Coughlan, D., Taylor, M. J. D., Wayland, W., Brooks, D., & Jackson, J. (2019). The effect of a 12-week strength and conditioning programme on youth golf performance. *International Journal of Golf Science*, *8*(1).

PUBLISHED PAPERS

The effect of a 12-week strength and conditioning programme on youth golf performance

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Keywords: golfer, resistance training, power, adolescent, clubhead speed

International Journal of Golf Science

Vol. 8, Issue 1, 2020

Physical preparation in golf is well-recognised as an essential component of high level performance, but research into youth golfers is limited. The purpose of this study was to determine the effect of a once weekly strength and conditioning session on physical performance over 12-weeks. Thirty-nine male golfers aged 11-17 years (age: 13.54 ± 1.10 yrs, mass: 59.68 ± 13.10 kg, handicap: 10.26 ± 4.67 strokes) were assigned to either an intervention or control group. The control group did not participate in structured training whereas the intervention group received supervised resistance training. Outcome measures were clubhead speed (CHS), ball speed (BS), countermovement jump (CMJ) predicted power and modified pull-ups. Magnitude based inferences and confidence intervals were used to assess the response between groups based on pre-determined threshold values. The intervention demonstrated likely increases in CHS (4.25mph; CI90 1.79 to 6.71), possible increases in ball speed (4.09mph; CI90 0.78 to 7.40), likely increases in CMJ predicted power (308.35W; CI90 176.97 to 439.73). There were only trivial differences in modified pull-ups. This study highlights the potentially positive impact a once weekly strength and conditioning programme can have on physical performance and CHS in youth golfers, and is therefore recommended in this population.

INTRODUCTION

Technical ability, tactical awareness and technological advances in golf have often been areas of primary focus (Farrally et al., 2003; Whittaker, 1999). However, the physical demands of golf are now being understood and appreciated (C. J. Smith, Callister, & Lubans, 2011) with courses becoming longer, players are hitting the ball farther, and elite golfers now regularly engage in resistance training. Maximal yet accurate displacement of the ball by achieving a high clubhead speed (CHS) is of great importance to the golfer and this has a strong relationship with handicap (Fradkin, Sherman, & Finch, 2004). Increases in CHS offer performance advantage due to the increased hitting distance and improved long game performance, which is a key performance indicator for the golfer (Broadie, 2008). The interplay between CHS, ball speed (BS) and driving distance is determined by clubhead

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kinematics (Sweeney, Mills, Alderson, & Elliott, 2013) and therefore improvements in CHS alone are not sufficient. It is essential that these improvements transfer to increases in BS and ultimately distance. Thus, increases in CHS as well as BS are being more actively sought by professionals and amateurs. To achieve these higher speeds, large forces are generated by the golfer during the full swing (M. Lindsay & A. Vandervoort, 2014) and overuse injuries are common (M. F. Smith & Hillman, 2012). As such, golfers are not only required to train for performance enhancement, but are likely to require the requisite physical qualities to tolerate these increased forces during the swing and thus minimise injury risk (Lauersen, Bertelsen, & Andersen, 2014).

With a growing demand for physical preparation of golfers, some national governing bodies and youth golf training environments have integrated strength and conditioning into their programmes (Coughlan & Ward, 2017). However, while there is a growing body of literature on physical preparation in golf, the research around strength and conditioning in youth golfers is extremely limited.

Several studies have investigated the relationships between key physical characteristics and CHS or other associated golf specific performance measures (Callaway et al., 2012; Coughlan, Taylor, Jackson, Ward, & Beardsley, 2017; Lewis, Ward, Bishop, Maloney, & Turner, 2016; Wells et al., 2019; Wells, Mitchell, Charalambous, & Fletcher, 2018). To the authors' knowledge, only one study has investigated these relationships in youth golfers (Coughlan et al., 2017). Coughlan et al. (2017) demonstrated strong, significant relationships between CHS and handicap (HCP) in youth male ($r=-0.50$) and female ($r=-0.52$) golfers. These findings are in alignment with those found in adult golfing populations (Fradkin et al., 2004). Moreover, the study demonstrated significant and strong positive relationships between CHS and body mass, as well as explosive strength tests including countermovement jumps, rotational and seated medicine ball throws. Countermovement jumps (CMJ) were only related to CHS when peak power was calculated, perhaps due to the relevance of body mass, showing CMJ peak power may be a more important measure than CMJ height alone in youth golf populations. These findings are similar to those in adult golf populations, where relationships have been demonstrated between CHS and CMJ, as well as medicine ball throw performance (Lewis et al., 2016; Read, Lloyd, De Ste Croix, & Oliver, 2013; Wells et al., 2018).

