Effects of Physical Training and Associations Between Physical Performance Characteristics and Golf Performance in Female Players: A Systematic Review with Meta-Analysis

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Abstract

The aims of this systematic review were to assess the association between physical performance and measures of golf performance, and the effects of physical training on measures of golf performance, in female golfers. A systematic literature search was conducted in PubMed, SPORTDiscus, Medline, and Cinahl. Inclusion criteria required studies to: 1) have conducted a physical training intervention of any duration in female players and determined the effects on measures of golf performance, 2) determined the association between physical performance in at least one test and golf performance in female players, and 3) be peer-reviewed and published in English language. Methodological quality was assessed using a modified version of the Downs and Black Quality Index tool, and heterogeneity was examined via the Q statistic and I^2. Pooled effect sizes were calculated using SMD (with 95% CI's) within a random-effects model, with Egger's regression test used to assess small study bias (inclusive of publication bias). Of the 2,378 articles screened, only 9 were included in the final review, with 3 of these being associative by design and 6 being training interventions. From an associative standpoint, clubhead speed (CHS) was reported in all 3 studies and was associated with measures of strength ($r = 0.54$), lower body power ($r = 0.60$), upper body power ($r = 0.56$-0.57), and flexibility ($r = 0.52$-0.71). When assessing the effects of physical training interventions, CHS was again the most commonly reported golf outcome measure ($n = 5$). The random effect model indicated that CHS significantly improves within each training group following training interventions (SMD = 0.73 [95% CI's: 0.32, 1.14], $Z = 3.50$, $p < 0.001$), with trivial heterogeneity ($I^2 = 0.00\%$, $Q = 0.18$; $p = 0.9963$) and no prevalence of small study bias depicted via the Egger's regression test ($z = -0.28$, $p = 0.78$). From the available research, it seems that CHS can be positively impacted from strength, power and flexibility training interventions. From an associative standpoint, only three studies have been conducted solely in female players, with one showcasing questionable methodology. Future research should aim to carefully select test measures which better represent the physical capacities needed for the sport when determining the effects of and relationships with golf performance.

Key Words: Clubhead speed; driving distance; power; strength.

Introduction

Golf is a sport that combines moderate paced walking, standing in golf posture, ball striking and is considered both a technical and tactical game in respect to accurate ball placement and decision-making (49,50). However, recently the physical demands of the game have been more widely recognised. This has brought about an increased appreciation and reliance on physical performance with practitioners recognising the importance of enhancing metrics such as: club head speed (CHS), ball speed, driving distance, and strokes gained (18,20). The most common metric in physical performance research appears to be CHS, which is likely because of its direct link to ball speed and distance the ball travels (7). Although anecdotal, this primary focus on CHS may be a result of golf courses becoming longer and more physically demanding (11). Consequently, this places increasing emphasis on physical preparation and injury prevention strategies, to better prepare the modern-day golfer for the demanding schedule, they are often exposed to week-in-week-out (3).

Owing to the increased importance of physical performance for golf, it stands to reason that an increasing number of studies have started to investigate the association between physical characteristics and performance in the sport (3,45,52). Enhancing physical characteristics such as: strength, power and speed can provide a golfer with a greater capacity to produce force rapidly, which is critical in maximising both CHS and drive distance (17). For example, when considering lower body strength specifically, Oranchuk et al. (42) reported a large correlation (r = 0.64) between back squat 1RM and CHS in NCAA collegiate golfers. This is further supported by Parchmann and McBride (44), who reported strong associations between CHS and 1RM relative back squat strength (r = 0.81) in 25 NCAA Division 1 golfers. In addition, Wells et al. (57) used an isometric mid-thigh pull to determine associations with CHS, showing significant moderate associations with peak force (r = 0.48) and rate of force development (RFD) from 0-150 ms (r = 0.34) and 0-200 ms (r = 0.40). However, despite the significant associations with RFD, it is worth noting that the reliability of these two metrics were questionable, with coefficient of variation values of 19.44% and 14.54%, respectively. With regards to lower body power, numerous studies by Wells and colleagues (55-57) have shown that positive impulse during the countermovement jump (CMJ) has a significant relationship with CHS (r range = 0.62-0.79). The relevance of lower body power is further reinforced by Hellstrom (26), who reported a large correlation between CMJ peak power and CHS (r = 0.61). When considering the upper body, Keogh et al. (34) reported a moderate correlation between a 1RM bench press and CHS (r = 0.50), alongside Torres-Ronda et al. (52) who reported a stronger correlation between a 1RM bench press with both peak ball speed (r = 0.61) and average ball speed (r = 0.62). Finally, Read et al. (46) reported strong between CHS and standing medicine ball rotational throws (MBSRT) (r = 0.67) and seated medicine ball throws (MBST) (r = 0.63). Thus, it appears there are notable associations between physical characteristics and golf performance; however, the majority of research to date has been conducted in male golfers. Furthermore, as useful as this information is, it is associative analysis, and therefore we cannot infer any cause and effect, which can only be done from training interventions.

With this in mind, several studies have been conducted looking at the effects of physical training interventions on golf performance, most commonly, CHS. Results have consistently demonstrated that physical training can have a positive effect on golf performance metrics. For example, Fletcher and Hartwell (19) aimed to determine the effects of an 8-week (twice per week) combined resistance and plyometric program on golf drive performance, which resulted in a 4.3% improvement in CHS. Similarly, Oranchuk et al. (42) investigated the effects of an 8-week strength and power training intervention (three times per week) on CHS. Post-intervention data showed a 3.2% increase in average CHS (effect size [ES] = 0.38) and only a 1% increase in peak CHS (ES = 0.11). Finally, Lephart et al. (38) investigated the effects of an 8-week physical training program (3-4 times per week) on golf performance on 15 trained male golfers, with results showing a 5.2% increase in CHS post-intervention. Thus, there appears to be a developing consensus that if an athlete becomes stronger and more powerful, this will in turn lead to a higher CHS, and ultimately, hitting the ball further (3,18). However, currently this consensus can predominantly be applied to male golfers (22,41,47,51,53), and thus, there is a distinct lack of information reporting the effects of such interventions in the female game.

