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The stroke has only a minor influence on direction consistency in golf putting among elite players

JON KARLSEN[1], GERALD SMITH[1], & JOHNNY NILSSON[1,2]

[1]*Norwegian School of Sport Sciences, Oslo, Norway and* [2]*Swedish School of Sport and Health Sciences, Stockholm, Sweden*

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Abstract
In the golf instructional literature, the putting stroke is typically given higher priority than green reading and aiming. The main purpose of this study was to assess the importance of the putting stroke for direction consistency in golf putting. Kinematic stroke parameters were recorded from 71 elite golf players (mean handicap = 1.8, $s = 4.2$) on 1301 putts from about 4 m. Of the different factors deciding stroke direction consistency, face angle was found to be the most important (80%), followed by putter path (17%) and impact point (3%). This suggests that improvements in consistency of putter path and impact point will have very little effect on overall putting direction consistency and should not be prioritized in the training of elite players. In addition, mean stroke direction variability for an elite player (European Tour) was found to be 0.39°, which is good enough to hole about 95% of all 4-m putts. In practice, however, top professionals in tournaments only hole about 17% of 4-m putts. We conclude that the putting stroke of elite golfers has a relatively minor influence on direction consistency.

Keywords: *Golf putting, stroke direction consistency, elite players, putting stroke, face angle*

Introduction

Accomplished golf performance depends on abilities in driving, wood play, iron play, short game, and putting. Alexander and Kern (2005) found that putting ability was the most important skill in determining earnings on the Professional Golf Association (PGA) Tour. At the highest professional level, about 43% of strokes are taken with the putter (Pelz, 2000). In the instructional literature on putting, stroke technique is afforded high priority. Other factors, such as aiming and green reading, have not received so much attention. However, instructional literature on putting is often perceived as anecdotal and based on observations by top coaches and players, rather than on published scientific research.

Direction in the putting process can be divided into four phases, each of which contributes to overall putting direction variability. In chronological order, they are as follows: green reading, aim, stroke, and ball roll. Because of inconsistencies in the surface of greens, the ball roll will contribute to the overall direction variability, but this cannot be controlled by the player. Green reading is the process of finding the correct initial ball direction by evaluating surface and topographical characteristics of the green. The goal of aiming is to place the club face square to the correct line of initial ball direction (aim line). In terms of direction, the purpose of the stroke is to start the ball on the actual aim line. The direction of the stroke is determined by the face angle at impact, the putter path at impact, and the horizontal point of impact on the putter face (Figure 1). The direction outcome of the stroke is most important on short putts. An overview of the main factors that determine putting direction is given in Figure 2.

The purpose of the present study was to determine the importance of the stroke (in chronological order, the third of the above four factors) for overall putting direction. We also examined the determinants of stroke direction consistency and how different stroke characteristics affect stroke direction consistency.

Top professional players have a very tough schedule that includes many tournaments and a lot of time-consuming travelling. Hence, it is important to prioritize during training. To do this, it is essential to understand the relative importance of the factors that affect performance. This will save players from spending a lot of time practising skills that have very little impact on performance. However, the relative importance of the factors that affect putting direction performance is an under-researched topic. Tierney

Correspondence: J. Karlsen, Norwegian School of Sport Sciences, PO Box 4014, Ullevål Stadion, NO-0806 Oslo, Norway. E-mail: jon.karlson@nih.no

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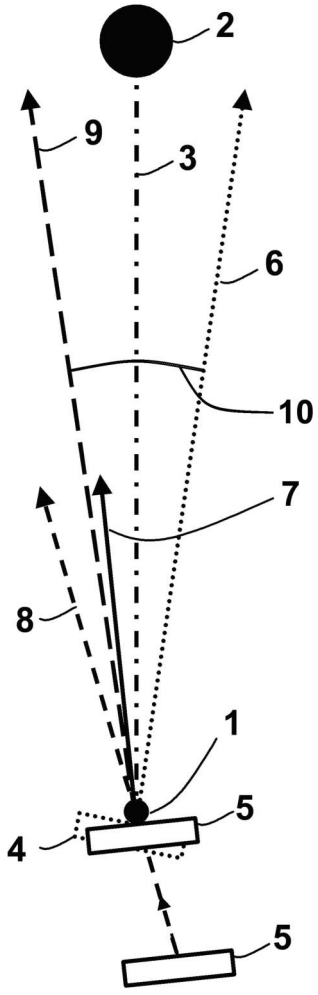


Figure 1. Schematic representation from above of the different parameters relevant for aim and stroke: (1) ball; (2) hole; (3) ball–hole line; (4) putter head at address; (5) putter head in downswing and at impact; (6) actual aim line; (7) face angle direction at impact; (8) putter path direction; (9) initial ball direction, which is decided by face angle, putter path, and impact point; and (10) stroke deviation angle.