Research into strength and conditioning interventions in the adult golfer have consistently demonstrated positive outcomes relating to CHS (Fletcher & Hartwell, 2004), ball launch conditions (Bliss, McCulloch, & Maxwell, 2015) and kinematic variables (Bull & Bridge, 2012). A number of studies have advocated the use of strength and conditioning in youth athletes (Faigenbaum et al., 2009), however the current research pertaining specifically to the youth golfer via interventional research is limited, with only one study to date investigating this area (C. J. Smith, Lubans, & Callister, 2014). This study investigated the effects of a 12-week intervention on junior golfers between the ages of 12-18 years. The intervention consisted of both mobility and resistance training, in-line with previous recommendations (Faigenbaum et al., 2009). The training programme resulted in moderate to large Cohen's D effect size (ES) differences in measures of strength (single leg squat; ES=0.64, side bridge; ES=0.96 and modified push-ups; ES=0.71), but no significant improvement in handicap (p=0.27; ES=0.42). While the study highlights the potential benefits of resistance training for youth golfers, there were some key limitations. The authors highlighted that the study was somewhat underpowered and therefore could not detect significant changes in handicap. Also, handicap is a performance measure which has many contributing variables outside of golfer physicality and is likely to be easily influenced by a range of unrelated factors over 12-weeks.

There is a strong evidence base supporting strength interventions in youth athletic populations across a range of sports outside of golf, demonstrating clear benefits to performance and injury risk reduction as well as long term health outcomes (Faigenbaum et al., 2009). We argue an equivalent level of understanding is required for the youth golfer and as highlighted throughout this introduction; the research is currently lacking. Therefore, the aim of this study was to investigate the effects of a once weekly, 12-week strength and conditioning intervention on youth golfers CHS, BS and physical performance characteristics.

METHOD

EXPERIMENTAL DESIGN

A quasi-experimental study design was used to ascertain the impact of a strength and conditioning programme on CHS, BS and physical characteristics in youth golfers. A control and intervention group performed a pre and post intervention field-based testing battery. During the 12-week intervention the control group continued their normal golf training regime, while the intervention group also continued their normal golf regime but had an additional one-hour coached strength and conditioning session per week.

PARTICIPANTS

Thirty-nine male golfers aged 11-17 years were recruited to take part in this study (age: 13.54 ± 1.10 yrs, mass: 59.68 ± 13.10 kg, HCP: 10.26 ± 4.67 strokes). All golfers were competing at a high level for their age group, as demonstrated through selection to an English county squad. The intervention took place over the off-season and players were injury free upon commencing the study. Informed consent was gained from all golfers, and their guardians. Ethical approval was granted by the University Ethics Committee in accordance with The Declaration of Helsinki.

All participants were members of the same county golf union and worked with the same county coaching team. Testing took place over the off-season where there were likely to be reductions in golf practice and tournament volumes. Convenience sampling was used to allocate participants into the intervention (n=24) or control (n=15) groups, based upon proximity to the training location and availability to train on the appropriate day. The Moore-2 maturity offset equation was used to calculate maturity offset by group (intervention: 0.08 yrs, control: 0.57 yrs), showing maturity status between groups at baseline (Kozieł & Malina, 2018).

TESTING

All testing for all golfers within a group was completed in two days (one day pre and one day post intervention), with each session lasting one hour by a team of researchers. Across all testing sessions, researchers were assigned to a specific test to improve reliability. In all tests, subjects completed three trials with a mean score taken for analysis. Body mass (kg) was measured prior to physical testing in all testing sessions. Golfers self-reported their most up to date handicaps. Testing was completed on the weeks before and after the 12-week intervention for all golfers.

CLUBHEAD SPEED AND BALL SPEED

An ES14 Pro (Ernest Sports, USA) doppler radar-based launch monitor was used to record CHS and BS. The system was calibrated per manufacturer recommendations. Golfers used their own driver, were blinded to all results throughout testing, and Titleist ProV1 golf balls were used for all shots. Shots were carried out on a golf mat and into a golf net on all occasions, to ensure a stable environment for testing. Golfers were permitted to complete a self-defined number of practice swings and hit balls until they felt ready to begin testing. Once ready, the subjects were instructed to 'hit the ball as hard as you can' and were given an appropriate and standardised target point behind the net. Three driver shots were taken, with a 60 second rest between shots, mean CHS and BS scores were used for analysis. Manufacturer reported accuracy for the ES14 Pro for CHS and BS are ±4mph and ±2mph respectively. Separate to this study, test-retest reliability was evaluated using the methods described above over 2 separate testing sessions. CHS and BS were shown to be highly reliable between testing sessions (r=0.99) with minimal detectable change scores of 1.47mph for CHS and 2.11mph for BS based on a 1.64 z-score, further details of the reliability study can been seen in the supplementary information.