Consequently, the primary aims of this systematic review were to: 1) assess the association between physical performance and measures of golf performance, and 2) assess the effects of physical training on measures of golf performance, in female golfers. Owing to the inherent biological differences between sexes, data obtained on male golfers cannot be considered directly transferable to female golfers. Thus, there is a direct need for this research to be conducted, especially given the growth in female sport of late.

Methodology

Study Design and Literature Search Methodology

The present study was undertaken in line with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (43). Four databases (PubMed, SPORTDiscus, CINAHL and Medline) were utilised to search for relevant literature and Figure 1 provides a visual representation of the methodological process used. A search strategy was used within Boolean operators in order to target specific articles relevant to the research question, with a summary of these provided in Table 1.

***** Insert Figure 1 about here *****

***** Insert Table 1 about here *****

Inclusion/Exclusion Criteria

Inclusion criteria required studies to have: i) conducted a physical training intervention of any duration in female players and determined the effects on measures of golf performance, such as: CHS, ball speed, driving distance, carry distance, etc., ii) determined the association between physical performance in at least one test and golf performance in female players, and iii) be peer-reviewed and published in English language. Studies were excluded if they were reviews, conference abstracts, and did not provide separate data for male and female players. After completing all relevant searches in the Boolean operators, an additional search was completed in Google Scholar for any articles that may be relevant and/or not fully available in the aforementioned databases. Reference lists of included studies, alongside forward citations, were also searched for relevant articles.

Screening Strategy

The articles produced from the search strategy were then screened through a three-stage process: 1) duplicates of articles from previous search terms and/or databases were removed, 2) article titles and abstracts were scanned for suitability and any articles that were deemed potentially suitable, were passed through for a full review, and 3) full articles were reviewed in line with inclusion and exclusion criteria by two reviewers (LR and CB). If any disagreement occurred, a third reviewer (AE) was consulted to resolve the issue.

Grading Article Quality

To review the quality of study methodology, the criteria of Black et al. (5) was used, where each study was appraised using nine criteria (Table 2) by two reviewers (LR and CB) If a consensus could not be reached, a third reviewer (AE) was consulted to resolve the issue. Each criteria were assessed on a scale of 0-2, where 0 = "no", 1 = "maybe" and 2 = "yes", with a total score of 18 possible. The third criterion was modified from "intervention described" to "intervention / procedures described", which has been done previously (4) because this review aimed to determine the effects of physical training interventions and associations between physical assessments and measures of golf performance, whereby the latter would report correlation statistics and thus, no intervention took place.

***** Insert Table 2 about here *****

Statistical Analysis

Initially, key data was directly extracted from studies that met the inclusion criteria and transferred into Microsoft Excel. For correlational studies, key information extracted included: i) sample population, ii) physical assessments, iii) measures of golf performance, and iv) correlation value between physical assessments and golf performance measures. For intervention studies, key information included: i) sample size, ii) summary of physical intervention conducted, and iii) mean and standard deviation (SD) data pre and post intervention for golf performance measures, with all data presented as mean ± SD.

To account for the magnitude of the standard error associated with each of the included studies (due to different methodologies, athlete samples, etc.), a random effects model utilising standardised mean differences (SMD) as the ES with 95% confidence intervals (CI) was adopted, enabling studies to be weighted relative to their standard error within the model. Reporting of multiple ES from the same cohort of participants within a meta-analysis violates the assumption of independence, and therefore to address this, in instances where this occurred (due to CHS being reported for multiple clubs [25]) we opted to use driver CHS for consistency across studies. To aid in visualising the data a forest plot is displayed, with information provided pertaining to the authors, and reference to the training methods used. The meta-analysis was performed using the 'metafor' package (version 3.8.1) (53) in R (v 4.2.2; R Core

Team, https://www.r-project.org/), and ES values were interpreted in line with suggestions by Cohen (10), whereby: < 0.2 = trivial, 0.2-0.49 = small, 0.5-0.79 = moderate, and ≥ 0.8 = large.

Stability and Validity of Changes in Effect Sizes

To assess for the presence and degree of heterogeneity in the data, both the Q statistic and I^2 were used (28-30). Statistical significance for Q was acknowledged at an alpha level of < 0.10 (28-30), and I^2 was interpreted as per the work of Higgins et al. (29), with I^2 thresholds of 0–25% (trivial), 25–50% (low), 50–75% (moderate), and 75–100% (high). Small study bias (including publication bias) was assessed firstly by the visualisation of funnel plots, and accompanied by the Egger's regression test to quantify any asymmetries in the spread of data, and thus risk of small study bias (16). The occurrence of small study bias was considered present where $p < 0.05$.

Results

Overview

The search strategy produced a total of 2378 articles, with nine meeting the inclusion criteria (Figure 1). Once full texts were assessed for eligibility, the most common reasons for studies being excluded were: i) no separation in male and female data, ii) no relationship determined between physical attributes and golf performance data, iii) cross-sectional information presented only, and iv) full-text unavailable. When examining the association between physical performance and measures of golf performance, only three studies met the inclusion criteria (8,12,40). When assessing the effects of physical training interventions on golf performance, six studies met the inclusion criteria, with one of these being acute in nature (i.e., effects on CHS reported on the same day in a potentiation-type study design) (38), and five being more traditional interventions (13,25,32,35,36).

Study Characteristics

Information on each study and intervention can be found in Tables 3 and 4. Sample populations for the studies included female golf teams (40), youth female players (12), Korean LPGA tour members (35,36), amateur female golfers (25), NCAA Division 1 golfers (13) and a single, high handicap golfer (32). The duration of each study varied from a single time point, cross-sectional study (8,12,40) to a 12-week training intervention performed twice per week (36). Finally, outcome measures to assess golf performance included: average and maximum distance, average and maximum CHS (12,13,32,36,39,40), 2-m and 5-m putting stroke timing (35), driver and 7-iron CHS, driver and 7-iron total distance (25), putting distance control (13), and X-Factor and maximum rotation of the upper body, both measured in degrees (32).