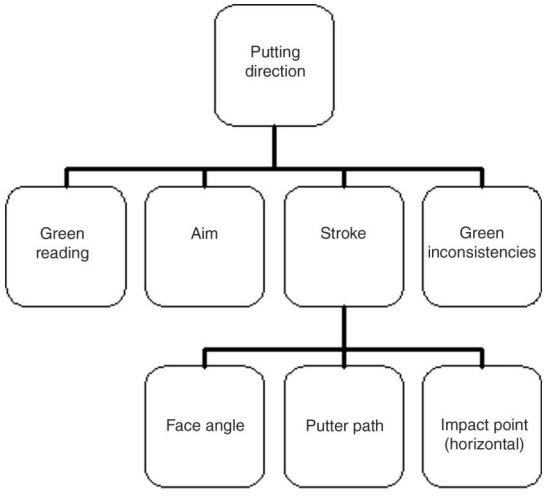


Figure 2. The main factors that affect putting direction.

and Coop (1998) reported the mean direction deviation in PGA Tour veterans to be 1.3% of the putting distance. Karlsen (2003) reported mean putting deviation for eight elite players to be 1.8% during repetitive putts on a flat indoor green. Pelz (2000) noted that about 17% of putts from 4 m are holed in PGA tournaments. Since there is some tolerance for distance errors on 4-m putts, direction is considered to be the main obstacle for holing such putts. In addition to human-controlled factors, inconsistencies in the green, and to a certain extent wind inconsistencies, will also affect directional performance. Using a device that could roll balls at constant speed and direction, Pelz (1989) measured the inconsistency of greens, and found that 84% of all putts from 12 feet (3.7 m) went in the hole on a green that was considered to be in excellent condition. At another golf course, Pelz found that 73% of the balls rolled into the hole in the morning before play, but after a day of play only 30% were holed.

Determining factors of stroke direction – face angle, putter path, and impact point

The direction outcome of the stroke is determined by three factors: face angle at impact, putter path, and impact point on the club face. Mechanically, we know that the face angle affects the direction more than the putter path. According to Pelz (2000), the face angle will determine 83% of initial direction, while the putter path counts for the remaining 17%. To determine the direction deviation from horizontal off-centre hits, 10 well-known putter brands were tested in a putter pendulum rig using the method described by Nilsson and Karlsen (2006). Using the putter pendulum rig, we were able to determine with accuracy club head velocity, face angle, putter path, and impact point on the club face at impact, as well as measure initial ball direction and velocity. With an average putter, horizontal miss-hits (toe–heel direction) made the ball deviate 0.034° per millimetre miss-hit from the sweetspot (J. Nilsson & J. Karlsen, unpublished raw data). Karlsen and Nilsson (2002) reported variability in face angle, putter path, and impact point of eight elite players to be 0.5°, 0.8°, and 2.9 mm respectively, but that was relative to the target direction. In other words, these measurements did not separate aiming from the stroke. To our knowledge, no research has reported variability in putter path and face angle relative to the direction of aim of each putt.

How stroke characteristics affect stroke direction consistency

Coaches and players are always searching for things that can improve performance. There is limited

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scientific research that can be used as a guide for optimal stroke making. Parameters perceived to be important for stroke direction consistency, and of relevance for coaches and players, were chosen for further analysis in the present study.

An ongoing debate concerns what the putter path and face angle should be throughout the stroke. DeGunther (1996) and Pelz (2000) advocate a putting stroke where the path is linear and the club face is square to the path (and the aim line) throughout the stroke. This view has been adapted by many top coaches and players. An opposite view is supported by several researchers and coaches, including Brooks (2002) and Harold Swash (www.haroldswashputting.com, 20060228). They advocate a stroke where the putter head moves inside the aim line in the backswing, and where the club face is square to the putter path, which means that the putter face is open to the aim line at the end of the backswing. Pelz's argument for having the putter face square throughout the stroke is that timing limitations result in the inability to square the club face exactly at impact. The main argument against Pelz's view is that the straight stroke is biomechanically complicated, since it relies on a fully horizontal axis of rotation for the putter, or muscle activity that compensates for deviation from a horizontal axis. Karlsen (2003) reported that upper-body rotation around the spine is the major motor in putting for elite players, contributing 70% to the club head speed at impact. Keeping the spine in a position so that the axis of rotation for the putter is horizontal requires a very forward bent address position, which is very rarely seen. Therefore, a straight putter path, for most players, must involve some kind of compensation that can be said to complicate the stroke.