COUNTERMOVEMENT JUMP

Countermovement vertical jump height was measured in accordance with previous research using the MyJump phone app, which has shown good validity in comparison to a force platform (Balsalobre-Fernández, Glaister, & Lockey, 2015). Peak power was then calculated using previous recommendations (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999), which have been shown to strongly relate to CHS in youth high level golfers (Coughlan et al., 2017).

$$\text{Peak anaerobic power } (W) = \\ 60.7 \times \text{jump height } (cm) + 45.3 \times \text{body mass } (kg) - 2055$$

Golfers were instructed to jump as high as possible, with hands on hips, and to maintain straight legs during the flight phase. Three trials were completed with a 60 second recovery between each, mean CMJ peak power scores were used for analysis.

MODIFIED PULL-UP

A modified pull-up was chosen as a measure of muscular endurance of the upper body, due to its high test retest reliability (Negrete et al., 2010). While previous research has shown no significant relationship between the modified pull-up and CHS (Coughlan et al., 2017), the measure was chosen as a low-skill general test of upper body strength/strength endurance to assess impact of the training intervention. To complete this test, golfers were required to adopt a supine position, holding onto a horizontal and fixed bar, with their body extended and heels placed on a weights bench. The golfers began with their arms extended and were required to go through a full range of motion, flexing their elbows and bringing their chest up to the bar, until their upper arms were parallel with the floor. Three trials of a maximal number of modified pull-ups were completed within 15 seconds, with a 45 second recovery between efforts. The mean number of modified pull-ups were used for analysis.

TRAINING

Golfers allocated to the intervention group completed a one-hour strength and conditioning session once per week. This training dose was selected following a survey of parents and players to ensure a realistic and long-term sustainable commitment to the programme and to ensure maximal compliance. Golfers were then split into one of two training groups to ensure appropriate group sizes and maintain session coaching quality.

Training sessions consisted of approximately 5-10 minutes of dynamic warm-up, 40 minutes of resistance training and 5-10 minutes of conditioning activities. A pragmatic approach was taken to the strength and conditioning intervention, using expert coaching from a qualified professional (Certified Strength and Conditioning Coach) to meet the needs of the group. While the approach was tailored to individual and group needs, the training sessions were designed with youth resistance training guidelines in mind (Faigenbaum et al., 2009). The training prescription is outlined in Table 1 (below), exercises selections and volume/intensity of training were progressed through the outlined repetitions, sets, rest periods and exercise guidelines shown. Technical competency was achieved, and players were progressed when they were able to complete the exercises with excellent technique and were also able to work through the prescription at a moderate to high level of intensity without significant technical breakdown.

Table 1: Resistance training programme outline

Phase	Method (progression based on technical competency and capacity)	Description	Sets/ Reps/ Rest (mins)	Typical coached lifts/exercises (modified to individual need, no more than 5-6 exercises per session)
1	Introduction to resistance training	Introduction to basic exercises and movement patterns	1-2/ 8-12/<1	Squat, press-up, modified pull-up, hinge, plank/other trunk
2	Bodyweight and soft resistance training	Development of movement patterns into structured exercise. Adding soft resistance (bands, dumbbells, kettlebells, suspension trainers)	2-4/ 6-12/<1	Goblet squat, press-up, modified pull-up, kettlebell (KB) Romanian deadlift (RDL), plank/KB loaded carries
3	Introduction to barbell training	Continuation of bodyweight work, but with an introduction of barbell lifts and technical coaching with low-moderate resistance	3-6/ 5-8/2-3	Barbell (BB) back/front squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, KB loaded carries, medicine ball throws
4	Barbell progressions	Building on barbell lifts by applying additional load and working at moderate-higher resistance with technical mastery.	2-5/ 2-5/2-5	BB back/front squat/jump squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, hex bar jumps, KB loaded carries, medicine ball throws