Effects of Physical Training and Associations between Physical Characteristics and Measures of Golf Performance

Associations between Physical Characteristics and Golf Measures

Only three studies met our inclusion criteria and determined relationships between physical assessments and golf performance measures. Marshall et al. (40) reported significant relationships were evident between the sit and reach test and maximum driving distance (r = -0.722; $p < 0.05$), sit and reach and maximum CHS (r = -0.735; $p < 0.05$), and the Balance Error Scoring System (BESS) and average distance (r = -0.714; $p < 0.05$). Coughlan et al. (12) reported positive associations between CHS and CMJ power (r = 0.60; $p < 0.05$), seated medicine ball throw for distance (r = 0.35; $p < 0.05$), and rotational medicine ball throw for distance (r = 0.56-0.57; $p < 0.05$). Finally, Brown et al. (8) reported positive associations between CHS and grip strength on the left hand (in right-handed golfers) (r = 0.54; $p < 0.05$), and seated flexibility in both clockwise and counter-clockwise directions (r = 0.52-0.71; $p < 0.05$).

***** Insert Table 3 about here *****

Effects of Physical Training Interventions on Golf Measures

Six studies met our inclusion criteria and examined the effects of physical training interventions on measures of golf performance. Collectively, CHS was the most commonly reported outcome measure for golf (n = 5), followed by distance (n = 3), ball speed (n = 1), the X-Factor (the difference in degrees between rotation at the hips and thoracic region) (n = 1), maximum rotation of the upper body (n = 1), putting performance was assessed in terms of accuracy during a 15-foot putt (n = 1), and putting precision and consistency was assessed via a 2-m and 5-m putting task (n = 1). CHS was the only metric to be carried forwards into a random effects model to synthesise the available literature, of which a total of five independent samples across four studies met the inclusion (noting that Hegedus et al. [25] included two intervention groups). Results indicate that CHS significantly improves within the training group following a training intervention (SMD = 0.73 [95% CI's: 0.32, 1.14], Z = 3.50, $p < 0.001$). Tests for heterogeneity were identified as trivial (I^2 = 0.00%, Q = 0.18; p = 0.9963), and there was no significant evidence of small study bias depicted via the Egger's regression test (z = -0.28, p = 0.78). Figure 2 shows a forest plot visualising the summary effect estimate for CHS and Figure 3 for the contour enhanced funnel plot visualising the effect sizes, relative to their standard error.

***** Insert Tables 4-5 about here *****

***** Insert Figure 2 and 3 about here *****

Discussion

The main aims of this systematic review were to: 1) assess the association between physical performance and measures of golf performance, and 2) assess the effects of physical training on measures of golf performance, in female golfers. From an associative standpoint, three studies showed that strength, flexibility, balance, jump, and ballistic medicine ball assessments were significantly associated with greater clubhead speed and distance. However, even at this stage, it is worth noting that one study misinterpreted the findings between flexibility and CHS/distance (40). When examining the effects of physical training interventions, small to large improvements were noted for CHS and distance, large improvements in rotational ability, and small improvements in putting performance.

Associations with Golf Performance

Marshall et al. (40) explored the associations between flexibility and balance with CHS and total driving distance in collegiate golfers. The authors used the BESS to assess balance and stability deficiencies in the body and hypothesized that superior performance in this test (by scoring as close to zero as possible) and increased flexibility, would display an increased CHS and total driving distance. Firstly, lower scores in the BESS were associated with increased average driving distance, indicating that better balance and stability may be associated with driving the ball further. Although this isn't causative, it's worth appreciating that a more stable base during the golf swing, is likely to improve a player's chance of producing more force (15) and ultimately hitting the ball as far as they can. That said, with the golf swing occurring on two limbs, the link between unilateral balance and golf performance seems likely to be tenuous at best. Second, the authors also suggested that significant negative correlations between distance, CHS and the sit and reach test, suggested a meaningful association between flexibility and these golf outcome measures. However, it appears the authors have misinterpreted the findings. For all metrics here, the desirable outcome is the larger value; thus, a negative relationship indicates that as one metric (e.g., flexibility) increases, the other shows a reduction (e.g., CHS or distance). Simply put, the significant negative correlations with the sit and reach test actually indicate that players who are more flexible are associated with lower CHS and reduced driving distance. Finally, two other points of critique should be acknowledged in this study. Firstly, correlations were conducted with a sample of five players, which is almost certainly too low for associative analysis (1). Secondly, given the rotational nature of the golf swing, the sit and reach test does not seem like the most appropriate method of assessing flexibility.

Coughlan et al. (12) showed significant associations between CHS and CMJ power and ballistic medicine ball for distance throws, in youth female players. Previous research has suggested that the CMJ and medicine ball throws are appropriate tests as part of a test battery, to determine physical capacity in both elite and youth golfers (3,48). This is primarily because the golf swing exhibits sizeable quantities of ballistic vertical force production (24,31) and ballistic rotational tests hold high levels of ecological validity to the swing (3). Thus, it seems more appropriate to see these types of physical assessments being used in golf players, with comparable data also shown in previous research using male players (55-57).

Brown et al. (8) showed significant associations between CHS and grip strength on the left side, but not on the right. Given the notable difference in relationships between strength of the left and right hands, it seems that for right-handed golfers, the lead side (left hand) is of greater importance for higher CHS. This is likely due to two reasons. Firstly, previous research has shown that the lead hand is the one exerting most of the pressure during the downswing to maintain CHS and ultimately, control of the swing (37). Secondly, the lead arm is also likely to be key in maximising rotational torque during the swing, as it remains straighter than the trail arm, which in turn, may be a reason why grip strength on the lead side is of greater importance. However, it's worth noting that further research is needed to corroborate this. When considering the other findings from Brown et al. (8), seated flexibility was also significantly associated with CHS; however, standing flexibility was not. When seated, the ability to rotate will be focused primarily on the upper body's range of motion in that task. In contrast, the body's ability to rotate when standing, will be impacted by other factors such as range of motion at the pelvis and femur. Thus, and although somewhat anecdotal, this potentially highlights the importance of thoracic mobility, which will play a pivotal role in maximising rotational torque during the swing, which has been acknowledged in previous literature (3).

In summary, with only three studies meeting our inclusion criteria, definitive conclusions are hard to come by, especially when some of the results have been misinterpreted (40). Therefore, more studies looking at the association between physical characteristics and measures of golf performance are undoubtedly needed in female players.

