.97 ± 3.00	14.41 ± 3.05*	.059	.958
	Face Angle (°)	-.87 ± 3.29	-.37 ± 3.99	-.12 ± 3.82	.016	.439
	Swing Direction (°)	-.68 ± 5.69	-.54 ± 5.10	-.40 ± 5.96	.003	.109
	Swing Plane (°)	43.45 ± 3.91	43.74 ± 3.60	44.48 ± 3.95*	.030	.721
Ball variables	Ball Speed (mph)	134.72 ± 17.69	135.37 ± 17.05	135.19 ± 16.83	.014	.364
	Carry Distance (yds)	207.11 ± 38.43	209.93 ± 36.74	208.56 ± 38.67	.020	.484
	Dispersion (yds)	22.90 ± 22.47	13.86 ± 9.54*	13.05 ± 8.00*	.126	.998
	Launch Angle (°)	13.49 ± 2.37	12.83 ± 2.92*	12.30 ± 2.93*	.060	.955
	Launch Direction (°)	.89 ± 3.01	-.54 ± 3.61	1.70 ± 9.00*,$	.060	.879
	Max Height (ft)	52.67 ± 35.49	25.08 ± 7.84*	24.09 ± 8.70*	.436	1.000
	Spin Rate (rpm)	2892.93 ± 822.13	2937.36 ± 766.06	2935.41 ± 646.76	.002	.083
	Total Distance (yds)	231.24 ± 37.40	232.93 ± 34.94	232.37 ± 36.53	.007	.196
Combined variable	Smash factor (au)	1.445 ± .036	1.441 ± .039	1.435 ± .040	.037	.799

*Note * indicates significant differences between control and dynamic or RAMP. $Indicates significant difference between dynamic and RAMP. Data provided as Means ± SD. Key: mph = miles per hour. yds = yards. ° = degrees. rpm = revolutions per minute. ft = feet, au = arbitrary units.*

which could be related to the golfers' kinematics (i.e. swing technique). Although CHS has been shown to be a strong predictor of ball speed, the centeredness of the impact with the golf ball (strike) also contributes significantly (Sweeney et al., 2013). The ability to maintain a centred strike with a faster CHS will allow greater yardage to be achieved through carry and total distances (Penner, 2002). Here, the calculated strike efficiency ('smash factor') was seen to reduce between control and RAMP conditions demonstrating that where increased CHS is an acute product of warm-up protocols, it is not translated to increased ball speed. The increased CHS may be a product of participant expectancy and deliberate faster swinging under experimental conditions (i.e. following both dynamic and RAMP protocols). The subsequent reduction in smash factor may be due to the cohort's inability to maintain control over centredness of strike with increased CHS. Another potential explanation is the use of a standardised control week (week one), opposed to a fully randomised protocol, which may have led to the underlying expectancy that the subsequent warm-up protocols would be of benefit to performance. However, these speculative interpretations should be taken with caution and as golfer education around the benefits of warm-up continues, this will remain a limitation of all warm-up studies.

To capitalise on increased CHS, golfers should be directed to coaching from a Professional Golfers' Association golf coach and to engage in dedicated / targeted practice to ensure that centredness of strike is optimised following acute warm-up adaptations. Furthermore, with the drive contributing ~28% towards scoring averages across a season (for top 40 male golfers; Broadie, 2023), an increase in drive distance could lead to more strokes gained on course during each tournament round. Greater drive distance allows a shorter, more lofted club to be used for the approach shot, generally producing a steeper swing plane (Penner, 2002) and angle of attack. This reduces the amount of grass between clubhead and ball through impact when compared with longer clubs. Ultimately this increases control over the strike, allows the ball flight's maximum height to be increased and reduces the roll upon landing (Coleman & Anderson, 2007).