STATISTICAL ANALYSIS

Data were reported as mean and standard deviation. All outcomes were expressed as the value with 90% confidence intervals. These values were given as both absolute data and standardised data. Standardised data were calculated using Hedges' g to give the measure of effect size. Threshold values for each dependant variable were carefully considered by the authors, to ensure changes in scores were evaluated against a meaningful threshold. BS was given the threshold value of 4mph and CHS a threshold of 3mph, which were both within the previously discussed minimal detectable change scores for the testing procedure. These values were also chosen because they are the likely degree of change required to elicit a 10-yard increase in driving distance (Cochran & Stobbs, 2005). A 10-yard improvement would result in a golfer being able to select a more favourable club on their second shot and therefore give them a noticeable performance improvement, this was therefore deemed as practically meaningful, and confirmed through discussions with experienced golf coaches. A CMJ peak power threshold of 200W was chosen. This value was calculated using mass and CMJ improvements shown in previous work with a similar group and training approach (Wong, Chamari, & Wisløff, 2010). In this case, mass and jump height scores were calculated as a percentage improvement from baseline from a study by (Wong et al., 2010) and those percentage improvements were then applied to the current studies baseline scores and converted into the peak power score of 200W. A minimum detectable change of 2 repetitions was used for modified pull-ups using previous minimal detectable change data for the protocol (Negrete et al., 2010).

Magnitude-based inferences were determined using Hopkins' approach (Hopkins, 2007). All inferences were based on the aforementioned thresholds. The chance of the difference being positive, trivial or negative and allocation of subjective descriptors were based on the following scale: 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and 99%, almost certain (Hopkins, Marshall, Batterham, & Hanin, 2009). Magnitude of effects were classified mechanistically, where if the 90% confidence limit crossed thresholds of the smallest positive and negative effects, the effect was 'unclear' (Hopkins et al., 2009).

RESULTS

The intervention group achieved 93% attendance, with players missing an average of 0.8 sessions of the 12 available.

Results looking into the change in the difference between groups, based on the pre-determined threshold values, suggested the 12-week intervention was likely to increase CHS (4.25mph; CI90 1.79 to 6.71) with possible increases in BS (4.09mph; CI90 0.78 to 7.40). Likely increases were seen in CMJ predicted

Table 2: Effects of 12-week intervention on CHS, BS and physical characteristics (descriptive changes in group results)

Variable	Control baseline	Intervention baseline	Control post	Intervention post
Age (yrs)	13.9 ± 1.1	13.3 ± 1.0	-	-
HCP (strokes)	8.7 ± 3.6	11.3 ± 5.1	-	-
Height (cm)	171 ± 8.4	167.8 ± 7.6	-	-
Mass (kg)	65.0± 14.3	56.4 ± 11.4	65.6 ± 14.7	59.4 ± 11.6
CHS (mph)	98.6 ± 10.0	91.1 ± 7.7	96.6 ± 11.0	93.4 ± 8.2
BS (mph)	139.9 ± 14.9	126.6 ± 10.6	139.8 ± 15.5	130.6 ± 11.6
CMJ pred. peak power (W)	2459.7 ± 700	1966.3 ± 469.8	2491.5 ± 750.9	2306.5 ± 535
Modified pull-up (reps)	6.2 ± 2.4	4.9 ± 4.7	6.5 ± 2.3	6.9 ± 5.2

peak power (308.35W; CI90 176.97 to 439.73), indicating the programme had the desired training impact and enhanced previously supported physical characteristics related to performance in youth golfers (Coughlan et al., 2017).

Table 3: Effects of 12-week intervention on CHS, BS and physical characteristics (confidence intervals and magnitude-based inferences, standardised using effect sizes)

Variable	Minimum important change thresholds (standardised value)	Δ difference between control/ intervention (90% CI)	Standardised Δ difference between control/intervention (90% CI)	Chances of effect better/trivial/worse (based on thresholds)	Subjective descriptors
CHS (mph)	3 (0.68)	4.25 (1.79 to 6.71)	0.96 (0.40-1.51)	80/20/0	Likely +ve
BS (mph)	4 (0.67)	4.09 (0.78 to 7.40)	0.69 (0.13 to 1.24)	52/48/0	Possibly +ve
CMJ pred. peak power (W)	200 (0.85)	308.35 (176.97 to 439.73)	1.30 (0.75 to 1.86)	93/7/0	Likely +ve
Modified pull-up (repetitions)	2 (0.78)	1.65 (0.24 to 3.07)	0.65 (0.09 to 1.20)	34/66/0	Possibly trivial

DISCUSSION

The purpose of this study was to investigate the effects of a once weekly strength and conditioning session over a 12-week period on youth golfers CHS and BS as well as measures of strength and explosive strength compared to a control group. The results from this study demonstrated that the intervention could augment performance by showing likely increases in CHS (CI90 1.79 to 6.71mph) and possible increases in BS (CI90 0.78 to 7.40mph). There appeared to be no notable change in the quality of strike in the intervention group, as indicated through the increases in both CHS and BS. This study has also shown that the training intervention could elicit meaningful improvements in measures if CMJ predicted peak power (CI90 176.97 to 439.73W) which highlight the effectiveness of the intervention.