Another part of the stroke technique that has received a lot of attention is the spatio-temporal characteristics of the putter head throughout the stroke. Many coaches advocate a putting stroke where the putter has positive acceleration at impact (e.g. DeGunther, 1996; Pelz, 2000). Positive acceleration at impact is often related to a stroke length ratio greater than one. The stroke length ratio has been defined as the horizontal length of the follow-through divided by the horizontal length of the downswing to impact. The stroke length ratio is more commonly used in golf teaching, as it is easier to visualize than acceleration. Delay and colleagues (Delay, Nougier, Orliaguet, & Coello, 1997) compared elite and novice players and found that elite players had higher stroke length ratios (1.88 – 2.23) than novices (1.14 – 1.28) on putts of 1 – 4 m. Karlsen (2003) found that eight elite players had stroke length ratios of 2.35, 2.17, and 1.78 on putts of 2 m, 8 m, and 25 m respectively. Pelz (2000) recommends a stroke length ratio of 1.2 independent of putting distance. No coach or scientist known to us advocates a stroke with deceleration before impact and a stroke length ratio < 1.

The tempo of the stroke in terms of the duration of the downswing to impact is also often focused upon in putting instruction. Delay *et al*. (1997) found downswing time in expert players to be 261 – 289 ms on putts of 1 – 4 m. Karlsen (2003) found no differences in downswing time on putts of 2 m (305 ms), 8 m (312 ms), and 25 m (297 ms) for elite players. A quick downswing will involve larger accelerations, and could therefore be hypothesized to influence consistency negatively. In addition, a very long downswing time is often considered by coaches to be less successful, as it is perceived to be a result of excessive control of the movement, and thus it would not be considered an automatised response. No research to date has evaluated downswing time in relation to direction consistency.

Methods

Participants

Seventy-one elite golfers participated in the study. Their mean handicap and age was 1.8 ($s = 4.2$) and 21.7 years ($s = 7.1$) respectively. Twenty-six of the players were professionals, 10 of whom had played tournaments at the highest professional level in Europe or the USA. The professionals' handicaps were estimated from tournament results in the 12 months before the study. All players had a handicap of less than 10.

Apparatus

Putting parameters were recorded with a three-dimensional kinematic ultrasound system (SAM PuttLab, Science & Motion GmbH, Mainz, Germany, www.scienceandmotion.de). A triplet with three 70-Hz ultrasound transmitters, which emitted signals to a base unit, was attached to the putter. The system was calibrated according to the user manual, and data were processed and analysed using the SAM PuttWare Pro version 1.1 software. Because the players were anticipated to show little variability in putting technique, the system was tested for reliability in face angle, which is the most important putting direction parameter. One putter was mounted in a putter pendulum rig that is able to reproduce the face angle very well (Nilsson & Karlsen, 2006). The test included 2×20 strokes and variability – calculated as the standard deviation in face angle at an impact position – was recorded as 0.09° and 0.10° for the two series. This variability was much less than that measured on the players (mean $= 0.59^\circ$). Therefore, the SAM system was assumed to be reliable for the recordings in the present study.

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Test procedure

Data were recorded both indoors and outdoors, on flat and relatively fast greens. The players were instructed to strike the ball as consistently as possible for distance and direction to a target that was either a hole on the green or a painted hole on a putting mat. They hit the balls using their chosen inter-stroke tempo with their own putter. The mean number of trials was 18.3 ($s = 5.1$) with distance range 3–4 m. The small variations in range and number of trials were considered to have an insignificant influence on the outcome of this study. Mean club head speed at impact was 1.40 $m \cdot s^{-1}$ ($s = 0.25$). Hence, there were no major differences in stroke intensity between the players.