Effects of Training Interventions on Golf Performance

Macadam et al. (39) investigated the acute effects of wearable resistance on CHS. Specifically, participants wore Lila Exogen exoskeleton suits for the wearable resistance of 1.6 kg (0.8 kg on the upper body, 0.8 kg on the lower body). CHS was collected on five players with and without this additional resistance, with results showing individual increases in CHS ranging from 2.2-5.6% when additional resistance was worn. It is important to note that the additional resistance was attached both posteriorly and laterally on the trail side of the body, which resulted in significant increases in ground reaction force on both the lead side (11.8%, $p = 0.01$) and trail side (7.9%, $p = 0.03$). This increase in force represents one plausible reason why moderate increases in CHS were seen. Practically speaking though, it seems the design of this study was done with the intention of trying to cause acute changes in CHS; however, the specific load and placement of this wearable resistance seems like something that would never get implemented into real life scenarios in the sport. Thus, although the efficacy of this study design must be questioned, it perhaps does highlight the possible advantages of gaining mass for golfers; something which seems apparent given how many elite players are taking strength training seriously these days. .

Hegedus et al. (25) compared the effects of a golf-specific resistance training (GSRT; $n = 14$) and traditional resistance training (TRAD; $n = 15$) on measures of golf performance, in 29 female golfers. Collectively, it appears that TRAD is more effective than GSRT at enhancing CHS and distance when using a driver (Figure 2). This could be due to a number of reasons; however, when the specific exercises of each programme are considered, it seems that this is likely to have been the most prominent reason. Put simply, the GSRT does not appear to be golf-specific as a resistance programme. For example, some of the exercises administered in the GSRT group, were unilateral (e.g., 1 arm, 1 leg cable row, 1 leg Russian deadlift, 1 arm, 1 leg cable bench). Whilst these exercises may serve a purpose in respect to asymmetry (2,21), there appears to be very little about these exercises that are "golf-specific", most notably, when we consider that the golf swing happens on two limbs. It is also interesting to note that TRAD group displayed large improvements in CHS using a driver ($g = 0.85$), yet visual inspection of the raw data when using a 7-iron shows a small reduction in CHS. This is unexpected, especially as the GSRT group's data did not follow the same trend. Although anecdotal, this inconsistency in the results may be explained by the fact that the participants were amateurs, with a high handicap (TRAD = 22; GSRT = 14). Our thought-process is further supported by the fact that both groups only achieved distances of 136-148 m with a driver, and indicates that these findings are not applicable to lower handicap and elite players.

Doan et al. (13) explored the effects of a physical conditioning program on CHS, consistency and putting distance control in 6 female NCAA division 1 golfers. Supervised strength and power training were carried out three times per week for 11-weeks, which should be seen as a positive aspect of the study design. Overall, exercise selection generally seemed to align with previous suggestions (3,18), which also had a positive effect on CHS (Figure 2). However, it should be noted that there was an extremely small sample size ($n = 6$), which again somewhat prevents the findings from being extrapolated to other female players. Furthermore, given the low sample size and the fact that golf is an individual sport, it would have been useful to have some individual data analysis conducted (e.g., are changes in CHS greater than each athlete's own measurement error), which has been conducted previously in male studies (6,45). This study also aimed to determine the effects on putting distance control, which showed noticeably smaller changes post-intervention. However, this should not be a surprise as the intervention was designed to improve the physical capacities (e.g., strength and power) of the players, and putting is very much a skill-based component of golf. Thus, if enhancing putting performance was a primary aim of improvement, then a focused skill-based putting session would have likely had a more positive impact.

Jung et al. (32) investigated the effects of upper-body flexibility in a single female amateur golfer on maximum rotation angle of the upper body, X-Factor stretch, CHS and carry distance. The main critique of this research is that the player involved had a high handicap of 20; therefore, the findings are again, not attributable to lower handicap or elite players. With golf being an individual sport, the case study nature of this investigation is likely not a huge limitation. However, it was not clear why the intervention only lasted 2-weeks, despite three sessions being completed per week. Furthermore, the intervention focused solely on flexibility, whereas previous research has highlighted the importance of physical characteristics such as strength and power in both the lower and upper body (3,18). Thus, when considering the raw data (Table 4), it seems likely that this intervention yielded positive results because the female was reported to be untrained and a higher handicap player. Therefore, and although somewhat speculative, it is argued that completing any form of physical intervention would have made improvements in golf performance.

Kim et al. (35) investigated the effects of using an interactive metronome with the intention of trying to reduce variation in the rhythm and timing of putting, twice a week over a 6-week period. Firstly, the dependent variables were swing speed performed from a 2 m and 5 m putts. However, as outlined in Table 4 and rather surprisingly, mean swing speed values were not reported; rather, the standard deviation of both the intervention (n = 10) and control (n = 10) groups were used as a reflection of the change in variability of time taken to perform the putts at these distances. The intervention group showed a 28% and 25% reduction in the time variation to perform 2 m and 5 m putts, respectively. Put simply, greater consistency in swing speed was achieved after using the interactive metronome equipment. However, from 2 m, the control group also showed a 16.7% reduction in time variation (i.e., more consistency in swing speed), but a very large 66.7% increase in time variation from 5 m. Collectively, these data show that this type of training may provide professional players with some improved consistency in putting timing. However, and to refer back to the study by Doan et al. (13), practitioners should not expect noticeable improvements in putting performance from traditional strength and power training interventions.

Finally, Kim et al. (36) investigated the effects of a 12-week training intervention, performed twice a week, focusing primarily on trunk strengthening. Moderate improvements were noted for CHS (g = 0.62) with raw scores also showing improvements for ball speed and carry distance (Table 4). Firstly, these findings highlight the positive impact of a stronger trunk for golf, which seems logical given the requirement to transfer force and energy from the ground, up through the trunk, to the upper extremities and down the shaft of the club (33). However, and as previously mentioned, when aiming to physically prepare golfers for increases in CHS, the development of strength and power is critical. Thus, although trunk strength is likely to be important, it should be seen as a part of a golfer's overall physical development and therefore, programmed accordingly.

