Do Kinematic Study Assessments Improve Accuracy & Precision in Golf Putting? A Comparison between Elite and Amateur Golfers: A Systematic Review and Meta-Analysis

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REVIEW

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ABSTRACT

Introduction: The purpose of this study was to evaluate whether kinematic assessments help to improve golf putting accuracy and precision, and increase the success rate of golf putts. Specifically, this study also investigated the differences in club head velocity and putter face angle at impact (°) between elite and amateur golfers.

Methods: A total of 25 articles were used in this review. An initial, broad search of electronic databases including PubMed, SPORT discus, Scopus, Science Direct and Google Scholar was conducted for literature using the keywords "biomechanics" AND "golf putting". The total number of studies screened for this review was n = 897. Among these articles, only n = 63 were assessed for eligibility. The number of articles were reduced further to n = 25 and included in the qualitative and quantitative synthesis.

Results: Out of the initial n = 897, n = 834 records were excluded. After the articles were assessed for eligibility, n = 17 articles were excluded for not meeting the inclusion criteria. The studies included demonstrated that kinematic approaches can help improve accuracy and precision of golf putts which help to increase the success rate of putts and reduce overall scoring. Elite golfers have a more accurate direction and face angle when compared to amateur golfers.

Conclusion: This systematic review and meta-analysis suggests that kinematic assessments of face angle at impact, putter path, the vertical spot and backswing are critical determinants of a golfer's success and are useful indicators to help improve accuracy and precision of golf putts. This study also noted that elite golfers had slightly less velocity but more precise putter face angles at impact which increased their accuracy in completing more successful putts than amateur golfers.

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KEYWORDS:

golf; golf biomechanics; golf putt; golf performance; ball speed; club head velocity

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This initial search was refined due to excessive and irrelevant studies. A further refined systematic search of the existing literature was conducted using the combined keywords "biomechanics" OR "kinematics" AND "golf putting" AND "accuracy and precision" on studies published between 2010 and 2020, using the same electronic databases PubMed, SPORT discus, Scopus, Science Direct and Google Scholar. This search also only included English journal articles. The inclusion criteria were: (1) Containing kinematic approaches on golf putting including accuracy and precision; (2) skill levels from novice to professional (inclusive of all handicaps), ages, and a population with no injuries; (3) Only journal articles in English. The exclusion criteria were: (1) studies not including kinematic approaches on golf putting; (2) studies not focussing on accuracy or precision; (3) publications that were not journal articles written in English.

The PRISMA flow chart shows the process of the refined systematic searches (Figure 1). Titles and abstracts of articles were screened for relevance for this systematic review and articles that did not make the criteria were removed. The remaining articles were read in full and articles that did not make the criteria were removed in addition to duplicate papers. The risk of bias was used to assess the cumulative evidence of the results. This was performed by evaluating the study design, including the 25 articles used for the review. The recommended tool used to assess the risk of bias involved assessing and presenting the risk of bias for each article. The outcomes of this assessment were then used to conclude the outcomes. Table 1 provides a summary table of all 25 journal articles that made the criteria and were selected for this systematic review. This table includes the purpose of each paper, kinematic methodology, and all relevant variables of each approach. These variables include: number and average age of participants, average skill level of participants determined by handicaps (Professional = <0, Expert = 1–6, High = 6–10, Amateur = 10–20, Novice = >20), Putt distance from strike to hole measured in metres, putter and golf ball used, stimpmeter reading to indicate the speed of the greens, and finally if the participant was right or left-handed.