Calculation of stroke direction variability

The intended direction for each stroke was defined as the direction where the putter head (face angle) was aimed when addressing the ball before starting the backswing (actual aim line). Because of the players' inability to aim consistently, the aim line differed from stroke to stroke even though the target was the same. Variability in face angle and putter path was expressed as the standard deviation (s) in degrees. Variability in horizontal impact point was expressed as the standard deviation (s) in millimetres.

Effective variability was calculated by multiplying variability by known coefficients of how much each parameter affects initial direction [effective variability = face angle variability · 0.83 (Pelz, 2000), putter path variability · 0.17 (Pelz, 2000), and impact point variability · 0.034 degrees · cm^{-1} (J. Nilsson & J. Karlsen, unpublished raw data)]. Based on the effective variability of face angle, putter path, and impact point, and the covariance between each pair of parameters, stroke direction variability (which equals variability of the stroke deviation angle in Figure 1) for each player was calculated using the following equation (for a detailed example calculation, see the Appendix):

$$\begin{aligned}\text{stroke direction variability} = [&\text{effective variance}_{\text{face angle}} \\ &+ \text{effective variance}_{\text{impact point}} \\ &+ \text{effective variance}_{\text{putter path}} \\ &+ 2 \cdot (\text{covariance}[\text{face angle, impact point}] \\ &+ \text{covariance}[\text{face angle, putter path}] \\ &+ \text{covariance}[\text{impact point, putter path}])]^{-2}\end{aligned}$$

Calculation of the relative importance of face angle, putter path, and impact point

How much a certain improvement in the variability of one of the three parameters (face angle, putter path, and impact point) affected overall stroke direction consistency (relative to each other) was defined as each parameter's relative importance for stroke direction consistency. The relative importance was expressed as a percentage, with the total relative importance of the three parameters equal to 100%. A detailed example calculation is provided in the Appendix.

Stroke characteristics

Based on the perceived relevance for teaching in putting, four parameters were selected for analysis of how they were related to stroke direction consistency. *Face rotation* in the downswing was defined as the difference between the club face angle at the end of the backswing and at impact. *Face change* was defined as the difference between the face angle at address and at impact. *Downswing time* was defined as the time taken from the end of the backswing to impact. The *stroke length ratio* was defined as the horizontal length of the follow-through divided by the horizontal length of the downswing.

Because we assumed that there was an optimum value for each parameter, a quadratic regression model was used to analyse how these four parameters affected stroke direction consistency, with the minimum of the 2nd degree equation used to describe an optimum characteristic (Statistical Package for Social Sciences 11.0, SPSS Inc., USA).

Results

Stroke direction consistency

Stroke direction variability was on average 0.59° ($s = 0.22$). The lowest variability of a single player, who was a PGA European Tour player, was 0.28°. According to the regression model in the present study (Figure 3), an average European Tour player

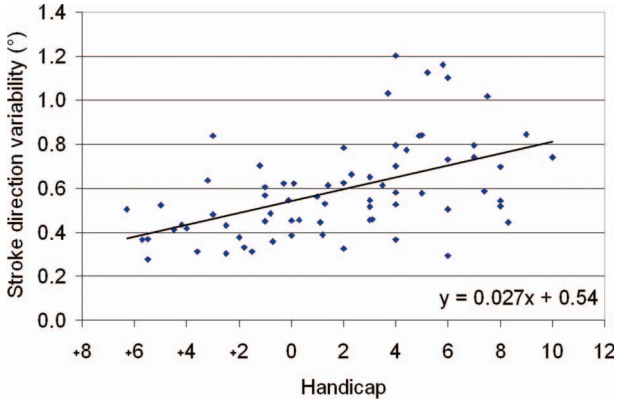


Figure 3. The stroke direction variability of all 71 players relative to their handicap. The regression line and regression equation are included.

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(handicap $\sim +5.5$) had a stroke variability of 0.39°. Regression analysis showed that stroke direction consistency was related to playing handicap ($P < 0.001$) (Figure 3).

Factors determining stroke direction consistency – face angle, putter path, and impact point

Our elite players were more consistent in face angle than in putter path ($P < 0.001$), with mean variability of 0.60° ($s = 0.22$) and 1.04° ($s = 0.38$) respectively. Horizontal impact point variability was 2.72 mm ($s = 0.78$). Because face angle errors have a greater effect on direction than putter path errors, the effective variability of face angle was much higher than for putter path. The effective variability of face angle, putter path, and horizontal impact point was 0.50°, 0.18°, and 0.09° respectively (effective variability = face angle variability $\cdot$ 0.83, putter path variability $\cdot$ 0.17, and impact point variability $\cdot$ 0.034 degrees $\cdot$ mm^{-1}). The relative importance of the three parameters regarding stroke direction consistency were 80% for face angle, 17% for putter path, and 3% for horizontal impact point (Table I).