Limitations and Directions for Future Research

Given the distinct lack of research in female golf and physical development, there are a number of limitations to this review, which naturally lend themselves to avenues which need further investigations. Firstly, from an associative analysis standpoint, only three studies met our inclusion criteria specifically investigating the relationship between physical characteristics and golf performance in female players. A number of studies have previously included both male and female players (9,23,27) however, data is often pooled with a clear delineation between male and female results often missing. As previously highlighted, research is heavily dominated in the male game, which is unlikely to be fully transferable to female players. Thus, associative research will provide a basis for selecting appropriate physical exercises and tests to monitor in female players. Linked to this, there has been a distinct lack of research investigating the association between anthropometric data (e.g., mass, arm length) and golf measures such as CHS and distance, which may also be of interest to practitioners.

Secondly, when considering the interventions in this systematic review, it seems prudent to mention that there was a wide variety of methodologies utilised, with some showcasing training programmes which were arguably not aligned with best practice in strength and conditioning. Thus, future research should first aim to establish which key physical characteristics need developing in golf (3,48), and then align exercise selection with the desired physical adaptation, rather than trying to mimic the movement of the swing, in a way that is erroneously believed to be "golf-specific". In addition, when considering measures of golf performance such as CHS, some studies reported this metric as "peak CHS" whilst others reported "mean CHS", noting that the latter is a result of averaging CHS over multiple swings. To the best of our knowledge, no study has directly investigated the magnitude of difference between peak and mean CHS in the same set of golfers. However, and regardless of which one is used, it seems logical to suggest that both practitioners and future research employs a consistent approach to using this metric when monitoring golf performance.

Thirdly, future studies should consider undertaking some individual data analysis, given golf is an individual sport, which has been done in a recent publication (14). Unsurprisingly, sample sizes in golf studies are often small, which is likely to result in them being under-powered. Whilst this cannot always be avoided, future golf research would benefit from interventions reporting whether changes in performance were greater than the measurement error of the test, as has been suggested in recent golf publications (3,7). Finally, when considering the over-arching quality of studies in this review (Table 5), it is clear that future research should also aim to give greater consideration to the over-arching study design. Specifically, interventions never scored higher than 13 on the quality assessment, with notable criteria being the interventions were sometimes too short, assessments not always practical, and conclusions not fully clarified. Naturally, when this happens it becomes challenging to extrapolate some of the findings to the wider female game.

Conclusion

The purpose of this systematic review and meta-analysis was to review the current literature surrounding the effects of and associations between physical performance and golf performance in the female game. First and foremost, it has been identified that there is a distinct lack of research in respect to physical characteristics and golf performance, in the female game; thus, further research is definitely warranted given the generally poor quality of studies included in this review. From the available research to date, it appears that CHS and distance can be positively impacted from strength, power and flexibility training interventions. However, exercise selection within interventions need to be carefully considered to maximise potential benefits. From an associative standpoint, only three studies have been conducted solely in female players, with one showcasing questionable methodology. Thus, further research is again needed to determine which physical characteristics have the strongest relationship with measures of golf performance.

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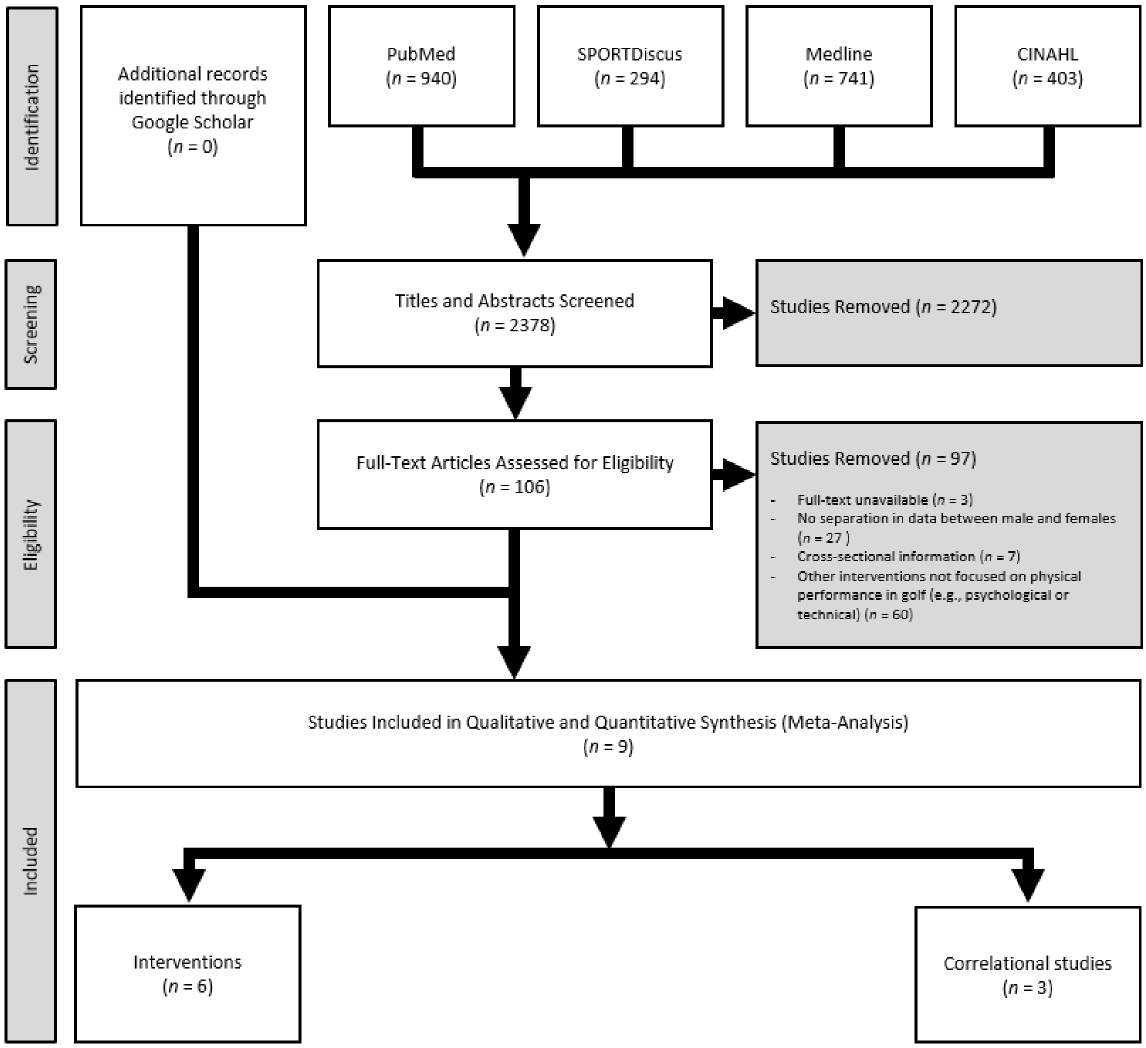

Figure 1. Schematic representing the processes, in line with PRISMA recommendations.