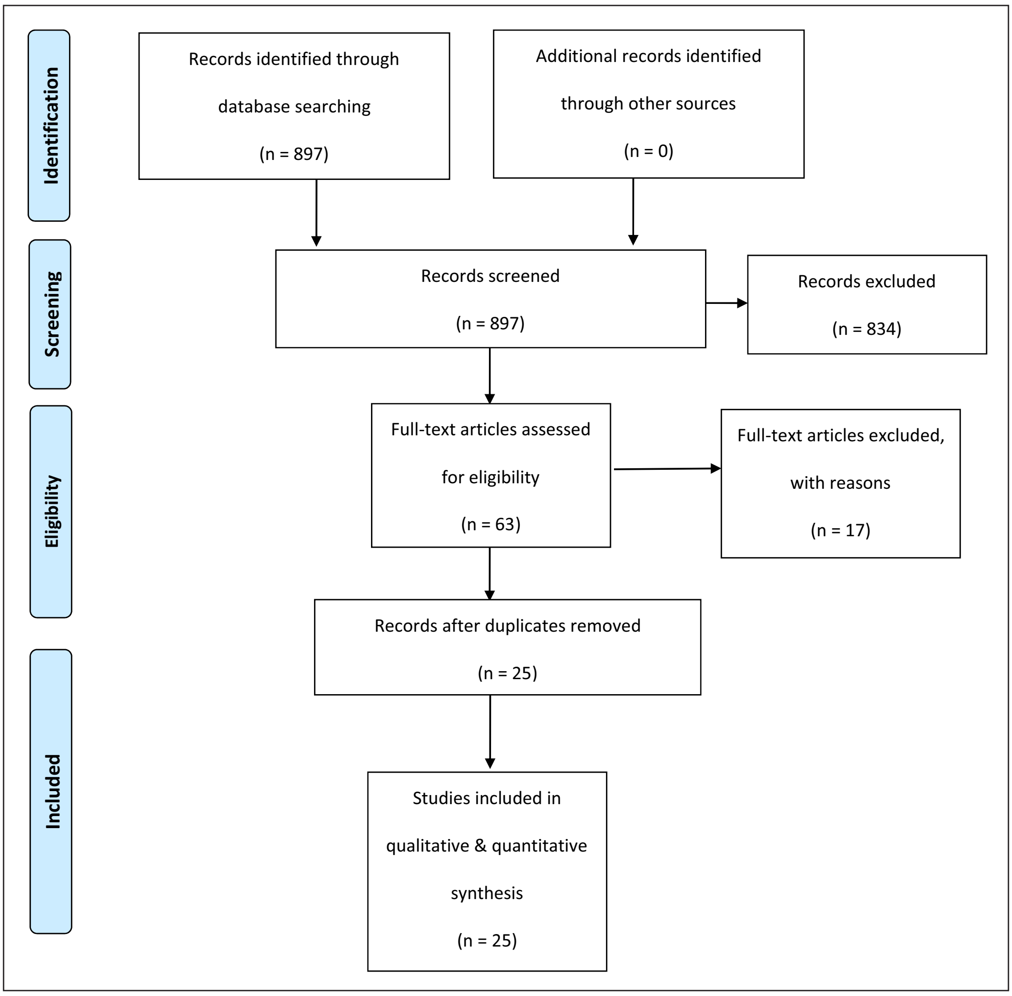

Figure 1 PRISMA Flow Chart.

Table 1 An overview of all kinematic studies selected for this systematic report. M = Male, F = Female, R = Right, L = Left, m = Metres, cm = Centimetres, ft = Feet, Hz = Hertz, Pro = Professional & – = not stated.

AUTHOR (YEAR)	PURPOSE OF STUDY	PARTICIPANTS (AGE)	SKILL LEVEL (HANDICAP)	PUTT DISTANCE (M)	PUTTER (CM) & BALL	HANDED & STIMPMETER READING (FT)	KINEMATIC/KINETIC METHODS
Cooke (2011)	To examine the performance of expert golfers and their psychological, physiological, and kinematic responses to competitive pressure.	44 M & 6 F (20.3 ± 1.5 years)	Expert (3.01 ± 2.21)	5 blocks of 6 putts at 1.8 m, 1.2 m, 2.4 m × 2	Scotty Cameron Circa 62, Titleist (90 cm) & Titleist Pro-V1 ball	R, 14ft	Acceleration of clubhead on X, Y & Z axes recorded using a tri-axal accelerometer (LIS3L06AL). Clubhead orientation, height, and impact velocity was assessed.
Delphinus & Sayers (2012)	To present detailed 3D kinematic profiles of pelvis and trunk during the putting motion and, second, to determine if differences in 3D kinematics of the pelvis and trunk exist between proficient and non-proficient putters.	10 M (19.5 ± 1.9 years)	Expert (5 ± 2)	18 putts at 2 m	Participants used their own putters.	–	3D analysis (100 Hz) was conducted on 10 single figure handicap golfers using a six-camera motion capture system.
Dias et al., (2014)	To understand the adaptation to external constraints and the effects of kinematic variability in a golf putting task.	10 M (33.80 ± 11.89 years)	High (average 10.82)	30 putts at 2, 3 & 4 m, no slope (90 putts). Repeated with slope constraint.	–	R, 10ft	Analysis of the putter's trajectory of dynamic movements, comparing frames using MatLab program
Dias et al., (2014)	The aim of this study was to investigate how a player responds to external constraints (slope and angle) in a golf putting task.	10 M (33.8 ± 11.89 years	High (average 10.82)	60 putts (30 each side) at 2 m (25°)	–	R, 10ft	Recording the trajectory of the putter to obtain the putting phases during the backswing, downswing, ball impact and follow-through, as well to analyse the amplitude, velocity, acceleration, and overall duration of the movement.
Gray et al., (2015)	This study studied the relationship between attentional focus, perceived hole size, and radial putting error in a golf task. They examined the effects of pressure on golf putting kinematics and accuracy.	17 M & 8 F (20.1 years)	High (average 7.3)	50 putts at 2.5 m (20 practice & 30 experimental putts).	McGregor M220™, (88.9 cm), putter & Wilson Ultra™ golf balls (size 1.68 in [4.27 cm]).	R, –	Evaluation of the effects of pressure on kinematic variables of golf putting by analysing the time to peak speed and velocity at impact IVI. The x/y/z location and angle of the putter head was recorded by mounting a Fastrak (Polhemus™) position tracker sensor.
Hasegawa et al., (2017)	The purpose of this study was to compare the degree of resolution in motor control during golf putting between professionals and high-level amateurs by comparing the kinematics of the club head.	Pro: 5 M & 5 F (34.4 ± 4.9 years) Amateur: 5 M ± 5 F (41.5 ± 11.5 years)	Pro & high (6.3 ± 2.5)	100 putts over 10 distances between 0.6 m and 3.3 m, in increments of 0.3 m (in sets of 10 putts).	Participants used their own putters & Srixon Z-Star XV balls.	–, 9ft	Recording the kinematics of each putt using six optical motion-capture system cameras (Qualysys oqus 300, Qualisys AB, Sweden). The sampling frequency of the cameras was 250 Hz. 10-mm markers were attached to the toe and heel of the putter head, and digitised the positions of both.
Hasegawa, Koyama & Inomata (2013)	This study examined the effect of anxiety states on the relationship between golf-putting distance and performance in an environment requiring high movement accuracy.	10 M &13 F (8.6 ± 13.3 years)	High (5.7 ± 2.8)	15 putts. 1 putt from each: 1.25 m, 1.50 m, and 1.75 m. (in sets of 5 putts)	Participants used SB-01 HB putter & Titleist Pro-V1 ball	–	Analysis of impact velocity and backswing amplitude of the club head. Backswing amplitude was analysed with respect to both horizontal (x-axis) and vertical directions (y-axis). relative time to peak club-head velocity was calculated to examine putting movement patterns.