The transfer of energy from CHS to BS is often seen as an indicator of the quality/centeredness of the strike, with research demonstrating the interplay between clubhead kinematics and ball flight (Betzler, Monk, Wallace, & Otto, 2014; Sweeney et al., 2013). Using CHS and BS, smash factor is often calculated to determine this change in strike quality; $Smash\ Factor = BS \div CHS$. This does have its limitations, with launch monitors measuring CHS from the geometric centre rather than centre of mass, different strike patterns can have impacts on the resultant CHS measurement and therefore influence the smash factor values. On initial observation it could appear as though the intervention groups centeredness of strike may have worsened (through a smaller improvement in BS than CHS, against the control group), the smash factor for the intervention group remained largely unchanged between the trials (pre: 1.39, post: 1.40). However, increases were seen in the control group (pre: 1.42, post: 1.45). Despite this and based on the prior test-retest reliability study, these differences would sit under the minimum detectable change scores required to determine a true change in smash factor, so indicate no overall difference between groups.

These findings demonstrate similar changes in CHS as seen with interventions in adult golfers, which have shown improvements of between 1.5 to 9.5% (C. J. Smith et al., 2011). At a 2% increase in CHS for the intervention group, the results are similar to those observed in collegiate (Doan, Newton, Kwon, & Kraemer, 2006) and skilled golfers (Fletcher & Hartwell, 2004). To the authors' knowledge, only one other study has investigated the effects of strength and conditioning interventions in youth golfers (C. J. Smith et al., 2014). This study presents similar positive findings over their intervention period, having shown moderate to large (*d*=0.64-0.96) increases in strength variables (single leg squat, side bridge and modified push-ups) and moderate improvements in handicap (*d*=0.42) over a 12-week intervention. However, no results from the previous study are directly comparable to this study.

The findings from this study have also shown the effectiveness of the 12-week intervention for enhancing general athletic qualities in youth athletes, having elicited similar responses in CMJ to youth athletes training similarly, but twice per week (Wong et al., 2010). This highlights the utility of a once weekly dose of strength and conditioning in the training of youth athletes. The improvements in jump peak power are likely to be mechanistically linked to the improvements observed in CHS and BS. Previous data shows a positive correlation between CMJ force characteristics and CHS in golfers (Coughlan et al., 2017; Wells et al., 2019). Also, the interplay between the ground and golfer has been identified as important during the swing, with ground reaction forces having strong associations with driving distance (Hume, Keogh, & Reid, 2005). Skilled golfers have also been shown to initiate their downswing from the ground up (Nesbit & Serrano, 2005), transferring energy through their kinetic chain to the club. Therefore, the observed improvements in CMJ peak power demonstrate an increased physical potential for the golfers to generate higher ground reaction forces during their downswing. Thereby transmitting more energy though the kinetic chain, leading to greater momentum in the clubhead.

It was also notable that the mean difference in CHS (4.25mph) and BS (4.09mph) was not only achieved by increases in intervention group scores, but also by worsening in control group CHS (-2.00mph) and BS (-0.93mph). No group mean regressions were seen in any of the other testing scores. Given the age of both groups, it was an unexpected finding that CHS and BS values in the control group regressed over the 12-week period. Due to the intervention taking place in the off-season, it could be that these regressions occurred due to significant reductions in golf volumes by all players over the winter period. As such, these findings not only demonstrate improvements in CHS and BS because of the intervention but also highlight the impact of the intervention in prevention of performance regression over periods of reduced sports specific practice during the off-season. Therefore, emphasising the importance of strength and conditioning interventions in off-season periods in youth golf to protect against performance decline.

