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ARTICLE

Video Analysis of Left and Right Breaking Putts

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The aim of this study was to investigate how a player responds to external constraints (slope and angle) in a golf putting task. The sample consisted of 10 adult male (33.8 ± 11.89 years), right handed and highly skilled golfers (average handicap of 10.82). The participants performed 30 putts at a distance of two meters with 25 degrees to the left of the hole (Angle 1) and 30 putts at a distance of two meters with 25 degrees to the right of the hole (Angle 2), with a constraint imposed by a slope. The data suggests that the performance of the golf putting may be improved if different situations and difficulty degrees are employed and exploited. In that sense, the manipulation of task related constraints forced the appearance of solutions uniquely adjusted to each player. This brings implications to the area of sports coaching and training, considering that the athlete can optimize his performance if he explores different couplings of information-movement, in different levels of complexity.

Keywords: constraints; golf putting; performance; golf training

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Karl Newell demonstrates that constraints contribute to the regulation and dynamic of human movement (Newell, 1986). Such approach gives a new understanding about the way how the components are connected, setting a specific form of organization. To do so, they must not be regarded as a behavioral negative influence, but as a set of constraints that may affect the action system (Davids, Button, & Bennett, 2008).

From this point of view, when noticing that constraints affected the dynamic of the human movement, Newell (1986) classified them into three categories (environmental, biological and task), associated with the individual's characteristics, the involvement and the task; thus describing the Approach Based in the Constraints (ABC). The individual's characteristics are connected to their intrinsic characteristics (physical and psychological). The constraints of the involvement refer to the physical, social and environmental aspects. Finally, the task constraints are related to its characteristics, complexity, difficulty, specificity, rules and goals.

Relating Newell's constraints with putting performance, it is noticeable that the morphologic (weight, height and stature) and functional (motivation, fatigue, among others) characteristics of the golfers may affect the acceleration, velocity and amplitude of this movement during the performance (Dias, Couceiro, Barreiros, Clemente, Mendes, & Martins, *in press*).

These aspects report to the characteristics and individual profiles that distinguish each player during the process of motor execution (Pelz, 2000; Mackenzie & Evans, 2010). Despite that, irregularities in the green (e.g., grass slope, angle and texture) may constrain the player, forcing him to adjust his technique to overcome the restrictions imposed by the task; hence, affecting his performance when putting.

Therefore, it seems that task constraints are truly relevant during golf putting, (considering the changeable context of the action). This is particularly relevant in putting because it is regarded by the Professional Golf Association (PGA Tour) the most important golf skill, as it represents approximately 40% of the total amount of strokes performed during a game (Alexander & Kern, 2005; Pelz, 2000).

Golf putting has mostly been analyzed within experimental context under linear trajectories (see Delay, Nougier, Orliaguet, & Coello, 1997; Coello, Delay, Nougier, & Orliaguet, 2000; Dias & Mendes, 2010; Porter & Magill, 2005). However, task constraints on golf putting (slope and angle) can change process variables such as movement amplitude, acceleration or duration in all putting phases (backswing, downswing, impact on the ball and follow-through), thus consequently changing the product variables (radial error; Pelz, 2000; Couceiro, Dias, Mendes, & Araújo, 2013).

In this sense, the aim of this study was to investigate how a player responds to the external constraints (slope and angle) in a golf putting task. Process variables were analyzed (e.g., movement amplitude, acceleration and duration) in all putting phases. Moreover, the product variables (lateral, length and radial error) are also investigated.

Methods

Participants

The sample consisted of 10 adult male (33.8 ± 11.89 years), right handed and highly skilled golfers (average handicap of 10.82). These athletes competed for the Portuguese Golf Federation national championship, including the European national pitch and putt champion who also joined this study. Therefore, considering athletes' availability to participate in this study, we chose those who had lower handicaps and showed better performance throughout the season. All participants were adult, volunteer, right handed males and signed a university-approved ethical consent form. The tests were conducted in accordance with the ethical guidelines set by the University of Coimbra.

Task and Apparatus

The putting was performed on a rectangular green carpet, which produced a fast putting surface (with an approximate stimp of 10). In that sense, two circles with the size of a golf ball were drawn in the carpet, pointing to the exact location for the execution of the putting (Angle 1 and Angle 2).

A ramp, where its legs measured respectively 1 meter and 10 centimeters, was placed beneath the carpet. A platform with 4 meter length was placed attached to the ramp (Figure 1).

The task was performed in an indoor space (i.e., a sports pavilion) and the participants were analyzed individually. Accordingly, each participant was informed about the aim of the study. After this, the practice session started, where the participants neither were verbally informed about the result of their movement nor about the result of each trial (the player could observe the result of each trial). For this purpose, only one practice session was considered.