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Hasegawa, Miura & Fujii (2020)	This study investigated how a practice motion in the preparation phase, of golf putting, would affect the accuracy of motor control in the execution phase and how proficiency would influence this relationship. They also examined the impacts on kinematics and final ball position, the velocities of practice strokes made by tour professional and amateur golfers.	10 pros (31.7 ± 4.4 years) & 11 amateurs (48.0 ± 11.5 years)	Professional & amateur (14.5 ± 1.4)	60 putts at 1.2 m & 7.2 m (6 patterns in sets of 10 putts)	Participants used SB-01 HB putter & Titleist Pro-V1 ball	–	Analysis of club head kinematics and final ball positions were recorded with nine optical motion-capture cameras (OptiTrack Prime13, Acuity Inc.; Tokyo, Japan) operating at 240 Hz. Additionally, 12-mm markers were attached to the toe, heel, and neck of the putter head to digitize the positions of the club.
Land & Gershon (2012)	This study examined a golf-specific secondary task to prevent choking under pressure during golf putting as well as examining kinematic variabilities in putting.	Novice: 19 F & 5 M (26.58 ± 7.51 years) Expert: 15 F & 5 M (21.2 ± 3.24 years)	Novice & expert (2.13 ± 2.71)	120 putts at 3.05 m (40 putts for 3 conditions)	Standard putter & ball	–	To examine kinematic variability, key parameters of the putting stroke were measured by the V1 Putt Visual Putting System. V1 Putt is a video-based motion analysis system for examining critical factors of putter head motion during golf putting. Using a Sony DCR-HC28 video camera with a shutter speed of 1/4000 s, the putting motion was digitally captured and analyzed via the V1 Putt software.
Mackenzie et al., (2011)	This study evaluated the traditional method, of visually focusing on the ball, in comparison to focusing on the hole, during the putting stroke as well as evaluating the kinematics of the putting stroke.	31 M (22.3 ± 4.1 years)	Amateur (18.7 + 10.4)	20 putts at 1.22 m & 4 m (5 putts at each distance × 2)	Nike Unitized retro putter (89 cm) & Callaway TOURi ball	11 L & 20 R, 11.5 ft	This study used the TOMI1 system to evaluate the kinematics of every putting stroke executed during testing (1240 strokes). The TOMI1 system consists of a battery charged clip, comprising four light emitting diodes (LEDs), which attaches directly to the putter shaft.
McLaughlin & Best (2013)	This study investigated the use of cluster analysis to determine if different putting techniques existed in a group of club level golfers by using kinematics.	34 M (55.3 ± 17.8 years)	Amateur (15.3 ± 6.9)	108 putts were analysed at 4 m.	–	–	This study used a Panasonic F-15 PAL video camera was placed 12 m in front of the player, off the edge of the putting green, perpendicular to the line of the putt (sample rate 50 Hz; shutter speed 1/2000s). They also used A pliance® pressure mat at 50 Hz (16 × 16 sensor matrix) for COP testing.
Moore et al., (2012)	This study evaluated kinematics of golf putting using quiet eye training interventions and evaluated performance under heightened anxiety of novice participants in a golf putting task.	40 – (19.55 ± 1.65 years)	Novice (–)	420 total putts over 7 days at 3.05 m.	Ping Sedona 2, putter (90 cm) & regular ball	R, 10.77ft	This study recorded acceleration of the clubhead in three axes using a tri-axial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland). A buffer amplifier with a frequency response of DC to 15 Hz was used. Both accelerometer and amplifier were mounted in a 39 mm × 20 mm × 15 mm plastic housing secured to the rear of the clubhead.

(Contd.)

AUTHOR (YEAR)	PURPOSE OF STUDY	PARTICIPANTS (AGE)	SKILL LEVEL (HANDICAP)	PUTT DISTANCE (M)	PUTTER (CM) & BALL	HANDED & STIMPMETER READING (FT)	KINEMATIC/KINETIC METHODS
Moore et al., (2012)	This study examined the effect of challenge and threat states on golf putting performance and several possible mechanisms, including kinematics.	64 M & 63 F (19.57 ± 2.48 years)	Novice (–)	6 putts each (762 total putts) 636 putts were analysed.	Ping Sedona 2, putter (90 cm) & regular ball	R, 10.9ft	This study recorded acceleration of the clubhead in three axes using a tri-axial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland). A buffer amplifier with a frequency response of DC to 15 Hz was used. Both accelerometer and amplifier were mounted in a 39 mm × 20 mm × 15 mm plastic housing secured to the rear of the clubhead.
Munzert, Maurer & Reiser (2014)	This study examined how varying the content of verbal-motor instructions and requesting an internal versus external focus influenced the kinematics and outcome of a golf putting task.	9 M & 21 F (–)	Novice (–)	Day 1: 6 blocks of 20 putts at 4.50 m. day 2: 40 more putts	–	–	This study collected kinematic data using 12-infrared-camera motion capture system (Vicon MX3, Oxford Metrics, Oxford, England). Three-dimensional data were sampled at a rate of 200 Hz and processed with Vicon Nexus Software. Biomechanical body markers were attached to participants upper body and putter.
Pataky & Lamb (2018)	The purpose of this study was to test whether physical randomness training can improve putting performance in novices. The authors measured putter face kinematics.	26 M, 6 F (21.7 ± 1.4 years)	Novice (–)	14,755 putts over 7 days At 5 m	–	R, 9.6ft	This study investigated putter head kinematics by recording during real laboratory putting at 100 Hz using a three-camera Oqus 5 system (Qualisys AB, Göteborg, Sweden). Four 5 mm square pieces of reflective tape were attached to the corners of the putter face were used to analyse club head velocity.
Pelleck & Passmore (2017)	This study assessed the implications of changing the attentional focus of novice and skilled golfers by measuring behavioural, neurophysiological and kinematic changes during a golf putting task.	11 novice: 4 M & 7 F (32.8 ± 14.4) 13 expert: 12 M & 1 F (33.5 ± 13.2)	Novice (>20) & expert (4.7 ± 2.5)	60 putts per participant at 3 m & 5 m	Standard putter & ball	–, 9ft	This study used 3D motion analysis system (Optotrak 3D Investigator, Northern DigitalInc., Waterloo, ON) positioned to face the participant and collect movement data at 300 Hz. Two infrared emitting diodes (IREDs) were fixed to the end of the putter blade and the distal shaft of the club.
Richardson, Hughes & Mitchell (2012)	The aim of this study was to examine Centre pressure excursion in low, mid, and high handicap golfers about the mediolateral axis and anterior-posterior axis.	19: 7 LH (33.9 ± 15.2 years), 5 MH (30 ± 15 years) & 7 HH (20.1 ± 1.8 years)	Expert (LH) (5.4 ± 2.9), amateur (MH) (16.6 ± 0.6) & Novice (HH) (25.9 ± 2.5)	5 successful putts per participants at 2.5 m	Participants used their own putters and Srixon Z-STAR golf balls.	R, 11ft	This study used a Sony HDR-XR155E Handycam sampling at 50 Hz which was positioned 90° to the path of the golf ball and was level with the artificial putting surface. This gave a clear view of the setup, top of backswing, impact, and follow-through, which was used in further analysis to break the putting stroke into phases. Pressure plates were also used.
Richardson, Hughes & Mitchell (2018)	The aim of this study was to assess whether variability of body segment rotations influence putting performance (ball kinematic measures)	8 (–) (34 ± 11 years)	High (6 ± 3.4)	10 successful putts per participants at 3.2 m	Participants used their own putters and Srixon Z-STAR golf balls.	R, 11ft	This study recorded body movement kinematics using a 10-camera motion analysis system (Motion Analysis Corporation., Santa Rosa, CA, USA) sampling at 120 Hz. Retro-reflective markers were attached to anatomical locations on each participant (total 31 markers: 14 mm).

