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RESEARCH ARTICLE

Putting Performance and Kinematics Differ with Skill Level in Female Golfers

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Abstract:

Background:

Female professional golf tours are gaining popularity around the world; there are key performance factors that are related to high performance on the female professional tour, like “driving distance and accuracy” and “putting per round”. However, there is a lack of research on the putting kinematics of female golfers with a lack of understanding the differences between the skill levels of female golfers.

Objective:

This study aimed to assess the putting performance and kinematics across three skill levels of female golfers.

Methods:

A total of one hundred and forty-nine right-handed female golfers were divided into three groups based on their playing skill levels: 64 professional tour golfers, 46 national team level golfers, and 39 college level golfers. Each participant executed seven putts on a straight, three meter indoor artificial turf. The three-dimensional kinematic data of each putt were captured using a high-precision ultrasound system (70Hz*3) (SAM PuttLab, Science&Motion Sports).

Results:

Significant differences were found between the three groups of female golfers in the face angle at impact ($p<0.000$), putter path at impact ($p<0.000$), vertical impact spot ($p<0.000$), rise angle ($p<0.000$), backswing duration ($p<0.000$), impact duration ($p<0.000$) and downswing duration ($p<0.000$). Additionally, the female professional golfers were more efficient than amateurs golfers on putter path ($g=-.645$), vertical impact spot ($g=.707$), rise angle ($g=.878$), shaft angle ($g=-.602$), backswing duration ($g=-.512$), impact duration ($g=-.873$), and downswing duration ($g=.752$). There were no differences between skill groups with horizontal impact spot, velocity at impact, backswing displacement, downswing displacement and face rotation from the top of backswing to impact.

Conclusion:

Our findings concluded that female professional golfers have a precise face angle and putter path relative to the target, with an upward stroke through impact, and a high impact spot on the putter, a shorter duration of the backswing time and time to impact, and a longer downswing. The study did not find significant differences in velocity at impact and swing phase displacement between the skill levels, which were found in previous studies on male golfers. There were differences in putting kinematics found between female and male professional golfers. Overall, female professionals have better putting performance, more precise direction, and optimized putting distance parameter control. These findings can be used as a guideline for golf coaching of female golfers. Future studies can focus on different distances, slopes, and additional skill levels.

Keywords: Putting technique, Putting Kinematics, Putting performance, Female athletes, Professional golf, Sports skills.

Article History

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1. INTRODUCTION

The Olympics had little influence on golf participation, as

it only featured at the last Olympics, yet has been played centuries beforehand, and there is increasing awareness for professional female golf [1, 2]. In some Asian countries, there are more tournaments on the female professional circuit than the male circuit. Female professional golfers have higher

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socioeconomic status due to the popularity of the sport, prize money, and media exposure [2]. From 2005 to 2010, there was a significant increase in international winners of the Ladies Professional Golf Association (LPGA) [1], and this is influencing more women to enter the sport. According to the National Foundation of Golf (NFG) [3], there has been a steady increase of golfers in the US (30.1 million to 33.5 million from 2014 to 2018), and although female golfers' population has been steady (est. 5.6 million), there is a steady growth for junior golf participants, especially in females (36%).