The performance of the players was filmed using two Casio Exilim/High Speed digital cameras. Camera one was in a frontal position at a distance of 4 meters from the player. Camera two allowed a lateral and superior (1.55m, with an inclination of 22 degrees) filming of the experimental apparatus, registering the lateral, radial and length error, as well as the trajectory of the golf ball.

Both cameras were static, with the same positioning, height and angle. The lens of Camera one was 55cm above the ground and parallel to it. A 26mm zoom and a resolution of 408 × 360 was used. Camera two was equipped with a 26mm and a resolution of 1280 × 720 zoom. Images were processed at 210 Hz (camera one) which allowed a detailed analysis of the movement of the putter, and 30 Hz (camera two) to analyze the trajectory of the ball.

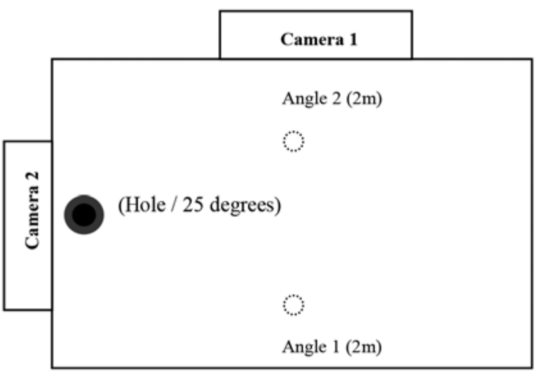

Figure 1 — Upper view of the experimental apparatus.

Detection Algorithm

Following the work of Couceiro et al. (2013), the same detection algorithm was used to detect the head of the putter, signaled by a red marker, accordingly with the red–green–blue (RGB) range values defined (Figure 2b):

1. Select the region of interest (Figure 2b), around the place where the red marker is, within the entire frame (Figure 2a), to be analyzed.
2. Analyze the region of interest of the current frame, searching for pixels with the RGB values within the defined RGB range (RGB ranges depicted in Figure 2).

The analysis of the video for each trial resulted in a vector that included the position of the object in the corresponding frame (pixel/frame).

Optionally, we converted the pixel/frame value of the object in metric units (m/s). This algorithm was computationally efficient as it relied in simple image processing techniques and ensured satisfactory results both in the detection of true positives and in the reduction of the processing times (Couceiro, Dias, Mendes, & Araújo, 2013; Dias, Mendes, Couceiro, Figueiredo, & Luz, 2013).

The Kinematical Model of Golf Putting

Kinematic measures were collected by filming the trajectory of the putter to obtain the putting phases during the backswing, downswing, ball impact and follow-through, as well to analyze the amplitude, velocity, acceleration and overall duration of the movement. The putting movement was analyzed using auto tracking

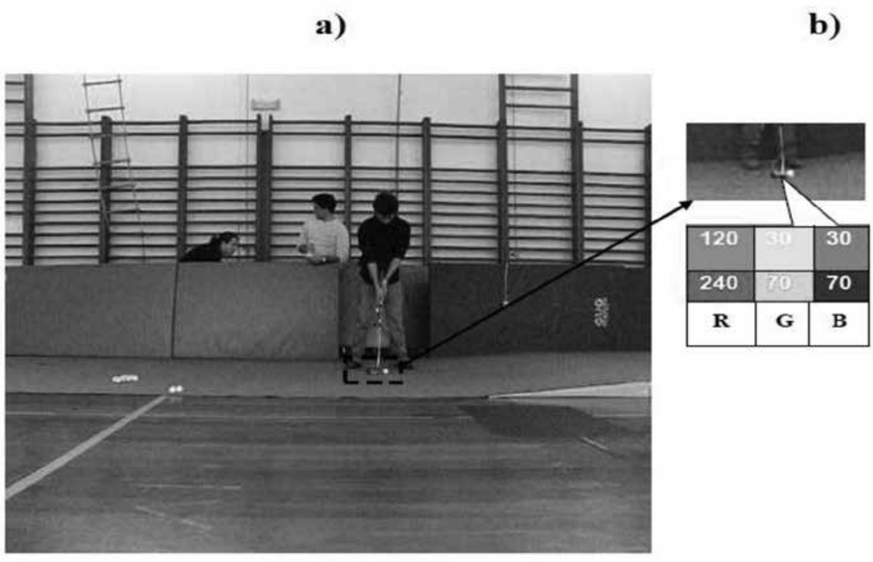

Figure 2 — Example of a registered scene: (a) full frame, (b) region of interest with the defined range of red–green–blue (RGB) values for putter detection (adapted from Couceiro, Dias et al., 2013).

methodologies by autonomously comparing the current frame with the previous frame using MatLab Program (Couceiro, Dias, Mendes, & Araújo, 2013).