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AUTHOR (YEAR)	PURPOSE OF STUDY	PARTICIPANTS (AGE)	SKILL LEVEL (HANDICAP)	PUTT DISTANCE (M)	PUTTER (CM) & BALL	HANDED & STIMPMETER READING (FT)	KINEMATIC/KINETIC METHODS
Sim & Kim (2010)	The aim of this study was to identify differences in kinematics and accuracy between expert and novice golfers.	10 (5 expert & 5 novice). Expert: 4 M & 1 F (32.4 years). Novice: 4 M & 1 F (30.6 years)	Expert (<10), Novice (–)	10 putts per participant for 6 conditions at: 1.7 m, 3.25 m & 6 m	Xings putters (80.3 cm) (500 g & 750 g), regular ball.	–	This study used 2 video cameras to capture movements at 60 frames/s, and APAS (Ariel Performance Analysis System) software was used to conduct three-dimensional motion analysis. Biomechanical markers were used for Kinematic analysis of the putter.
Tanaka & Iwami (2018)	This study investigated the sense-of-distance for skill differences between experts and novice golfers in both putting-swing consistency and accuracy of outcome estimation using kinematics.	18 (9 expert & 9 novice). Expert: 3 M & 6 F (19–22 years). Novice: 3 M & 6 F (19–23 years).	Expert (<3), Novice (–)	10 putts per participant at: 1.2, 2.4, & 3.6 m	Ping putter (Anser 2, Ping, USA)	R, –	Biomechanical reflective marker was attached to the putter. Three high-speed cameras (OptiTrack Prime13, NaturalPoint, USA) recorded all movements of the reflective marker at 240 frames per second. Three-dimensional (3D) coordinates of the marker's position were automatically computed using motion-capture system software (Motive:Body, NaturalPoint, USA)
Tanaka & Sekiya (2010)	This study examined relationships between psychological/physiological and behavioral variables when participants are placed under pressure in a golf-putting task. As well as examining the relationships between psychological/physiological variables and performance.	16 M (19.6 ± 0.5)	Novice (–)	150 putts at 1.5 m (15 blocks of 10 putts. Followed by 10 pressure putts.	Standard putter & ball	R, –	This study used a digital high-speed camera (DKH B cam), with a sampling frequency of 100 Hz to record putting movements. The camera was placed in front of the participant to capture movement in the frontal plane. Movement kinematics were analyzed using a two-dimensional analysis (DKH Frame-DIAS for Windows).
Tanaka & Sekiya (2011)	This study examined kinematic characteristics and force control during a golf-putting task under a pressure condition. The authors also investigated the relationship between changes in behavior (kinematics and force control) and performance on the one hand, and psychological (attention and affect) and physiological (arousal level) changes on the other.	20 M (19.7 ± 0.5 years)	Novice (–)	150 putts at 1.5 m (15 blocks of 10 putts. Followed by 10 pressure putts.	Standard putter & ball	R, –	This study used a digital high-speed camera (DKH B cam), with a sampling frequency of 100 Hz to record putting movements. The camera was placed in front of the participant to capture movement in the frontal plane. Movement kinematics were analyzed using a two-dimensional analysis (DKH Frame-DIAS for Windows). 6 anatomical markers were attached to participants as well as 2 on the putter.
Toner & Moran (2011)	This study split their investigation into 2 experiments. **Experiment 1:** The aim was to examine the influence of conscious processing (in the form of making technical adjustments to a skill) on expert golfers' putting proficiency and key kinematic aspects of their putting strokes (as measured by a motion analysis system).	14 M (27.14 ± 11.42 years)	Expert (2.6 ± 1.9)	45 putts per participant at 2.5 m	Participants used their own putters & regular golf balls were provided.	–	This study used 3D kinematic ultrasound system called SAM PuttLab to examine putting actions. SAM PuttLab records putting stroke positional data, stores it on a computer, reconstructs movement from the data, and then provides an in-depth kinematic analysis of the stroke.