Table 1. Schematic to represent 10-level search strategy.

Operator	Search Term Order	Search Term(s)
	#1	Golf AND Female
AND	#2	Training
AND	#3	Intervention
AND	#4	Injury
AND	#5	Strength
AND	#6	Power
AND	#7	Range of Motion
AND	#8	Speed
AND	#9	Physical
AND	#10	Velocity

Table 2. Study quality scoring system, as per Black et al. (5).

Criteria No.	Item
1	Inclusion criteria stated
2	Subjects assigned appropriately
3	Intervention / procedures described
4	Dependent variables defined
5	Assessments practical
6	Training duration practical (acute *vs.* long-term)
7	Statistics appropriate
8	Results detailed (mean, SD, percentage change, effect size)
9	Conclusions insightful (clear, practical application, future directions)

Table 3. Summary of methods and results for the study which examined the association between physical assessments and measures of golf performance (*n* = 3).

Author(s)	Sample	Physical Assessments	Golf Measures	*r* Values
Marshall et al. (40)	Subjects were recruited from the Nebraska Wesleyan women's golf team (*n* = 5).	Sit and reach test, BESS, and range of motion measurements using a goniometer included: shoulder flexion, shoulder extension, shoulder abduction, shoulder adduction, shoulder internal rotation, shoulder external rotation, trunk rotation, hip flexion. *Note:* Three measurements collected and the average used in subsequent data analysis.	Average distance, maximum distance, average clubhead speed, and maximum clubhead speed.	Sit and reach *vs.* maximum distance: (*r* = -0.72), sit and reach *vs.* maximum clubhead speed: (*r* = -0.74), BESS test *vs.* average distance: (*r* = -0.71).
Coughlan et al. (12)	Youth female players aged 13-17 (*n* = 33).	Countermovement jump (CMJ) height and power, standing long jump distance, seated medicine ball throw (left and right), rotation medicine ball throw (left and right), maximum push ups in 15-seconds (3 sets), and maximum inverted rows in 15-seconds (3 sets).	Clubhead speed.	CMJ power (*r* = 0.60), seated medicine ball throw to the left (*r* = 0.35), rotational medicine ball throw to the left (*r* = 0.57) and right (*r* = 0.56).
Brown et al. (8)	Category 1 female golfers (*n* = 16) with a mean handicap of 1.75 ± 2.35.	Grip strength (left and right), standing flexibility (clockwise and counter-clockwise), seated flexibility (clockwise and counter-clockwise).	Clubhead speed.	Grip strength left (*r* = 0.54), seated flexibility clockwise (*r* = 0.52), seated flexibility counter-clockwise (*r* = 0.71).

Note: all reported r values are significant at p < 0.05.

Table 4. Summary of methods and results for studies which examined the effects of physical training interventions on measures of golf performance (*n* = 6).

Author(s)	Sample	Training Intervention	Mean ± SD (pre)	Mean ± SD (post)
Kim et al. (35)	Female golfers on the Korean Ladies PGA Tour, participants either in a control (CON: *n* = 10) or intervention (INT: *n* = 10) group.	The protocol consisted of a basic exercise program with the metronome set at 54 beats per minute for all sessions. Subjects engaged in 35-41 minute sessions, twice per week for six weeks. Sessions 1-4 involved a progressive LFA with 14 movements for participant ability regarding responses and inter-response time. Sessions 5-11, participants alternated between two movements, such as clapping the right hand and tapping the left foot requiring coordination and sequential motor tasks.	*2m putter SD (s):* INT = 0.25 s CON = 0.24 s *5m putter SD (s):* INT = 0.20 s CON = 0.15 s	*2m putter SD (s):* INT = 0.18 s CON = 0.20 s *5m putter SD (s):* INT = 0.15 s CON = 0.25 s
Hegedus et al. (25)	Amateur female golfers (*n* = 29), divided into traditional resistance training group (TRAD; *n* = 15; mean handicap = 22) or a golf-specific resistance training group (GSRT; *n* = 14; mean handicap = 14).	TRAD group performed: back extensions, wrist curls, side planks, bench press, lat pulldowns, shoulder shrugs, bent over rows, modified RDL's and reverse hypers. GSRT group performed: back extensions, wrist flexion (on cable machine), cable chop, 1-arm 1-leg cable chest press, standing lat pulldown, shoulder shrugs, 1-arm 1-leg cable rows, 1-leg RDL and lateral plyometrics.	*Driver CHS ($m·s^{-1}$):* TRAD = 28.3 ± 0.8 GSRT = 30.2 ± 0.8 *Driver distance (m):* TRAD = 128.7 ± 5.7 GSRT = 145.6 ± 5.9 *7-iron CHS ($m·s^{-1}$):* TRAD = 24.4 ± 0.8 GSRT = 24.9 ± 0.8 *7-iron distance (m):* TRAD = 85.8 ± 3.9 GSRT = 99.5 ± 4.0	*Driver CHS ($m·s^{-1}$):* TRAD = 29.0 ± 0.8 GSRT = 30.8 ± 0.8 *Driver distance (m):* TRAD = 136.3 ± 5.7 GSRT = 148.4 ± 5.9 *7-iron CHS ($m·s^{-1}$):* TRAD = 24.2 ± 0.8 GSRT = 26.7 ± 0.8 *7-iron distance (m):* TRAD = 95.0 ± 3.9 GSRT = 107.0 ± 4.0
Doan et al. (13)	NCAA Division 1 golfers (*n* = 6)	11-week training program. Key exercise examples, with sets x repetition ranges included: Parallel squats (3 x 7-12), bench press (3 x 7-12), rows (3 x 7-12), overhead press (3 x 7-12), lunges (3 x 7-12), leg curls (3 x 7-12), back extensions (3 x 7-12), and medicine ball throws (2-4 x 8-10).	*CHS (m/s):* 43.45 ± 2.48 *Putting distance control-15 ft putt (cm):* 28.69 ± 7.80	*CHS (m/s):* 44.91 ± 1.59 *Putting distance control-15 ft putt (cm):* 26.74 ± 8.42