The kinematical model of the golf putting consisted of two different stages that had to be accomplished for each trial: 1) The detection of the putter using a simple color-based detection algorithm; 2) The estimation of the kinematical model. In this sense, Figure 3 depicts the two-stage algorithm showing an example of a point cloud that represents the detected position, in the horizontal plane, of a golf club during putting execution of an expert subject and the several kinematical models obtained (Couceiro et al., 2013).

Through the analysis of the shape of various point clouds given by the detection algorithm, it was clear that a sinusoidal-like function had to be used to model the horizontal position of the putter in time. However, a function composed only by one or even two sinusoids was not precise enough to describe the gesture, as it is clear in f1 and f2 of Figure 3, which results, in this case, in a mean square error (MSE) of 2.6568 and 0.7124 units, respectively. This happens due to the amplitude, angular frequency and phase of the descending half-wave, which corresponds to the player's backswing and downswing, usually different than the ascending half-wave, which corresponds to the impact of the ball and follow-through (Couceiro, Dias, Mendes, & Araújo, 2013; Luz, Couceiro, Portugal, Rocha, Araújo, & Dias, 2013).

Hence, to obtain a more precise model, a sum of sinusoidal waves was employed. However, a compromise between precision and complexity of the problem had to be assumed, as each sinusoid adds three more dimensions to the estimation problem (amplitude, angular frequency and phase of the corresponding sine wave).

In order not to let the complexity of the problem grow inappropriately, a function composed of the sum of three sinusoids was used (f3 of Figure 3), due to its precision, with a MSE of 0.6926. Thus, having the estimation function defined as a sum of three sine waves (1), the estimation process resulted in a nine dimension mathematical (sinusoidal) function for each of the 30 trials of the 10 players in study (Couceiro et al., 2013; Dias et al., 2013; Luz et al., 2013).

$$f(t) = a1\sin(b1t + c1 + a2\sin(b2t + c2) + a3\sin(b3t + c3) \quad (1)$$

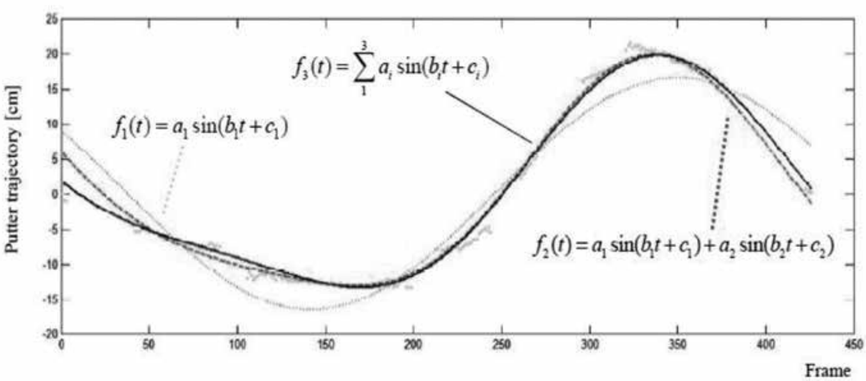

Figure 3 — Fitting sinusoidal functions to a point cloud, representing the position of a golf club during putting execution (adapted from Couceiro, Dias et al., 2013, p. 42).

It is possible to represent that function by compiling the 9 parameters in six two-dimensional groups (a1 vs b1, a1 vs c1, a2 vs b2, a2 vs c2, a3 vs b3, a3 vs c3). However, such representation would result in a complex scatter chart with a large number of data points plotted within the same space making it difficult to distinguish individual data subsets and difficult to associate each data subset to a specific player. Finally, the radial error—ε_i can be obtained using the Pythagoras theorem (Couceiro, Dias, Martins, & Luz, 2012) as it is the hypotenuse of the right triangle relating both legs defined by lateral error ε_i^x and longitudinal error ε_i^y (Figure 4).

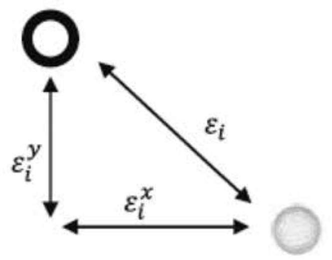

Figure 4 — Representation of the three measured errors (adapted from Couceiro, Dias et al., 2012, p. 2).

This metric allows an "analog" putting accuracy assessment, as it considers more than the number of balls placed in the hole, i.e., (ε_i=0). Therefore, when a player hits the hole, the radial error is zero (0), in all the components of length, lateral and radial error (Couceiro et al., 2012).