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AUTHOR (YEAR)	PURPOSE OF STUDY	PARTICIPANTS (AGE)	SKILL LEVEL (HANDICAP)	PUTT DISTANCE (M)	PUTTER (CM) & BALL	HANDED & STIMPMETER READING (FT)	KINEMATIC/KINETIC METHODS
	Experiment 2: employed motion analysis to investigate empirically whether or not a certain form of conscious control (i.e. making technical adjustments) and conscious monitoring (i.e. paying attention to a specific aspect of one's skill) will have differential influences upon the putting proficiency and putting stroke kinematics of expert golfers	18 M (29.2 ± 11.46 years)	Expert (3.56 ± 1.88)	65 putts per participant at 2.5 m	Participants used their own putters & regular golf balls were provided.	–	Experiment 2 used the same kinematic technique as experiment 1 whilst adding a dictaphone (Sony tp-s350) to record the "think-aloud" protocol.
Vine et al., (2017)	The aim of the study was to explore the significance of the 'timing' of the quiet eye, and the relative importance of late (online control) or early (pre-programming) visual information for accuracy. Kinematic variables were assessed by kinematic measures.	27 (24.53 ± 8.57 years)	High (5.8 ± 5.01)	6 putts at 3.05 m for each of the 3 conditions.	Ping Sedona 2, putter (90 cm) & regular ball	–	This study used a tri-axial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland) to compute the acceleration of the putter club head in X (lateral), Y (vertical), and Z (back-and-forth) axes.
Wu et al., (2020)	This study aimed to assess the putting performance and kinematics across three skill levels of female golfers	149 F. Pro: 64 (26.55 ± 3.90 years), Elite: 46 (21.02 ± 2.07 years) & amateur: 39 (19.92 ± 2.13 years)	Pro, elite & amateur (–)	7 putts at 3 m	Participants used their own putters & Titleist Pro-V1 balls	R, 10ft	The three-dimensional kinematic data of each putt were captured using a high-precision ultrasound system (70Hz*3) (SAM PuttLab, Science&Motion Sports)

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RESULTS

STUDY SELECTION

The total number of studies screened for this review equalled n = 897. Among these articles, only n = 63 were assessed for eligibility. The number of articles was reduced further to n = 25. These 25 articles were included in the qualitative and quantitative synthesis (Figure 1). Out of n = 897, n = 834 records were excluded. After the articles had been assessed for eligibility, n = 17 articles were excluded. The main reason for the exclusion of n = 834 articles was due to the lack of relevance to the given qualitative and quantitative analysis. The outcome evaluations for the articles were very different compared to the desired results. In some articles, the full texts were missing and were eliminated to avoid presenting incomplete data. A further n = 63 involved articles that were also excluded. This was mostly due to the repetitive nature of some articles.

Different aspects of articles were included in more than two reports. The studies were also not eligible in relation to the context of the study. An overview of the results from the individual studies are displayed in Table 2.

Table 2 Overview of search results from selected individual studies.

RECORDS	PROPORTION	PERCENTAGE OF THE PROPORTION
Records excluded	834/897	92.98%
Full-text articles assessed for eligibility	63/847	7.44%
Full-text articles excluded, with reasons	17/847	2%
Records after duplicates removed	25/847	3%
Studies included in qualitative synthesis	25/847	3%
Studies included in quantitative synthesis (meta-analysis)	25/847	3%

STUDY CHARACTERISTICS

All the articles used in the review were selected based on the relevance to the topic being discussed. The main inclusion criteria included participants who were gauged based on their average skills (Professional ≤ 0, Elite = 1–6, High = 6–10, Amateur = 10–20, Novice ≥ 20). The type of intervention was classical, and all the outcomes were assessed based on the level of experience and age. The primary outcome indicated limited changes in the results. The secondary outcomes, on the other hand, showed a prevalence of eligible data. The timing of the outcomes was categorised, and every evaluation recorded. Table 3 shows the risk of bias in each study.

SYNTHESIS OF RESULTS

Elite vs Amateur data were available for only 25 articles from the 847 reports that were initially chosen. Seventeen articles were excluded from the reports due to lack of eligibility. In the pooled analysis, the relative risk was 0.7 while the confidence level was 95%, P = 0.05, the data showed no evidence of heterogeneity (0%). The meta-analysis based on the Elite vs Amateur Club Head Impact Velocity is displayed in Figure 2 while details of the Club Head Impact Velocity outputs are presented in Figure 3. There was strong evidence of heterogeneity in the data, and to explore this, a forest plot was created. The plot showed significant evidence of heterogeneity (confidence intervals: 95%, $P < 0.05$). Specifically, 27 of the articles were excluded without reason. The omission represents about 3% of the original 847 articles. The purpose of using the data was to avoid publication bias hence the need for referencing. The report, therefore, consisted only of the articles approved to be eligible for the systematic review.

The benefits of using the reports and the assessed results of 95% confidence intervals were clear in articles with adequate concealment of allocation compared to those excluded for lack of eligibility (P for interaction = 0.025) and (P = 0.009) for the data excluded without reason. When compared, the interaction was (P = 0.034). Subgroups analysis after removal of duplicated reports showed no differences in the results.

Table 3 Risk of Bias display from each study.