A spectrum of golf skills to perform well professionally was evaluated in LPGA players in order to predict performance and chance of winning, including "driving distance and accuracy" and "putting per round" [4, 5]. Landerholm's [5] study indicated that the putting per round was one of the most critical factors to evaluate performance on the LPGA Tour, which accounts for 42% of all strokes (LPGA) [6]. In addition, putting is also a critical factor for earning ranking in male professionals playing on the Professional Golf Association (PGA) [7]. To make a successful putt, the golfer must interpret the green slope and hit the putt with optimal speed and direction. By doing the above, will result in the higher percentage of one-putt probability or holing success rate. A study by Broadie [8] on PGA Tour stroked gained metrics found that male tour players for one-putt probability of 50% were from eight feet while amateur golfers from five feet, while elite golfers (handicap from 0-10) on indoor level straight putts (3.2 m) proficiency ranged from 53-83% [8]. Past putting studies have focused on putting kinematics [9 - 11], which are the putting stroke and technique [12 - 14]. Typical aspects of the putting stroke are putter face angle, putter path direction, and a horizontal spot at impact, which are key influencers for the ball direction [12, 13, 15]. Putting distance control is also vital for putting performance. The optimal velocity for any distance, irrespective of gender, has to have enough energy to move the ball past the hole by 43 cm [15]. Therefore, energy transfer from putter to ball and optimized ball roll are vital indicators for the level of expertise. Putting distance is determined by putter velocity, the vertical spot from the center of the face, rise angle, and shaft angle at impact [13, 14]. Past researches have shown that skill level differs in impact velocity and utilizing backswing amplitude to achieve distance control [11, 14]. Additionally, researchers have tested with robotic arm, results suggested that impacting the ball with less effect loft can decrease skid and backspin [14]. Putter designs researches also review that a vertical impact spot above the sweet spot or the center of gravity of the putter can take advantage of the vertical gear effect, which can also decrease skid length [14].

It has been shown previously that the contributions to the direction in male putting strokes are putter face angle (80%), putter path (17%), and impact spot (horizontal) (3%) for distances ranging from 3-4 m [12, 13]. Findings on professional male golfers' putting parameters relative to target were 0.3-0.5° for face angle, 0.8° for putter path, and 1.6-2.9 mm off-set for horizontal impact spot from the face center [12, 13, 16]. Past findings suggest that the impact vertical height of impact spot on the putter face [15, 17] and rise angle at impact [14] could enhance ball roll efficiency. Many putting

proficiency literatures use putting kinematics [12 - 14] and putting performance parameters [12, 13, 17, 18] to compare various skill levels.

Past studies on expert level golfers between genders were mainly focused on the driving [19 - 22] as opposed to putting. Researches on female expert-level golfers have been mainly focused on swing characteristics of driver shot [23], assessment between clubs [24], fitness and strength [25, 26], physiological characteristics [27] and biomechanical analysis of golf swings [28]. Findings from these studies suggested that expert-level female golfers have a higher level of physical fitness (left hand grip strength, maximal strength, muscle endurance, isokinetic trunk strength, and peak power), lower cardiac fat percentage [27], and longer driving distances [29]. Current putting researches on professional players have been limited and predominantly focus on male golfers [12, 13], and limited to comparison between male's different skill levels [14]. Previous findings suggested that expert male golfer slows club head velocity at impact, and an upward rise angle at impact position [13, 14]. However, research on female golfers' putting performance have been very limited, and only a few studies included female golfers with a gender ratio of less than 20% [12, 14]. There has not been a putting study that compares putting between professional female golfers, nor a study comparing these golfers with other skill levels. Thus, it is important to identify the kinematic differences between the female skill levels and then implementing the appropriate techniques for putting performance enhancement.

The purpose of this study was to compare three skill levels of female golfers' putting performance based on their putting kinematics. It is hypothesized that significant differences between female golfers across the skill-levels will be found.

2. MATERIALS AND METHODS

2.1. Subjects

A total of 149 right-handed female golfers participated in this study and were divided into 3 groups based on their skill and playing levels. The professionals were all tour-level golfers (Professional) who competed on tour, 3 played on LPGA, 4 played on Symetra Tour, 2 on Ladies European Tour (LET), and rest on the professional tours in Asia. The elite group was either first or second national team squad players (Elite). The amateur group was college golf team golfers (Amateur).

All participants were free of musculoskeletal injury for a minimum of 3 months and played a minimum of 1 round per week. Participants wore their own golf shoes and used their personal putters. All participants provided written informed consent before the experiment. Participant demographics are presented in Table 1.