Jung et al. (32)	Case study (*n* = 1), 43-year old female who had been playing golf for 17-months (handicap = 20)	6 x 1-hour training sessions completed over a period of 2-weeks (3 sessions per week). Training consisted of: 5-minute warm-up, 20-minutes of upper body flexibility exercises (e.g., bretzels, kneeling thoracic rotations, prayer stretch, and side bend with rotation), and golf swinging for 30-minutes.	*CHS (m/s):* Session 1 = 29.4 Session 2 = 29.0 Session 3 = 28.5 Session 4 = 28.2 Session 5 = 30.1 Session 6 = 30.7 Average = 29.3 ± 0.95 *Carry distance (m):* Session 1 = 84.0 Session 2 = 82.2 Session 3 = 83.4 Session 4 = 80.1 Session 5 = 88.0 Session 6 = 91.0 Average = 84.8 ± 4.0 *X-Factor (º):* Session 1 = 10 Session 2 = 18 Session 3 = 16 Session 4 = 13 Session 5 = 17 Session 6 = 18 Average = 15.3 ± 3.2 *Maximum rotation of the upper body (º):* Session 1 = 40 Session 2 = 50 Session 3 = 50 Session 4 = 44 Session 5 = 48	*CHS (m/s):* Session 1 = 30.8 Session 2 = 30.0 Session 3 = 31.1 Session 4 = 32.2 Session 5 = 33.8 Session 6 = 34.4 Average = 32.1 ± 1.8 *Carry distance (m):* Session 1 = 99.0 Session 2 = 84.7 Session 3 = 96.6 Session 4 = 94.0 Session 5 = 101.0 Session 6 = 106.0 Average = 96.9 ± 7.2 *X-Factor (º):* Session 1 = 20 Session 2 = 20 Session 3 = 21 Session 4 = 20 Session 5 = 22 Session 6 = 24 Average = 21.2 ± 1.6 *Maximum rotation of the upper body (º):* Session 1 = 60 Session 2 = 65 Session 3 = 66 Session 4 = 64 Session 5 = 66

			Session 6 = 51 Average = 47.2 ± 4.3	Session 6 = 69 Average = 65.0 ± 3.0
Macadam et al. (39)	Skilled right-handed golfers with a mean handicap of 4.1 ± 1.2 (*n* = 5)	Acute potentiation study, whereby 10 golf shots (6-iron) performed with and without wearable resistance of 1.6 kg attached to the posterior trail side of the body (0.8 kg on the lower body, 0.8 kg on the upper body representing ~2.8% body mass).	*Unloaded CHS (m/s):* Subject 1 = 32.0 Subject 2 = 35.8 Subject 3 = 35.6 Subject 4 = 36.2 Subject 5 = 32.5 Average = 34.3 ± 1.7	*Loaded CHS (m/s):* Subject 1 = 33.8 Subject 2 = 36.9 Subject 3 = 36.7 Subject 4 = 37.0 Subject 5 = 33.7 Average = 35.5 ± 1.5
Kim et al. (36)	Seventeen registered Korean LPGA members were split into an intervention group (INT: *n* = 9) or a control group (CON: *n* = 8).	12-week training programme performed twice per week, consisting of 3 sets of 12-14 repetitions of squats and deadlifts performed against resistance tubing and a range of trunk strengthening exercises (e.g., abdominal crunch, back extension, kneeling rollouts, medicine ball twists).	*CHS (m/s):* INT = 38.77 ± 2.13 CON = 39.33 ± 1.38 *Ball speed (m/s):* INT = 55.43 ± 3.20 CON = 57.02 ± 2.91 *Carry distance (yds):* INT = 208.25 ± 9.99 CON = 210.57 ± 8.88	*CHS (m/s):* INT = 40.12 ± 1.99 CON = 38.56 ± 0.98 *Ball speed (m/s):* INT = 56.83 ± 2.71 CON = 56.89 ± 1.83 *Carry distance (yds):* INT = 217.12 ± 13.37 CON = 211.57 ± 8.67

SD = standard deviation; CHS = clubhead speed; LFA = long form assessment; BESS = balance error scoring system; CMJ = countermovement jump; TRAD = traditional resistance training group; GSRT = golf specific resistance training; INT = intervention group; CON = control group; NCAA = national collegiate athletic association.

Table 5. Individual quality scoring system results for included studies (*n* = 9).

Author(s)	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6	Criteria 7	Criteria 8	Criteria 9	Total
Associative studies										
Marshall et al. (40)	2	1	1	2	0	1	1	1	0	9
Coughlan et al. (12)	2	2	2	2	2	1	1	1	2	15
Brown et al. (8)	1	1	1	2	1	1	1	2	1	11
Intervention studies										
Kim et al. (35)	2	2	2	1	0	1	1	1	1	11
Hegedus et al. (25)	2	2	1	2	1	1	1	2	1	13
Doan et al. (13)	0	0	2	1	1	2	2	2	1	11
Jung et al. (32)	2	0	1	2	2	1	0	2	1	11
Macadam et al. (39)	1	0	2	2	1	1	2	2	1	12
Kim et al. (36)	1	2	2	1	2	2	2	1	1	13