AUTHOR	PURPOSE OF THE STUDY	STUDY BIAS
Cooke (2011)	To examine the performance of expert golfers and their psychological, physiological, and kinematic responses to competitive pressure.	low
Delphinus & Sayers (2012)	To present detailed 3D kinematic profiles of pelvis and trunk during the putting motion and, second, to determine if differences in 3D kinematics of the pelvis and trunk exists between proficient and non-proficient putters.	high
Dias et al., (2014)	To understand the adaptation to external constraints and the effects of kinematic variability in a golf putting task.	high
Dias et al., (2014)	This study aimed to investigate how a player responds to external constraints (slope and angle) in a golf putting task.	low
Gray et al., (2015)	This study studied the relationship between attentional focus, perceived hole size, and radial putting error in a golf task. They examined the effects of pressure on the golf putting kinematics and accuracy.	unclear
Hasegawa et al., (2017)	The purpose of this study was to compare the degree of resolution in motor control during golf putting between professionals and high-level amateurs by comparing the kinematics of the club head.	high
Hasegawa, Koyama & Inomata (2013)	This study investigated how a practice motion in the preparation phase of golf putting would affect the accuracy of motor control in the execution phase and how proficiency would influence this relationship. They also examined the impacts on kinematics and final ball position, the velocities of practice strokes made by the tour professional and amateur golfers.	high
Land & Tenenbaum (2012)	This study examined a golf-specific secondary the task to prevent choking under pressure during golf putting as well as examining kinematic variabilities are inputting.	low
Mackenzie et al., (2011)	This study evaluated the traditional method, of visually focusing on the ball, in comparison to focus on the hole during the putting stroke as well as evaluating the kinematics of the putting stroke.	high
McLaughlin & Best (2013)	This study investigated the use of cluster analysis to determine if different putting techniques existed in a group of club level golfers by using kinematics.	high
Moore et al., (2012)	This study evaluated the kinematics of golf putting using quiet eye training interventions and evaluated performance under heightened anxiety of novice participants in a golf putting task.	low
Moore et al., (2012)	This study assessed the threat states on golf putting performance and several possible mechanisms, including kinematics.	unclear
Munzert, Maurer & Reiser (2014)	This study examined how varying the content of verbal-motor instructions and requesting an internal versus external focus influenced the kinematics and outcome of a golf putting task.	high
Pataky & Lamb (2018)	The purpose of this study was to test whether physical randomness training can improve putting performance in novices. The authors measured putter face kinematics.	low
Pelleck & Passmore (2017)	This study assessed the implications of changing the attentional focus of novice and skilled golfers by measuring behavioral, neurophysiological and kinematic changes during golf putting task.	high
Richardson, Hughes & Mitchell (2012)	This study evaluated pressure excursion in low, mid, and high handicap golfers about the mediolateral axis and anterior-posterior axis.	low
Richardson, Hughes & Mitchell (2018)	This study aimed to assess whether variability of body segment rotations influence putting performance (ball kinematic measures).	low
Sim & Kim (2010)	This study aimed to identify differences in kinematics and accuracy between expert and novice golfers.	low
Tanaka & Iwami (2018)	This study investigated the sense-of-distance for skill differences between experts and novice golfers in both putting-swing consistency and accuracy of outcome estimation using kinematics.	high
Tanaka & Sekiya (2010)	The study examined relationships between psychological/physiological and behavioral variables when participants are placed under pressure in a golf-putting task. As well as examining the relationships between psychological/physiological variables and performance.	low
Tanaka & Sekiya (2011)	This study examined kinematically characteristics and force control during a golf-putting task under a pressure condition. The authors also investigated the relationship between changes in behaviour (kinematics and force control) and performance on the one hand, and psychological (attention and affect) and physiological (arousal level) changes on the other.	high
Toner & Moran (2011)	This study split their investigation into 2 experiments. Experiment 1: The aim was to examine the influence of conscious processing (in the form of making technical adjustments to a skill) on expert golfers' putting proficiency and key kinematic aspects of their putting strokes (as measured by a motion analysis system).	low
Vine et al., (2017)	The aim of the study was to explore the significance of the 'timing' of the quiet eye, and the relative importance of late (online control) or early (pre-programming) visual information for accuracy. Kinematic variables were assessed by kinematic measures.	high
Wu et al., (2020)	This study aimed to assess the putting performance and kinematics across three skill levels of female golfers.	unclear

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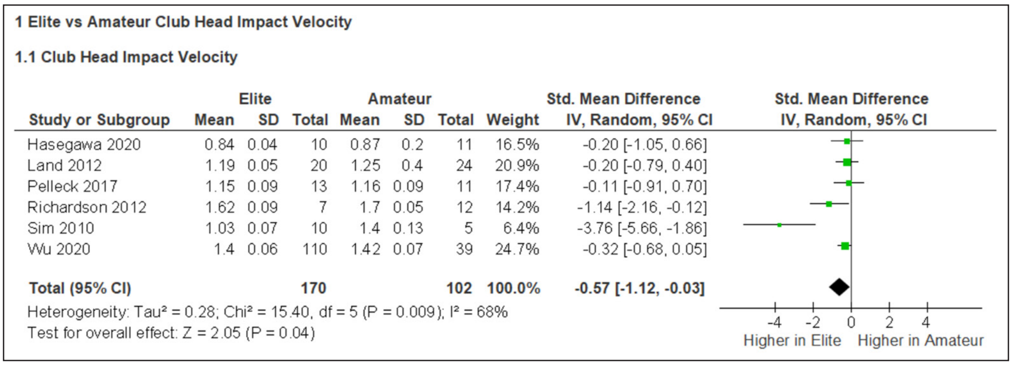

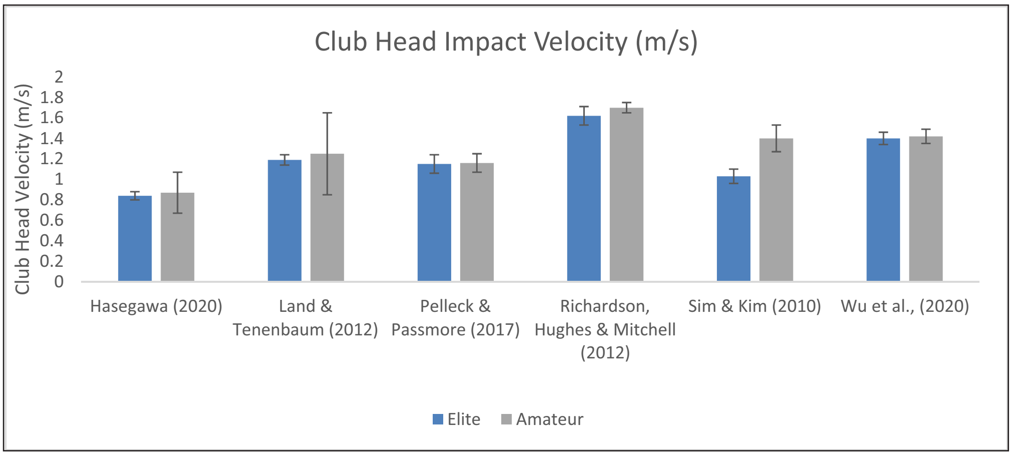

Figure 2 Meta-analysis – Elite vs Amateur Club Head Impact Velocity. The Forest plot shows 6 studies that compared elite vs amateur golfers club head velocity at impact (when striking the ball to the hole). The mean shows the velocity of the putter at impact in m/s and the standard deviation (SD) shows the variation of velocity at impact in m/s. The standard mean difference reports the efficacy, in terms of the continuous measurement of the 6 studies.