A simultaneous limitation and strength of this study was the pragmatic nature of the exercise intervention. While sacrificing some control over a specific programming prescription, the exercise prescription was kept intentionally broad to allow for an individually tailored approach, where exercise progressions and regressions as well as alterations in load and volume were given based on individual need. This approach allows for a more realistic intervention which would be in-line with real world strength and conditioning support in youth golf. The quasi-experimental nature of this work, and resultant methods of recruitment and group allocation were a limitation of this study, with proximity/access to the training facility being a key determinant of group allocation. This is likely to have facilitated the high attendance rates achieved in the investigation but did not allow for a randomisation of the groups. It is notable that there were some differences in group scores at baseline, with the intervention group starting with lower performing scores in all areas. The intervention group also had a lower maturity offset at 0.08 years in comparison to 0.57 years for the control. While the differences cannot be considered meaningfully divergent, given the inherent error within the Moore-2 maturity offset equation (Kozieł & Malina, 2018), the differences in maturation between groups is worthy of consideration. Despite these potential between group differences, it is also notable that we would expect the older group to have a greater training effect (Moran et al., 2017), and therefore the advantage was unlikely to sit with the intervention group in this regard. Moreover, the intervention group increased their mass by 3kg whereas the control group only increased by 0.6kg. This is not an unusually high gain in mass against previous observations (Wong et al., 2010), and given the maturation status of the groups, it is feasible that the increase in mass could be due to the training intervention. Increases in muscle cross-sectional area can occur over this training period in adolescents (Faigenbaum et al., 2009), these adaptations could result in increased force production and may be a reason for the increases seen in CHS and BS. However, there were some differences between groups at baseline, so this change in mass could also partly be explained by differences in growth during this period between groups. As such the limitations around group allocation are worthy of consideration when interpreting these results and may temper firm assertions of the effectiveness of the intervention. It is also notable that activities outside of the training intervention were not monitored, and it is likely that the participants were engaging in other sports and activities outside of the intervention, making it difficult to attribute the observed improvements to the intervention alone. Therefore, where possible future research should attempt to monitor outside activities alongside the training intervention. Furthermore, while the intervention resulted in many positive changes in physical characteristics, the intervention was only one day per week, despite youth strength and conditioning guidelines recommending more frequent doses (Faigenbaum et al., 2009). Despite this, the investigation was able to demonstrate changes in physical characteristics in-line with other previous and more frequent interventions (Wong et al., 2010).

Future research would therefore benefit from comparing once per week doses to more frequent doses in youth golfers and youth athletes in general to understand if an increase in frequency would lead to a larger response. Despite the once per week dose being a limitation, it also represents a realistic training volume for many young athletes where time is likely to be split between a range of sports, academic, social and other commitments (Crane & Temple, 2015). This is likely to be further supported by the highly encouraging attendance rates within the current study. Recent research has highlighted a strong relationship between rotational and seated medicine ball throws and CHS (Coughlan et al., 2017), but the present study did not measure medicine ball throws due to space limitations within the facility. Future research may wish to evaluate the effectiveness of interventions in eliciting changes in medicine ball throw ability in golfers, as well as specifically target medicine ball interventions which have previously been shown favourable outcomes in sports requiring high rotational velocities (Ignjatovic, Markovic, & Radovanovic, 2012; Szymanski et al., 2010). Finally, the inclusion of a maximal force production measure, such as the isometric mid-thigh pull for peak force, as used in previous work, (Wells, Mitchell, Charalambous, & Fletcher, 2018) could be a valuable future measure to allow for improved quantification of maximal strength changes in youth golfers over the course of an intervention. However, a limitation of using this method of analysis may come through its subsequent practical application due to the likely limited access to force plates in youth golf training environments.

CONCLUSION

The results from this work demonstrate a likely positive increase in CHS and possible increases in BS in youth golfers training only once per week for 12-weeks. These improvements in CHS and BS are likely to lead to noticeable performance improvements on the golf course. This research also indicates that resistance training may be protective against CHS and BS decline over the off-season in youth golfers. This study outlines a framework for programme design which can act as a guide for strength and conditioning professionals working with youth golfers. As a result of these findings, it is strongly suggested that youth golfers partake in regular resistance training for performance enhancement.

REFERENCES

Balsalobre-Fernández, C., Glaister, M., & Lockey, R. A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of Sports Sciences*, *33*(15), 1574–1579. https://doi.org/10.1080/02640414.2014.996184

Betzler, N. F., Monk, S. A., Wallace, E. S., & Otto, S. R. (2014). The relationships between driver clubhead presentation characteristics, ball launch conditions and golf shot outcomes. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *228*(4), 242–249. https://doi.org/10.1177/1754337114541884

Bliss, A., McCulloch, H., & Maxwell, N. S. (2015). The effects of an eight-week plyometric training program on golf swing performance characteristics in skilled adolescent golfers. *International Journal of Golf Science*, *4*(2), 120–135. https://doi.org/10.1123/ijgs.2015-0009

Broadie, M. (2008). Assessing golfer performance using golfmetrics (pp. 253–262). Presented at the Science and golf V: Proceedings of the 2008 world scientific congress of golf.