2.2. Procedures

Participants were allowed 10 minutes to warm up and to practice before trials. Participants then performed their pre-shot routine and putted as in a tournament, and the 3D putting data were captured. Each participant was asked to perform 7 putts in a row [13].

Testing was conducted on an indoor artificial putting green (4.5 m × 1.5 m), registering 10 on the stimpmeter (The United States Golf Association, Far Hills, NJ, USA). The putting green was level and straight to minimize green reading, and green consistency was verified using a ball ramp device. The Perfect Putter (The Perfect Putter LLC, Jacksonville, FL, USA) registered 4 × 10 trials from the intended test location, where no-miss was recorded. Putting distance was 3 m to the front lip of the hole.

Table 1. Means and standard deviations for age, height, and weight for three groups of female golfers.

	<i>N</i>	<i>Age (yr)</i>	<i>Height (m)</i>	<i>Weight (kg)</i>
<i>Professional</i>	64	26.55±3.90	1.62±0.04	55.23±3.97
<i>Elite</i>	46	21.02±2.07	1.63±0.02	50.32±3.81
<i>Amateur</i>	39	19.92±2.13	1.58±0.04	49.25±2.89

Participants used their own putters for the test, and ProV1 golf balls (Acushnet, New Bedford, MA, U.S.) were used for this study. The 3-dimensional putting data were recorded using the high-precision ultrasound system SAM PuttLab (Science & Motion Sports GmbH, Flörsheim, Germany), mounted on the SAM Station to a secure leveled setup, perfect alignment to the target, and minimum variability of the putting data. A transmitter with 3 sensors was clipped onto the putter shaft, and data frequency is 70 Hz for each sensor. The putter was calibrated to the target line using the SAM PuttStation, where the reference frame is the theoretical center of the putter face, as illustrated in Fig. (1). The kinematic 3D data were analyzed by SAM PuttLab 6 software, which included specific algorithms for analyzing human movement data [30]. Past research suggested that the accuracy of SAM PuttLab was 0.1mm and 0.1° [13]; SAM PuttLab testing on a robot showed

0.1mm and 0.09° over 2x20 putts [31].

2.3. Calculation of Kinematic Variables

The negative x-axis was from the center of the putter face along the initial direction of the putt and was coincident with the target line. The positive y-axis extended parallel to the ground away from the golfer, and positive z-axis extended vertically up from the ground, according to the right-hand-rule [32]. The face angle was calculated in the x-y plane, which was perpendicular face angle relative to the target line and recorded at address position and impact with the ball. Putter path was in the plane parallel to the ground and defined as the angle between the putter head velocity vector to the target line at impact. The face center was defined as geometric center of the putter head, defined by alignment marking on the putter head and calibrated to the target line. The horizontal spot was the face impact position along the heel-toe axis or y-axis of the putter. Velocity at impact was defined as the velocity of the putter face center along the x-axis at the impact position. The vertical spot was defined as the distance from the putter face center on the z-axis at impact. The rise angle was defined by the angle of the movement of the putter head relative to the z-axis plane at the impact position. The shaft angle was defined as the z-axis or the vertical position of the shaft at impact.

The putting phases were divided into three key phases, backswing phase (address to top-of-backswing), impact phase (top-of-backswing to impact) and follow-through phase (impact to finish) which combines the downswing phases. Putting kinematics were collected from these three phases (backswing, impact, and downswing), and two displacement data (backswing and downswing). Rotation to impact was the face angle degree change from top-of-backswing to impact. Putting proficiency was the percentage of successful putts made. The measurement conventions are illustrated in Fig. (2).