Figure 3 Elite vs Amateur – Club Head Impact Velocity comparison showing a bar chart display of the Club Head Velocity at Impact (m/s) from 6 studies among elite and amateur golfers.

Within the study designs and the interventions, and the reported outcome measures, the focus was to create a description of the studies. This description involved their results as well as the applicability and limitations of the data obtained. Additional analyses on the face angle (°) at impact is reported in Table 4 where the three studies displayed analyse the putter face angle at impact (°). Land & Tenenbaum (2012) and Wu et al., (2020) compared the putter face angle at impact (°) between elite and amateur golfers whereas Mackenzie, Foley & Adamczyk (2011) compared the Putter Face Angle at Impact (°) of amateur golfers over two putting distances (1.22 m and 4 m).

Table 4 Face angle at impact (°).

AUTHOR (YEAR)	PARTICIPANTS AGE (YEARS)	SKILL LEVEL (HANDICAP)	PUTT DISTANCE (M)	FACE ANGLE AT IMPACT (°)
Land & Tenenbaum (2012)	Amateur: 19 F & 5 M (26.58 ± 7.51) Elite: 15 F & 5 M (21.20 ± 3.24)	Elite (2.13 ± 2.71) Amateur (>20)	3.05 m	0.50 ± 0.42 0.76 ± 0.88
Mackenzie, Foley & Adamczyk (2011)	31 M (22.30 ± 4.10)	Amateur (18.7 ± 10.4)	20 putts at 1.22 m & 4 m (5 putts at each distance × 2)	1.22 m: 0.75 4 m: 0.99
Wu et al., (2020)	149 F Pro: 64 (26.55 ± 3.90) Elite: 46 (21.02 ± 2.07) Amateur: 39 (19.92 ± 2.13)	Elite (<5) Amateur (>20)	3 m	0.75 ± 1.30 0.79 ± 1.37

DISCUSSION

The results of this study showed that there was a significant difference in the putting performance and kinematics between elite and amateur golfers. The holing success was highest for elite golfers. (Hasegawa et al., 2020, Land and Tenenbaum, 2012, Pelleck and Passmore, 2017, Richardson et al., 2018, Sim and Kim, 2010, Wu et al., 2020). Therefore, the results were used to conclude that the holing success rate could be used as a determinant for establishing the skill level of individuals.

The purpose of this study was to evaluate whether kinematic assessments help to improve golf putting accuracy and precision, and increase the success rate of golf putts. Thus, reducing the golfer's number of putting strokes and overall strokes to improve performances. This study also investigated whether there were any differences in club head velocity and club head angle at impact between elite and amateur golfers. Therefore, the holing success can be used as a determinant for future experiments regarding this topic (Wu et al., 2020).

It would be worth evaluating future studies to determine the performance in various distances and breaks (Cooke et al., 2011). Research indicated that the putter face angle was not significant in determining the skill level between elite and the amateur golfers. Based on the articles used in this review, the face angle was the most crucial determinant for direction. It was also concluded that the elite players have a better technique at controlling their face angle during the backswing and impact during golf performance (Dias et al., 2014). The rise of initial deviation during the study was to have a variance of 0.03 degrees between the amateur and elite players. According to the study, elite golfers have better control of the face angle with a slight deviation in the stroke (Richardson et al., 2012, Wu et al., 2020). The second determinant was the stroke path, which was 0.04 degrees for professionals and 0.23 degrees for elite golfers. The impact spot for the three groups was negligible for the missed putts and had a 10 m variation for the direction deviation. All groups showed a similar accuracy compared to the correct target accuracy (Dias et al., 2014). Generally, elite golfers have a precise face of impact for the face angle. They also have a high holing rate which is relative to the target line.

Table 4 analysed the putter face angle at impact (°) where two studies (Land and Tenenbaum, 2012, Wu et al., 2020) compared the putter face angle at impact (°) between elite and amateur golfers. While Mackenzie, Foley & Adamczyk (2011) compared the putter face angle at impact (°) of amateur golfers over two putting distances (1.22 m and 4 m); Land & Tenenbaum (2012) analysed various kinematic variables of each individual putt of the participants 120 putts from 3.05 m from aim at address, rhythm of putt and club face angle at impact. However, this study focussed on the putter face angle at impact (°) and the relationship this has with the accuracy and precision of the putt with respect to increasing the success rate of putts. Their study found the putter face angle at impact (°) to be more accurate for elite golfers with an impact angle of 0.50° ± 0.42° than 0.76° ± 0.88° of the amateur golfers who holed less putts. Elite golfers putter face angles at impact were more accurate and precise as their angle at impact was closer to 0°, which represents a flush impact with the ball and straighter putt towards the hole. Additionally, the elite golfers face angle was more consistent, as shown by a lower standard deviation indicating less variation. Therefore, illustrating that elite golfers were able to hole more putts than amateurs. Wu et al.'s, (2020) study also compared elite vs amateurs putter face angle at impact (°) and found similar results to Land & Tenenbaum (2012). Their agreement states that elite golfers putter face angles were lower than those of amateur golfers with less variation, they found elite golfers to have a putter angle of 0.75° ± 1.30° whereas amateurs had a putter angle of 0.79° ± 1.37° at impact for a 3 m putt. Therefore, the elite golfers were more accurate and precise and holed more putts than the amateur golfers.