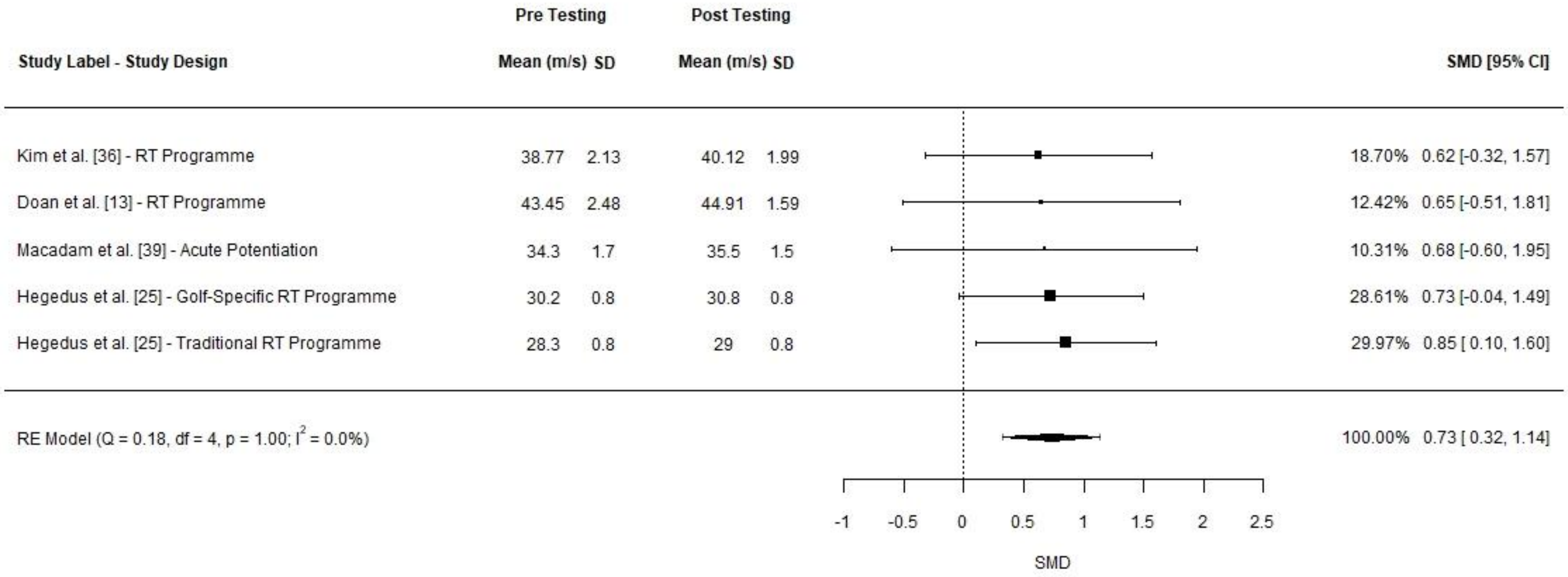

Figure 2. Forest plot presenting the effects of training on clubhead speed (CHS). *Note: SMD = standardised mean difference, RT = resistance training, CI = confidence interval, RE = random effects.*

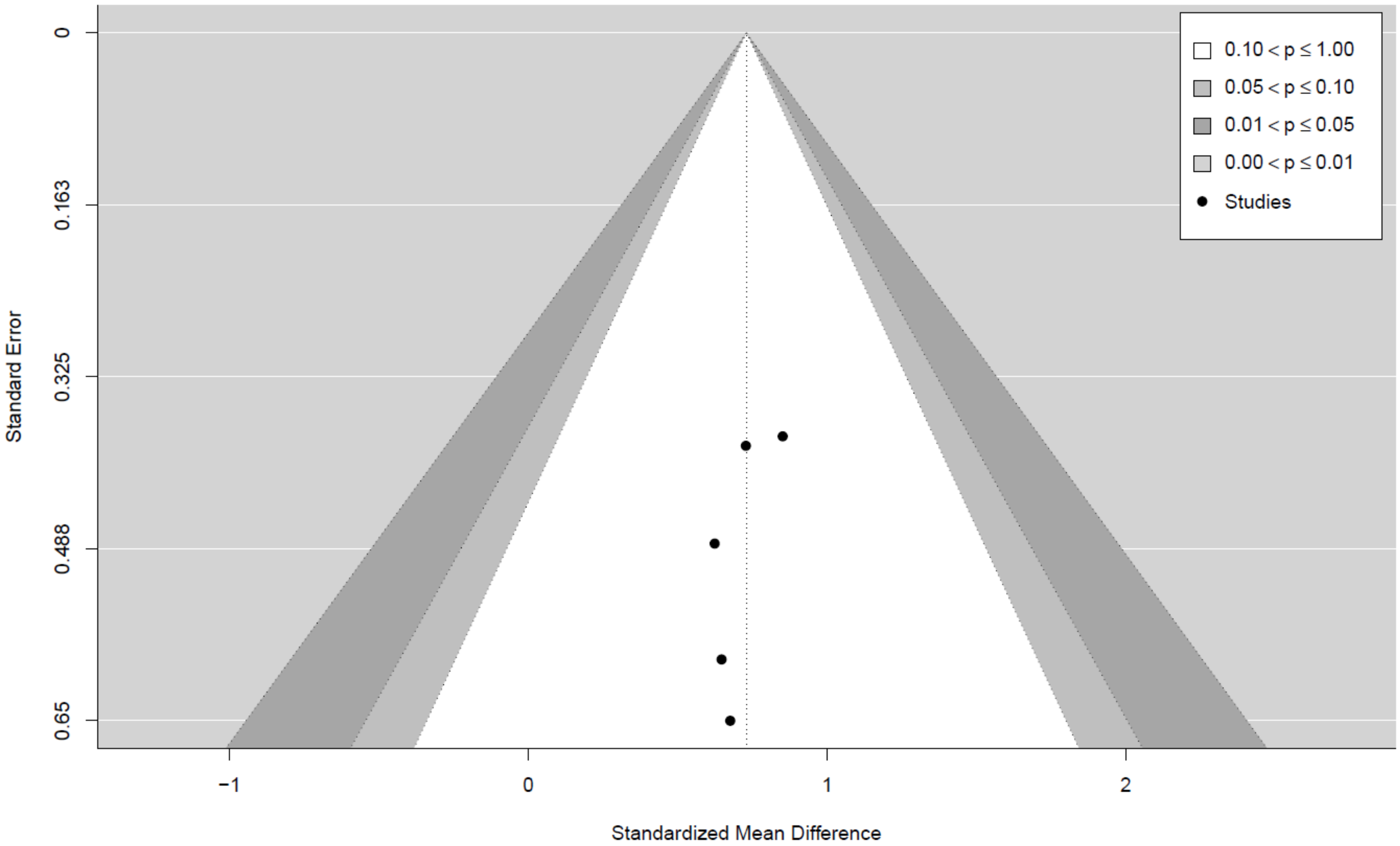

Figure 3. Contour enhanced funnel plot presenting the standardised mean difference data for clubhead speed (CHS), plotted against its standard error.