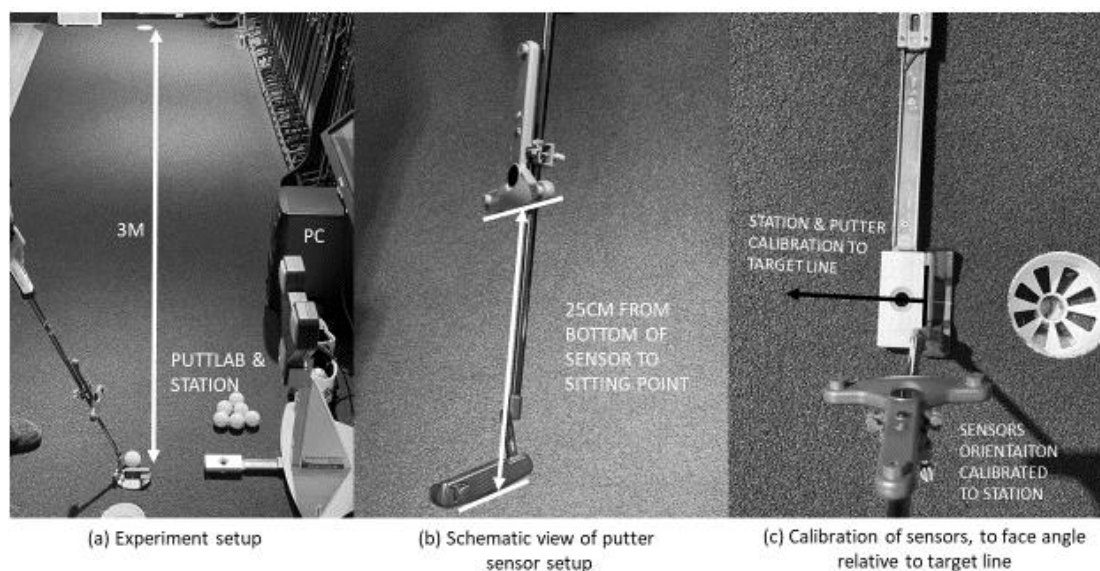


Fig. (1). (a) Illustration of experimental setup of the starting position, PuttLab, Station orientation; (b) Illustration of sensors calibration on putter; (c) Illustration for sensors on putter relative to target orientation.

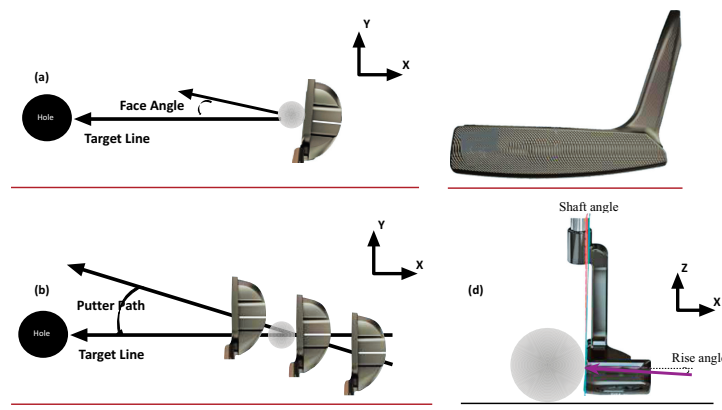


Fig. (2). (a) Face angle measurement convention. (b) Putter path measurement convention. (c) Horizontal and vertical impact spot on putter face measurement convention. (d) Rise angle and shaft angle at impact measurement convention.

2.4. Statistical Analysis

All data were exported to the statistics software package SPSS 23 (SPSS Inc., Chicago, IL., USA) and analyzed using one-way ANOVA. The significance level was set at $\alpha < 0.05$. The post-hoc analysis used LSD for analysis. Additionally, we calculated the effective-size indices. All results were presented as standard deviation errors to the mean unless stated otherwise. Effect sizes were reported as Hedge's *G* due to unequal sample sizes between the three groups [32].