Stroke characteristics

Four parameters were tested with a quadratic regression model to determine optimum values for stroke direction consistency. The regression models were significant for three parameters: face rotation in the downswing ($P < 0.001$), face change from address to impact ($P < 0.001$), and downswing time ($P < 0.001$). According to the regression models, the optimum stroke with respect to stroke direction consistency had a face rotation in the downswing of 1.6°, face change of 0°, and downswing time of 325 ms.

The quadratic regression model for stroke length ratio and stroke direction variability was not significant ($P = 0.13$). Regression models and equations for all four parameters are given in Figure 4.

Table I. Variability, effective variability, and relative importance of face angle, putter path, and horizontal impact point for stroke direction consistency (mean $\pm$ *s*).

	Face angle	Putter path	Impact point
Variability (*s*)	$0.60 \pm 0.22^\circ$	$1.04 \pm 0.38^\circ$	2.72 ± 0.78 mm
Effective variability (*s*)	$0.50 \pm 0.18^\circ$	$0.18 \pm 0.06^\circ$	0.09 ± 0.03 mm
Relative importance for stroke direction consistency	80%	17%	3%

Discussion

The importance of the stroke for putting direction consistency

The putting instructional literature contains anecdotal information that is perceived to prioritize the putting stroke. However, the findings of the present study show that, in general, the direction variability of putting strokes is very low: mean stroke direction variability of all players in the present study was 0.59°. According to the regression model, the mean stroke direction variability of top professional players was about 0.39°. A stroke with direction variability of 0.39° will only miss approximately 5% of putts from 4 m (assuming everything else is perfect). In tournaments, top professionals miss about 83% of all putts from 4 m (Pelz, 2000). This clearly suggests that the stroke itself is of little importance for direction performance in putting. This is in sharp contrast to the perceived priorities in the putting instructional literature.

This raises the question of what the limiting factors for holing 4-m putts are. Research on green inconsistencies is limited, but such inconsistencies do not appear to be the main factor why professionals miss 83% of 4-m putts. A reasonable assumption based on Pelz's (1989) data, with everything else but the greens being perfect, is that about 30% of all putts from 4 m will miss because of green inconsistencies.

The present study does not allow conclusions to be drawn about which of the human-controlled factors (green reading and aiming) is more important for direction consistency in putting, but one or both of these factors seems to influence direction variability much more strongly than stroke kinematics.

Determining factors of stroke direction consistency – face angle, putter path, and impact point

Of the different components of stroke direction, face angle is the most important. A 10% improvement in consistency of the face angle will result in an improvement in stroke direction consistency of $\sim$8%. A 10% improvement in consistency of the putter path and impact point will result in an improvement in stroke direction consistency of 1.7% and 0.3% respectively. We observed some significant interactions between face angle, putter path, and impact point. Some players also closed the club face when the putter path was outside-in. This can be considered a negative interaction, since the negative effect of an outside-in stroke was magnified by the closing of the club face. Thus, it could be argued that the putter path is of greater importance, because it could affect the club face