Bull, M., & Bridge, M. W. (2012). The effect of an 8-week plyometric exercise program on golf swing kinematics. *International Journal of Golf Science*, *1*(1), 42–53. https://doi.org/10.1123/ijgs.1.1.42

Callaway, S., Glaws, K., Mitchell, M., Scerbo, H., Voight, M., & Sells, P. (2012). An analysis of peak pelvis rotation speed, gluteus maximus and medius strength in high versus low handicap golfers during the golf swing. *International Journal of Sports Physical Therapy*, *7*(3), 288–295.

Cochran, A. J., & Stobbs, J. (2005). *Search for the perfect swing: The proven scientific approach to fundamentally improving your game*. Chicago, IL, USA: Triumph books.

Coughlan, D., Taylor, M., Jackson, J., Ward, N., & Beardsley, C. (2017). Physical Characteristics Of Youth Elite Golfers And Their Relationship With Driver Clubhead Speed. *Journal of Strength and Conditioning Research*, 1. https://doi.org/10.1519/jsc.0000000000002300

Coughlan, D., & Ward, N. (2017). England Golf's physical preparation programme, implemented for the under-16 regional elite golf players. *Professional Strength and Conditioning*, *46*.

Crane, J., & Temple, V. (2015). A systematic review of dropout from organized sport among children and youth. *European Physical Education Review*, *21*(1), 114–131. https://doi.org/10.1177/1356336x14555294

Doan, B. K., Newton, R. U., Kwon, Y.-H., & Kraemer, W. J. (2006). Effects of physical conditioning on intercollegiate golfer performance. *The Journal of Strength and Conditioning Research*, *20*(1), 62. https://doi.org/10.1519/r-17725.1

Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J. R., Jeffreys, I., Micheli, L. J., Nitka, M., & Rowland, T. W. (2009). Youth resistance training: Updated position statement paper from the national strength and conditioning association. *Journal of Strength and Conditioning Research*, *23*, S60–S79. https://doi.org/10.1519/jsc.0b013e31819df407

Farrally, M. R., Cochran, A. J., Crews, D. J., Hurdzan, M. J., Price, R. J., Snow, J. T., & Thomas, P. R. (2003). Golf science research at the beginning of the twenty-first century. *Journal of Sports Sciences*, *21*(9), 753–765. https://doi.org/10.1080/0264041031000102123

Fletcher, I. M., & Hartwell, M. (2004). Effect of an 8-week combined weights and plyometrics training program on golf drive performance. *The Journal of Strength and Conditioning Research*, *18*(1), 59. https://doi.org/10.1519/1533-4287(2004)018

Fradkin, A., Sherman, C., & Finch, C. (2004). How well does club head speed correlate with golf handicaps? *Journal of Science and Medicine in Sport*, *7*(4), 465–472. https://doi.org/10.1016/s1440-2440(04)80265-2

Hopkins, W. G. (2007). A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a P value. *Sportscience*, *11*, 16–21.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, *41*(1), 3–13. https://doi.org/10.1249/mss.0b013e31818cb278

Hume, P. A., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine*, *35*(5), 429–449. https://doi.org/10.2165/00007256-200535050-00005

Ignjatovic, A. M., Markovic, Z. M., & Radovanovic, D. S. (2012). Effects of 12-week medicine ball training on muscle strength and power in young female handball players. *Journal of Strength and Conditioning Research*, *26*(8), 2166–2173. https://doi.org/10.1519/jsc.0b013e31823c477e

Kozieł, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: Validation in independent longitudinal samples of boys and girls. *Sports Medicine*, *48*(1), 221–236. https://doi.org/10.1007/s40279-017-0750-y

Lauersen, J. B., Bertelsen, D. M., & Andersen, L. B. (2014). The effectiveness of exercise interventions to prevent sports injuries: A systematic review and meta-analysis of randomised controlled trials. *British Journal of Sports Medicine*, *48*(11), 871–877. https://doi.org/10.1136/bjsports-2013-092538

Lewis, A. L., Ward, N., Bishop, C., Maloney, S., & Turner, A. N. (2016). Determinants of Club Head Speed in PGA Professional Golfers. *Journal of Strength and Conditioning Research*, *30*(8), 2266–2270. https://doi.org/10.1519/jsc.0000000000001362