3. RESULTS

Female Professionals have the highest holing success rate (67.8%), followed by Elite golfers (60.2%), and then Amateur (54.6%). The data on aiming suggested that the three skill levels had similar accuracy for face angle at address ($p < 0.000$, $F = 17.200$). The results for face angle at impact showed significant differences between the groups ($p < 0.000$, $F = 142.284$), whereas female professionals have the least deviation from the target direction. The putter path was also significant ($p < 0.000$, $F = 71.141$), professionals with the least deviation from target. The horizontal impact spot was not significant ($p = .181$, $F = 1.714$), whereas Amateur golfers were the most deviated from target.

Results suggested that putter velocity at impact was not significant ($p = .001$, $F = 6.899$). The Amateurs have the higher velocity than the other two groups. Vertical impact spot at impact was significant between groups ($p < 0.000$, $F = 32.349$). Professionals had the highest vertical spot while Amateurs were the lowest. The rise angle at impact was significant between groups ($p < 0.000$, $F = 82.353$). Professionals have the most upward stroke compared with the other two groups. For shaft angle at impact, there were differences between the groups ($p < 0.000$, $F = 38.732$). The Amateurs golfers tend to increase their shaft lean angle at impact.

Putting kinematics results suggested that there were significant differences between the backswing duration ($p < 0.000$, $F = 25.755$), impact duration ($p < 0.000$, $F = 49.929$) and downswing duration ($p < 0.000$, $F = 40.535$). Findings suggested that female professional golfers have shorter backswing and impact duration and longer duration compared with the other two groups. Both displacement in the backswing ($p < 0.000$, $F = 15.710$) and downswing ($p = .060$, $F = 2.821$) were

not significant between groups. Lastly, the face angle rotation from the top of the backswing to impact ($p = .976$, $F = .024$) was not significant between groups. The mean and deviations for putting kinematics variables of the three skill levels are listed in Table 2

4. DISCUSSION

Results of this study found that there was a difference in putting performance and kinematics between skill levels of female golfers, similar to their male counterparts [11, 14]. Holing success was highest for Professionals, followed by Elite, and the lowest holing success for Amateurs. There was limited information for female tours, unlike the PGA Tour, which has ShotLink to capture every shot [8]. Our results were higher than PGA Tour averages (15%). However, our results were similar to the indoor experiment setup for elite (handicap 0-10) male golfers (52-83%) [34]. Our results suggested that indoor turf level straight putt setup could have minimized key external influence factors, like green turf unevenness and green reading technique, also participants can benefit from putting repeatedly from the same location. Therefore, we concluded that the holing success rate can be used as determinate for skill level, which means that holing success rate can be used as a benchmark for the future indoor experiments. Lastly it would be worth exploring future studies to evaluate putting performance from various distances and breaks.

Our researches suggested that putter face angle at address was not significant between the skill levels. Based on previous researches, face angle at impact is the most influential factor for initial direction (80%) [12, 13] which suggested that the angle for initial deviation from target for female Professional was 0.27° , 0.60° for Elite, and 0.63° for Amateur. It was also concluded that the Professionals have better control of the face angle during backswing and impact, in order to limited deviation. The stroke path was the second determinate and accounted for 17% of the initial direction [12, 13, 15] which was 0.04° for Professionals, 0.23° for Elite, and 0.29° for Amateurs deviation from the target line. Karlsen *et al.* [12] suggested that horizontal impact point variability for male professional players was 2.72 mm, which was similar to our findings for female professionals. Additionally, the impact spot from the face center for the three skill levels was negligible for missed putts, as it was all within 10 mm tolerance for direction

deviation [14]. Comparing genders at the professional level, both sexes showed similar accuracy with slightly right-of-target, face angle at impact (0.34° vs. 0.3°-0.5°), and close to face center at horizontal impact spot (1.7 mm vs. 1.6-2.9 mm). The female professional golfers exhibited better accuracy of the putter path to the target line (0.23° vs. 0.8°) than male professional golfers [12, 13]. In general, Professional golfers have precision at impact for the face angle and horizontal impact spot, and females have less deviation path angle to target [12, 13]. Overall, female professional golfers have higher holing successful rate, and higher precision of the face angle at impact and putter path relative to the target line. We concluded that the face angle at impact and putter path angle are were determinate factors among skill levels