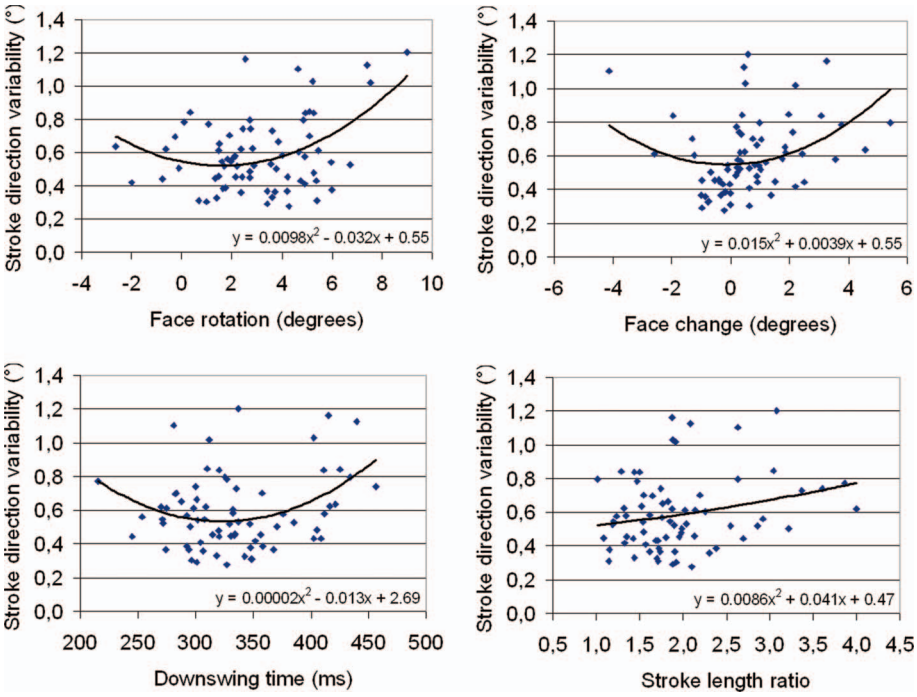


Figure 4. How stroke direction consistency is affected by face rotation in the downswing, face change from address to impact, downswing time, and stroke length ratio. Regression lines and equations are shown. The vertical lines are where the regression equation value is equal to the group average stroke direction consistency of 0.59°. Between the vertical lines, mean variability is less than average, forming an ''optimal zone''. Face rotation from about 1° opening to 4° closing, face changes within about ±1.5°, and downswing time of 270–370 ms are stroke strategies within the ''optimal zone''. Positive face rotation is the same as closing the face in the downswing. Positive face change means that the face is opened from address to impact.

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angle as well. However, such interactions are already incorporated into the calculation of relative importance.

Bearing in mind that stroke variability has less of an influence on direction variability than aiming and green reading, an improvement of the putter path and horizontal impact point consistency will have very little influence on improvement in putt direction consistency. This suggests that putter path and horizontal impact point kinematics should be given low priority in putting direction training. This standpoint is confirmed by the putter path consistency of an average European Tour player (which, according to our results, is about 0.7°). We can calculate from this that he will only miss about 1% of all putts from 10 m, keeping everything but the putter path perfect. In elite tournament play, the same players miss about 95% of putts from 10 m (Pelz, 2000).

How stroke characteristics affect stroke direction consistency

The quadratic regression models for face rotation, face change, and downswing time (Figure 4) were all significant, indicating that there is an optimum solution for those variables in terms of stroke direction consistency. These optima were face rotation of about 1.6° closing, no face change, and a downswing time of 325 ms. For all three parameters, there were quite large individual variations, indicating that solutions different from the optima could still result in high performance for some players.

The optimum club face rotation of 1.6° closing indicates that the stroke suggested by Pelz (2000) with square putter face is not optimal, but it also indicates that strokes with a lot of face rotation in the downswing could affect consistency negatively. Very few players kept their club face square at the end of the backswing in the present study. Of 71 players, 69 had a significant rotation of the putter face in the downswing ($P < 0.05$), which suggests that adoption of the stroke theory proposed by Pelz (2000) is rare.

Not surprisingly, the optimum face change was about 0°. It is hard to find good arguments for having a face change (which means that one is not aiming at the target, or consequently misses putts to one side). Note that most of the players (65%) open the club face from address to impact (0.6° on average). This means that they probably are aiming

left of the target. This is in line with findings from aiming tests (J. Karlsen, unpublished raw data) in which 24 expert players on average aimed 1.2° left of the target. The reason for this is hard to explain. Results indicated that a small face change is acceptable for stroke direction consistency, possibly up to $\pm 1.5°$.

There was some indication that long downswing times had a negative effect on consistency for some players. The reason for this might be that players with long downswing times are taking too long and are consciously controlling the motion. A more pronounced concious control of the motion is more common in the early stages of learning a motor skill. In a skilled performance, it might be more beneficial to have an automatised movement. Downswing times between 270 and 370 ms seemed to result in the best overall performance. Only three players had downswing times shorter than 270 ms, but 16 players were slower than 370 ms, perhaps indicating that some players might benefit from a faster downswing movement.