With accuracy off the tee being another sought after variable by golfers (Richardson, 2019), it is encouraging to note the significant decrease in dispersion (improved accuracy) following both a dynamic protocol (-9.04 yds) and a RAMP protocol (-9.85 yds), when compared to the control protocol. Using US PGA Tour data, Hellstrom et al. (2014) established that the score on both par-4 and par-5 holes were strongly correlated with a golfer's total drive distance (and therefore distance remaining to the pin) and accuracy to hit the fairway. Furthermore, Burnham et al. (2013) showed that both 9-iron and pitching wedge shots from the fairway were more accurate and generated greater spin than those played from the rough. Golfers can expect to lose 0.1 shots on average if playing the second shot from the semi-rough, 0.3 shots from the rough, 0.4 shots from a fairway bunker and 1.4 shots if their drive ends up in a water hazard or declared unplayable (Hellstrom et al., 2014). More recently, Broadie (2023) has reported that golfers can expect to lose 0.28 shots when attempting to hole out from the rough compared to from the fairway. Therefore, while translation of CHS gains into ball striking distance metrics and reducing distance to the pin for the second shot is of importance, the accuracy to find the fairway as often as possible should also remain a key priority of golfers. Indeed, Hellstrom et al. (2014) advocate that where fairways are so narrow that the player is likely to miss the fairway, then distance should be prioritised. In contrast, Richardson (2019) offers that better golfers may choose to strategise with a shorter, straighter tee shot rather than hit their standard drive.

The dispersion decrease was found alongside a significant difference in mean launch direction (LD), with the RAMP protocol showing an average direction further to the right of target compared to control and dynamic (which was slightly left of target, on average). This may imply that golfers were better placed to control the ball flight (shot shape) following the warm-up protocols to allow the curvature of the trajectory to bring the ball back closer to the target line. It should be noted here that off-centred strikes can also influence the curvature of ball flight through the effects of horizontal gear effect (i.e. shots hit towards the heel of the clubface will generate fade/slice spin and shots hit towards the toe will generate draw/hook spin; Trackman, n.d.). With both warm-up conditions having slightly lower smash factors, this may represent greater off-centred horizontal strike locations which would influence results here. Further research assessing specific impact location on the clubface would allow further insight.

Despite no significant differences in face angle or swing direction, results suggest golfers were trending towards swinging the club closer to an in-square-in swing path (-.40°) (i.e. with the clubhead travelling on an inside swing path pre- and post-impact and square to the target through impact) (-.12° on average) for the RAMP protocol compared to the other conditions, potentially allowing them to achieve greater accuracy towards the target. Moran et al. (2009) found similar results with significantly straighter (in-square-in) swing paths resulting from their dynamic stretching warm-up protocol.

There were also decreases in launch angle following both warm-up protocols employed here. Specifically, launch angle decreased by -0.66° and -1.19°, with the dynamic and RAMP protocols respectively when compared to control. It should be noted here that vertical gear effect can impact upon the launch angle and spin rates generated, with shots hit or higher or lower on the driver club face respectively reducing or increasing spin by as much as 1000 rpm and vice versa for low on the face (Trackman, n.d.). With both warm-up conditions having slightly lower smash factors, this may represent greater off-centred vertical strike locations which would influence results here. This is supported by the most mishits being generated by the experimental warm-up protocols. This could be a limitation related to using a junior cohort or it could be that the warm-up conditions need to be refined in order to allow the golfers to utilise the physiological benefits for better ball striking. Future research should look to assess the impact of warm-ups on off-centred strikes further.

The decreased launch angles could lead to a more penetrative ball-flight seen here with the reduction in maximum height of the ball trajectory following both warm-up protocols (~28 ft). Similar findings were observed by Langdown et al. (2019), who found a decrease in mean launch angle following a dynamic warm-up protocol (-1.35°) and a resistance-band warm-up protocol (-1.08°), when compared to control conditions with skilled adult golfers. Indeed, Wallace et al. (2007) suggested that elite adult golfers can achieve maximal distance through launch angles between 10-14° when using a driver but noted that the level of spin and launch angle can, to some extent, be controlled by the choice of golf ball used (note: consistent ball type was used here). In contrast, Broadie (2023) presented statistics from the PGA tour that show higher launch angles (~17 ± 4°) and lower spin rates (~2200 ± 500 rpm) optimise carry distance and total drive distance. However, the optimal launch conditions vary considerably across golfers, based on their angle of attack and dynamic loft of the club head presented at impact with the ball. Here, dynamic loft was found to reduce following a RAMP warm-up which may have contributed to the launch angle results. Furthermore, angle of attack was significantly lower following the warm-up protocols, which again contributes to a reduced dynamic loft and subsequently a reduced launch angle. It is important not to speculate on the underlying biomechanical principles that explain the adaptations to club and ball data here. Rather, in conjunction with this current methodology, kinematic and kinetic assessment of these acute adaptations to impact factors and ball flight should be performed to further our understanding of warm-ups in golf. It is important that coaches, and golfers alike, do not consider variables in isolation, but take account of changes in all impact factors to assess the likely cause of changes to ball flight, launch conditions, accuracy and distance achieved. Despite the increased CHS, decreased launch angles and lower height, the carry and total distances of this sample of junior golfers has not changed. As above, this is likely due to no change in ball speed following the warm-ups.