Our findings suggest no differences in impact velocity between skill levels for female golfers, unlike the male [10, 13] A reason could be the differences in skill levels between the studies which should be explored in future studies. Past research suggested that optimal energy to hit 3-m putts would require approximately the velocity of 1.418 m/s [14], which matches our findings (1.40-1.42 m/s). Previous studies indicated that expert golfers have less impact velocity [11, 14] compared with novices. However it has been suggested that expert level golfers have less skidding [11] and better ball roll by an upward stroke and vertical impact above the sweet spot [14]. Our study has found no difference in impact velocity, but did find a different pattern of putting stroke with an upward rise angle and high vertical impact spot for Professionals. An upwardstroke and hitting above sweet spot could increase more topspin and decrease skidding of ball roll, and thus increase efficiency in ball roll [14, 18]. Past research concluded that the ball launch and ball roll (spin) are determined by the putter’s effective loft, vertical impact spot and the rise angle at impact

[13], whereas effective loft parameter is determined by the putter loft together with the vertical shaft angle at impact. Brouillette [17] suggested an upward rise angle and high vertical impact spot will generate better roll ratio or “top-spin”-like putting technique. Despite this, the characteristics of each putter (loft, center of gravity) were not collected. However, considering that the industry standard for putter loft angles design has small deviations(3-4°), parameters like vertical impact spot, rise angle, and shaft angle parameters can be used to determine ball roll efficiency (skid). Results suggested that vertical impact spot can be used to determinate, and the highly skilled golfers tend to putt vertically higher above sweet spot. Additionally, the Professionals also have the highest rise angle at impact. Both Professional and Elite have a more neutral-shaft- angle- lean- at impact [10, 13, 14] than the Amateurs. Professional golfers were most efficient with putting techniques, *i.e.*, rise angle and vertical impact spot. Comparison between past researches suggested that both genders have a neutral shaft angle at impact (0.10° vs. 0.0°) [13]; while female professionals have higher vertical impact spot (7.3mm vs.4.9mm) and also more upward rise angle than male (3.92° vs. 2.80°) [13]. Overall, the Professionals have the highest vertical impact spot from the face center with an upward rise angle, which increases the vertical gear-effect and ball roll efficiency [16, 18]. Interestingly, our findings supported a similar trend for full swing, whereas the LPGA professionals have higher efficiency from clubhead speed to ball speed by utilizing more upward swing (positive attack angle) than PGA professionals [29]. Surprisingly, the Amateur golfers in our study did not show significantly higher velocity at impact We concluded that Professional golfers were the most efficient, the Amateurs showed less efficiency due to lower vertical spot, less rise angle, and increased shaft angle, which will increase backspin, causing a decrease in ball roll efficiency.

Table 2. Means and standard deviations of putting kinematics for professional, elite and amateur female golfers.