Several other studies analysed putter face angle at impact (°) using various 3D and high-speed cameras, such as SAM Putlab, OptiTrack Prime 13 & TOMI1 system (Mackenzie et al., 2011, Pataky and Lamb, 2018, Richardson et al., 2018, Tanaka and Sekiya, 2011, Toner and Moran, 2011). However, these studies did not compare elite vs amateur golfers, instead the studies analysed putter face angle at impact (°) in relation to accuracy and precision to determine if face angles would impact the success rate of putts. Mackenzie, Foley & Adamczyk (2011) analysed 20 putts for 31 amateur golfers across 4 m and 1.22 m putts and found the golfers to have a more accurate face angle at 1.22 m in comparison to the 4 m putt as the average putter face angle at impact for the 1.22 m putt was 0.75° in comparison to 0.99° at the 4 m putt. These results suggest that the golfers were more accurate from the shorter putt of 1.22 m and holed more putts than the further putt at 4 m, due to a shorter and more precise backswing of the putter path. All studies agree with one another and conclude that the closer the putter face angle at impact (°) is to 0 °, the more accurate and precise the putt is (which increase the success rate of putts being holed).

However, the studies used different kinematic approaches to analyse the golfers putting accuracy. Pataky & Lamb (2018) and Richardson, Hughes & Mitchell (2018) analysed putter face angle at impact (°) where a negative angle meant the golfers putt was left of the target (hole) and a high positive angle meant the putt was right of the target. Richardson, Hughes &

Mitchell (2018) analysed 10 putts of 8 participants at 3.2 m which averaged to be just left of the target at –0.10°. Pataky & Lamb (2018) found similar results as they tested 32 participants who accumulated 14,755 putts over 7 days at a putt distance of 5 m and found an average of the putts to be left of the target at –0.17°.

Furthermore, many studies used different kinematic approaches to analyse the accuracy and precision of golf putts to determine the success rate of putts. Tanaka & Sekiya (2011) used a digital high-speed camera (DKH B cam), with a sampling frequency of 100 Hz to record putting movements. Whereas Toner & Moran (2011), used a 3D kinematic ultrasound system called SAM PuttLab to examine putting actions but both studies did use a point scoring system to analyse the accuracy of their participants putts. Tanaka & Sekiya's (2011) scoring system for accuracy was conducted by nine concentric circles making up each goal for a 1.5 m putt. The outermost circle was 90 cm in diameter, and each subsequent circle was 10 cm smaller, until the innermost circle was 10 cm in diameter. Areas within one circle and the next were given values of 9, 8, 7, 6, 5, 4, 3, 2, and 1 point for scoring purposes (from inner to outer circle). Toner & Moran (2011) scoring system for accuracy was assessed in putts that finished in the hole received 5 points, 3 points if they reached the lip of the hole but did not go in (with some control over their pace), 2 points if they went past the hole (again, with some control over their pace), and 1 point if they finished short of the hole.

Figure 2 shows a meta-analysis, in the form of a Forest plot, for 6 studies (Hasegawa et al., 2020, Land and Tenenbaum, 2012, Pelleck and Passmore, 2017, Richardson et al., 2018, Sim and Kim, 2010, Wu et al., 2020) that compared elite vs amateur golfers club head velocity at impact (when striking the ball to the hole). Figure 3 displays a bar chart comparing Club Head Velocity at Impact (m/s) for Elite vs Amateur golfers. From the meta-analysis & bar chart it is shown that elite golfers have a slightly lower club head velocity at impact in comparison to the amateur golfers in all 6 studies. All 6 studies agree with one another's findings that elite golfers have a marginally slower, yet more controlled face angle at impact which enables them to putt more accurately and precisely which results in more putts being holed. However, despite this, there was no significant difference between elite and amateur golfers club head velocity at impact.

The findings suggest no significant difference between the velocities of the skill levels of the two groups of individuals and this needs further scientific research. Past research indicates that the optimal energy required to hit the 3 m putt is 1.42 m/s (Wu et al., 2020). Previous studies also show that elite golfers have less impact velocity than amateurs (Hasegawa et al., 2020, Land and Tenenbaum, 2012, Pelleck and Passmore, 2017, Richardson et al., 2018, Sim and Kim, 2010, Wu et al., 2020). It has, however, been suggested that these elite golfers have less skidding and a better ball roll when they hit the ball by an upward stroke. Thus, the study showed no difference in the impact velocity but indicated a difference in the upward stroke of how elite golfers hit the ball. The upward stroke can increase the topspin while reducing skidding and increasing the ball roll's general efficiency (Hasegawa et al., 2020). The rising angle determines the ball rolls at impact and the vertical impact shot. Research has shown that the upward rise of the ball and the vertical impact spot is likely to generate a better ball roll. The results on the impact of gravity were however, not collected. The elite golfer had the highest rise at the angle of impact. Both the professional and the elite players have a neutral angle lean, but the professional golfers were more experienced with putting techniques. Comparing various past studies indicated that the three types of golfers had different shafts at impact (Richardson et al., 2012, Wu et al., 2020). The amateur golfer in the study did not show significant velocity at impact. Hence it was possible to conclude that the elite golfers were the most efficient whilst the amateur golfers showed less efficiency. The differences were due to the low vertical point, the rise in angle and the shaft angle. The amateurs had a low vertical spot, less rise angle, and increased shaft angle – which increases the backspin, limiting the ball roll's efficiency.

The findings suggested that the backswing, the impact, and the downswing were the topmost essential skills. According to the articles, the professional has the shortest backswing and impact duration with the most extended downswing. Past research also shows that expert golfers have shorter backswing and more extended downswing displacement. Golf putting instruction emphasises the need for a neutral face angle.

The statistical analysis of the results displayed that from the 25 articles that were included, there was no significant difference between elite and amateur players and was indicated at the