M. Lindsay, D., & A. Vandervoort, A. (2014). Golf-related low back pain: A review of causative factors and prevention strategies. *Asian Journal of Sports Medicine*, *5*(4). https://doi.org/10.5812/asjsm.24289

Moran, J., Sandercock, G. R. H., Ramírez-Campillo, R., Meylan, C., Collison, J., & Parry, D. A. (2017). A meta-analysis of maturation-related variation in adolescent boy athletes' adaptations to short-term resistance training. *Journal of Sports Sciences*, *35*(11), 1041–1051. https://doi.org/10.1080/02640414.2016.1209306

Negrete, R. J., Hanney, W. J., Kolber, M. J., Davies, G. J., Ansley, M. K., McBride, A. B., & Overstreet, A. L. (2010). Reliability, minimal detectable change, and normative values for tests of upper extremity function and power. *Journal of Strength and Conditioning Research*, *24*(12), 3318–3325. https://doi.org/10.1519/jsc.0b013e3181e7259c

Nesbit, S. M., & Serrano, M. (2005). Work and power analysis of the golf swing. *Journal of Sports Science and Medicine*, *4*(4), 520.

Read, P. J., Lloyd, R. S., De Ste Croix, M., & Oliver, J. L. (2013). Relationships between field-based measures of strength and power and golf club head speed. *Journal of Strength and Conditioning Research*, *27*(10), 2708–2713. https://doi.org/10.1519/jsc.0b013e318280ca00

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise*, *31*(4), 572–577. https://doi.org/10.1097/00005768-199904000-00013

Smith, C. J., Callister, R., & Lubans, D. R. (2011). A systematic review of strength and conditioning programmes designed to improve fitness characteristics in golfers. *Journal of Sports Sciences*, *29*(9), 933–943. https://doi.org/10.1080/02640414.2011.571273

Smith, C. J., Lubans, D. R., & Callister, R. (2014). The Effects of Resistance Training on Junior Golfers' Strength and On-Course Performance. *International Journal of Golf Science*, *3*(2), 128–144. https://doi.org/10.1123/ijgs.2014-0023

Smith, M. F., & Hillman, R. (2012). A retrospective service audit of a mobile physiotherapy unit on the PGA European Golf Tour. *Physical Therapy in Sport*, *13*(1), 41–44. https://doi.org/10.1016/j.ptsp.2010.09.001

Sweeney, M., Mills, P., Alderson, J., & Elliott, B. (2013). The influence of club-head kinematics on early ball flight characteristics in the golf drive. *Sports Biomechanics*, *12*(3), 247–258. https://doi.org/10.1080/14763141.2013.772225

Szymanski, D. J., Szymanski, J. M., Schade, R. L., Bradford, T. J., McIntyre, J. S., DeRenne, C., & Madsen, N. H. (2010). The relation between anthropometric and physiological variables and bat velocity of high-school baseball players before and after 12 weeks of training. *Journal of Strength and Conditioning Research*, *24*(11), 2933–2943. https://doi.org/10.1519/jsc.0b013e3181f0a76a

Wells, J. E. T., Charalambous, L. H., Mitchell, A. C. S., Coughlan, D., Brearley, S. L., Hawkes, R. A., ... Fletcher, I. M. (2019). Relationships between Challenge Tour golfers' clubhead velocity and force producing capabilities during a countermovement jump and isometric mid-thigh pull. *Journal of Sports Sciences*, *37*(12), 1381–1386. https://doi.org/10.1080/02640414.2018.1559972

Wells, J. E. T., Mitchell, A. C. S., Charalambous, L. H., & Fletcher, I. M. (2018). Relationships between highly skilled golfers' clubhead velocity and force producing capabilities during vertical jumps and an isometric mid-thigh pull. *Journal of Sports Sciences*, *36*(16), 1847–1851. https://doi.org/10.1080/02640414.2018.1423611

Whittaker, A. R. (1999). A study of the dynamics of the golf club. *Sports Engineering*, *1*(2), 115–124. https://doi.org/10.1046/j.1460-2687.1999.00004.x

Wong, P., Chamari, K., & Wisløff, U. (2010). Effects of 12-week on-field combined strength and power training on physical performance among U-14 young soccer players. *Journal of Strength and Conditioning Research*, *24*(3), 644–652. https://doi.org/10.1519/jsc.0b013e3181ad3349