The mean stroke length ratio was 1.96, which is in line with the 1.78 and 2.35 of Delay *et al*. (1997) and Karlsen (2003) respectively for elite players. Delay *et al*. (1997) showed that low stroke length ratios were a characteristic of novice players. In the present study, the stroke length ratio had no effect on stroke direction consistency, even though 24% of the players had stroke length ratios between 1.0 and 1.5. These players can be said to adopt the same strategy as the novices in the study of Delay *et al*. (1997), and that they also follow Pelz's (2000) recommendation of a stroke length ratio of 1.2. One might ask why most elite players incorporate much higher stroke length ratios than novices if the stroke length ratio does not affect performance. It could be that it affects club head speed consistency, but a *post-hoc* analysis did not show any effect of stroke length ratio on club head speed consistency either. A more likely explanation is the focus in the putting teaching literature on having positive acceleration at impact. This focus might have affected some elite players to increase their stroke length ratio unnecessarily.

Conclusions

In contrast to the perceived importance of the putting stroke in the putting instructional literature, overall direction variability is probably influenced relatively little by stroke variability. Which of the human-controlled factors (aiming and green reading) is the primary determinant of putting direction consistency is still to be determined, but we believe that coaches and players would benefit from changing their focus away from the stroke technique towards green reading and/or aiming in training. Stroke direction consistency is greatly influenced by the variability of the putter face angle. Putter path and horizontal impact point variability are of minor importance for putting direction consistency. ''Optimal zones'' for three stroke parameters are suggested as guidelines for putting instruction. These are face rotations in the downswing of 1° opening to 4° closing, face changes from address to impact of less than $\pm 1.5°$, and downswing times between 270 and 370 ms. Consideration of individual characteristics is necessary when following these guidelines.

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Appendix

Example calculation for one top international player

Methods for calculation are described in detail with an example from one top international player. This player had a variability in face angle at impact (relative to where the face was aimed at address) of $s = 0.39°$. Variability in putters path was $s = 0.65°$ and variability in horizontal impact point on the club face was $s = 2.6$ mm. The effective variabilities for this player were: face angle $0.32°$ $(0.39° \cdot 0.83)$, putter path $0.11°$ $(0.65° \cdot 0.17)$, and impact point $0.09°$ $(2.6\ \text{mm} \cdot 0.034° \cdot \text{mm}^{-1})$. Stroke direction

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variability (which is the same as variability in the stroke deviation angle in Figure 1) was then calculated using the following equation:

$$\begin{aligned}\text{stroke direction variability} = [&\text{effective variance}_{\text{face angle}} \\ &+ \text{effective variance}_{\text{impact point}} \\ &+ \text{effective variance}_{\text{putter path}} \\ &+ 2 \cdot (\text{covariance}[\text{face angle, impact point}] \\ &+ \text{covariance}[\text{face angle, putter path}] \\ &+ \text{covariance}[\text{impact point, putter path}])]^{-2}\end{aligned}$$

$$\begin{aligned}\text{stroke direction variability} = &[(0.32^\circ)^2 + (0.11^\circ)^2 \\ &+ (0.09^\circ)^2] + [2 \cdot (0.0060^\circ + 0.0066^\circ \\ &+ (-0.0073^\circ))]^{-1}\end{aligned}$$

$$\text{stroke direction variability} = 0.368^\circ.$$

The importance of face angle, putter path, and impact point for stroke direction variability is defined by how much a small improvement in one of the parameters affects overall stroke direction variability. A 10% improvement in face angle variability from $s = 0.65^\circ$ to $s = 0.58^\circ$ results in an improvement in stroke direction variability of $s = 0.0289^\circ$ (from 0.368 to 0.329°). A 10% improvement in putter path variability from $s = 0.39^\circ$ to $s = 0.35^\circ$ results in an improvement in stroke direction variability of $s = 0.0030^\circ$ (from 0.368 to 0.365°). And a 10% improvement in impact point variability from $s = 2.6$ mm to $s = 2.4$ mm results in an improvement in stroke direction variability of $s = 0.0017^\circ$ (from 0.368 to 0.366°).

The relative importance of face angle for stroke direction consistency would then be $0.0289^\circ \cdot (0.0289 + 0.0030 + 0.0017)^{-1} = 86\%$. The relative importance of the putter path for stroke direction consistency would be $0.0030^\circ \cdot (0.0289 + 0.0030 + 0.0017)^{-1} = 9\%$. Finally, the relative importance of the impact point for stroke direction consistency would be $0.0017^\circ \cdot (0.0289 + 0.0030 + 0.0017)^{-1} = 5\%$.

For these calculations, we assume that the covariance between the three parameters remains constant when this player is improving. Corresponding mean values for all participants are presented in Table I.

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