Parameters	Professional	ES ^{1&2}	Elite	ES ^{2&3}	Amateur	ES ^{1&3}
Face angle at address (°)	0.23±1.06	.001	0.24±1.21	.339	-0.27±1.77	.362
Face angle at impact (°)	0.34±1.07	.348	0.75±1.30*	-.030	0.79±1.37*+	-.375
Putter path (°)	0.23±1.84	.487	1.21±2.20*	-.191	1.69±2.79*+	-.645
Horizontal spot (mm)	-1.70±3.71	-.154	-2.30±4.11	.106	-2.74±4.13	.267
Velocity impact (m/s)	1.40±0.06	.000	1.40±0.06	-.306	1.42±0.07	-.310
Vertical Spot (mm)	7.33±2.09	-.391	6.26±3.41*	.221	5.53±3.12*+	.707
Rise (°)	3.92±1.25	-.865	2.74±1.49*	.089	2.59±1.85*	.878
Shaft angle (°)	0.10±1.33	.119	0.17±1.53	-.514	1.19±2.38 ⁺	-.602
Backswing duration (sec)	0.75±0.08	.497	0.79±0.08*	-.099	0.80±0.12*+	-.512
Impact duration (sec)	0.32±0.03	.575	0.34±0.04*	-.248	0.35±0.04*+	-.873
Downswing duration (sec)	0.91±0.08	-.589	0.86±0.09*	.199	0.84±0.11*	.752
Backswing displacement (m)	0.21±0.03	.288	0.22±0.04	.000	0.22±0.04	-.291
Downswing displacement (m)	0.62±0.08	.000	0.62±0.08	.117	0.61±0.09	.118
Rotation to impact (°)	4.30±1.61	.006	4.31±1.83	-.010	4.33±2.05	-.002

Significance level was set at $\alpha < 0.05$

*statistically significant with Professional female golfers

+ statistically significant with Elite female golfers

ES^{1&2} Hedge’s G effective size between Professional and Elite female golfers

ES^{2&3} Hedge’s G effective size between Elite and Amateur female golfers

ES^{1&3} Hedge’s G effective size between Professional and Amateur female golfers

Our findings suggested that backswing, impact and downswing duration were significant among three skill levels. The professionals have the shortest backswing and impact duration while the Professionals' downswing duration was the longest. Comparing professional skills among genders showed that female professionals have longer backswing duration (0.75 s vs. 0.67 s), and downswing duration (0.91 s vs. 0.82 s) while similar with impact duration [13, 14]. Past researches suggested that expert golfers have shorter backswing displacement and longer downswing displacement [13, 14], while no differences were found between three female skill level golfers. Comparing gender differences at the professional level, females have shorter displacement with their backswing (0.21 m vs. 0.24 m) and downswing (0.62 m vs. 0.67 m) [14]. Golf putting instructions have emphasized keeping the face angle neutral to the path [15]. This can help to create a more consistent natural face rotation on a tilted plane [14]. There were no significant inter-group differences for rotation impact or the degree of face rotation from backswing to impact. Female professional golfers have a larger angular rotation from impact than males [13]. We concluded that the critical putting kinematics to determinate skill levels for female golfers are the backswing, impact and downswing duration.

Our study is one of the first studies to analyze putting kinematics in female professional golfers, and comparing them with other skill levels, *i.e.*, national team level and college level golfers. These findings will promote understanding of the development of skills in order to achieve professionalism.

4.1. Limitations

Putter characteristics, ball parameters, and putting styles of each player were not collected, which could influence the variability in putting kinematics across all groups. Future studies should include ball parameters like ball velocity, launch direction, and roll ratio for further analysis. Additionally, adding various distances and adjusting various slope settings would also help to replicate a tournament setting.

CONCLUSION

This is one of the first studies to analyze golf putting proficiency and putting kinematics of female professional golfers and compare different skill levels. We established that face angle at impact, putter path, rise, vertical impact spot, backswing, impact and downswing duration are the critical determinates in putting kinematics for female golfers. Female professional players have optimized putting kinematics, with accurate direction and distance parameters control, like face and path, neutral shaft angle, upward rise angle, and high vertical impact spot. Findings will provide coaching guidelines to improve putting performance based on skill level. Female professional golfers have a more accurate putting stroke and optimize their technique more efficiently than males. However, a further exploratory study should be conducted to continue these evaluations.

LIST OF ABBREVIATIONS

LPGA = Ladies Professional Golf Association
PGA = Professional Golf Association

NFG = National Foundation of Golf

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals were used for this study. All humans research procedures performed in the current study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

CONSENT FOR PUBLICATION

All participants were informed about the protocol and gave their written informed consent before participating in the study.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declared no potential conflict of interest concerning the research, authorship, and publication of this article.

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