Non-significant improvements were observed for mean ball speed (dynamic +0.65 mph; RAMP +0.47 mph), mean carry distance (dynamic +2.82 yds; RAMP +1.45 yds) and mean total distance (dynamic +1.70 yds; RAMP +1.13 yds) compared to the control condition. Similar trends were observed by Langdown et al. (2019), who found a significant increase in ball speed did not transfer to a significant increase in carry distance in skilled adult golfers following warm-up protocols. Further research is required to understand the impact of acute physiological adaptations brought about by varying warm-up protocols. This will allow coaches and other support personnel (e.g. strength and conditioning coaches, biomechanists, etc.) to support optimisation of strike and subsequent ball flight.

Individual vs. group level responses provide additional insight. For CHS, eight participants were responders or most responsive to the RAMP protocol, and two were most responsive to the DYN protocol. However, three participants did not show acute adaptation following either warm-up protocol and could, therefore, be considered 'non-responders' who performed better under the control condition. This indicates that an individual approach to designing and implementing a warm-up protocol is critical to ensuring benefits are realised by each golfer. Warm-ups should be validated with launch monitors and adapted to ensure acute adaptations are realised for performance gains. Moreover, future research would benefit from both group and individual response analysis.

LIMITATIONS

Although the methods utilised, and results acquired, are in-line with previous studies, there are limitations to this study that must be acknowledged. First, the nature of the participants resulted in large variations within the acquired data set. The sample included junior golfers across a large handicap range. Furthermore, the movement competency of the young athletes is still developing and has been shown to improve through supervised practice (Rogers et al., 2020). Despite the use of familiarisation sessions, this may have impacted the junior golfers' abilities to complete technical movement patterns, such as those included within the RAMP warm-up, potentially limiting the impact of the warm-up, without further practice of the exercises included. Second, the small sample size and dropout rate of the study limits the ability to generalise results to this population of golfer. Indeed, the significant results for swing plane was underpowered (.72), and further findings may have come to light had there been greater numbers recruited. However, all other significant findings were deemed to have sufficient power (>.8; Cohen, 1992). Third, the data was collected from a controlled environment, via a driving range. Results may have differed in a more representative, competitive setting, out on a golf course, where internal and external factors play a greater role. Future research should look to establish the impact of these warm-up protocols on subsequent tournament rounds.

CONCLUSION

The findings from the current study showcase favourable outcomes for a golf specific warm-up on measures of drive performance, when compared to control conditions. Both experimental warm-ups yielded significant increases in CHS, and significant decreases in dispersion. This provides golfers with the potential to harness greater CHS for increased distance through more centred strikes while also benefiting from increased accuracy toward the fairway. Alongside these findings, there were also changes to angle of attack, dynamic loft, launch angle, and max height, all of which can provide a more penetrative ball flight. However, further investigation is needed to examine how the acute physiological adaptations impact on underlying swing kinematics and kinetics.

It should be noted that the increases in CHS did not translate into increases in ball speed, carry or total distance, and it is recommended that golfers work with a PGA golf coach and strength and conditioning coach to optimise a warm-up protocol and enable translation of any acute and chronic physiological adaptations into their performance, for example improved strokes gained stats over the course of a single round and season.

Exposing junior golfers to minimal equipment, simple, yet effective warm-up practices at a young age, may have positive applied implications, such as longer-term adherence, especially when seeing the impact upon their drive metrics.

While this study has shed further light on the acute adaptation a warm-up can bring about, additional research needs to be undertaken to expand the evidence base for S&C practices within golf, particularly in youth and female populations. Where possible, this should be representative in nature to assess the translation of increased performance to strokes gained on the golf course.

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CONFLICTS OF INTEREST

The authors report no conflict of interest.

FUNDING DETAILS

This project was unfunded and undertaken on a voluntary basis.

ETHICAL APPROVAL

The study was approved by the University Centre Middlesbrough's Research Ethics Committee.

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