Procedures

Each participant performed 3 adaptation trials at a distance of 2.20 meters. During the experiment the players had neither verbal feedback about the movement nor about the result of each trial but they had visual access to the trajectory of the ball and stop position. Then, the participants performed 30 putts at a distance of two meters with 25 degrees to the left of the hole (Angle 1) and 30 putts at a distance of two meters with 25 degrees to the right of the hole (Angle 2), with a constraint imposed by a slope. Such a distance was chosen by considering the lack of performance players often face at 2 meters from the hole during the PGA Tour (Pelz, 2000).

Statistical Procedures

The differences between variables outcomes during practice conditions were assessed through the one-way ANOVA test when there was normality and homogeneity. When it was not possible to assess normality and homogeneity through the Central Limit Theorem the method of Games-Howell was used for the post hoc test (Maroco, 2010). The estimation of the effect size, η^2 (i.e., the proportion of the variance in the dependent variables that can be explained by the independent variables) was done according to Pallant (2011).

Apart from the effect size, the power of the corresponding test was also presented. The analysis of the power of the test is a fundamental procedure to validate the conclusions reached in the inferential analysis (Pallant, 2011). The IBM SPSS program (version 20) for a significance level of 5% (alpha level was set at .05) was used.

Results

A general overview is presented in Table 1 that depicts the mean, standard deviation and variation coefficient values for the putting process at each condition.

Table 1 Mean (M), Standard Deviation (*SD*) and Variation Coefficient (VC %) Values for the Putting Process Variables in Angle 1 and Angle 2.

Putting phases	Values	Angle 1	Angle 2
Downswing amplitude [mm]	Mean (M)	181	258
	Standard Deviation (*SD*)	26	40
	Variation Coefficient (VC) (%)	14	15
Follow-through amplitude [mm]	M	326	355
	SD	41	82
	VC%	13	23
Speed of impact on the ball [$m.s^{-1}$]	M	1.28	1.75
	SD	0.21	0.34
	VC%	16	19
Backswing duration time [ms]	M	519	492
	SD	100	112
	VC%	19	23
Downswing duration time [ms]	M	269	270
	SD	39	88
	VC%	14	33
	M	431	353
Follow-through duration time [ms]	*SD*	81	88
	VC%	19	25
Maximum acceleration of the putting [$m.s^{-2}$]	M	6.33	8.77
	SD	2.29	3.53
	VC%	36	36
Radial Error [mm]	M	448.35	671.21
	SD	607.54	772.84
	VC%	136	115

Legend: mm = millimeters; $m.s^{-1}$ = meters per second raise to the power of -1; ms = milliseconds; $m.s^{-2}$ = meters per second raise to the power of -1.

Angle 2 shows higher values in most of the putting phases, when compared with Angle 1 (backswing, downswing and follow-through amplitude, speed of impact on the ball, downswing duration and maximum acceleration).

Amplitude of Phases

Figure 5 shows the maximum amplitude of the putting for angle 1 and 2. It can be verified that Angle 2 results in higher values of backswing, downswing and follow-through amplitude when compared with angle 1. The one-way ANOVA

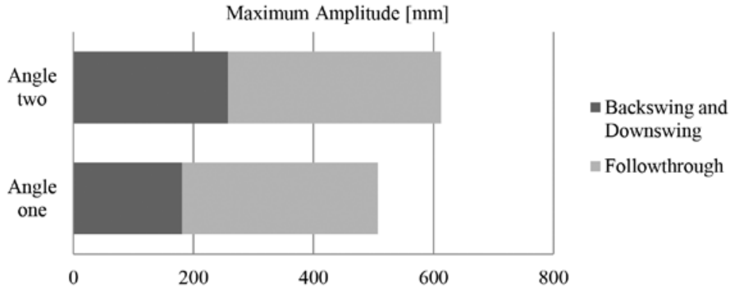

Figure 5 — Maximum amplitude of the putting for each condition angle 1 and 2.

was carried out to highlight the significant differences between angles for the backswing amplitude ($F_{(1,598)}$ = 339.589; *p-value* = 0.001; η^2 = 0.362; *Power* = 1.000), downswing amplitude ($F_{(1,598)}$ = 339.589; *p-value* = 0.001; η^2 = 0.362; *Power* = 1.000) and follow-through amplitude ($F_{(1,598)}$ = 16.435; *p-value* = 0.001; η^2 = 0.027; *Power* = 0.982).

Maximum Speed of Impact on the Ball

Figure 6 presents the maximum speed of impact on the ball for Angle 1 and Angle 2. The speed of impact on the ball is higher for Angle 2. It was also possible to observe significant differences between Angle 1 and Angle 2 for the maximum velocity of backswing ($F_{(1,598)}$ = 246.743; *p-value* = 0.001; η^2 = 0.292; *Power* = 1.000) and maximum velocity of impact on the ball ($F_{(1,598)}$ = 314.372; *p-value* = 0.001; η^2 = 0.345; *Power* = 1.000).

Maximum Duration

Figure 7 shows the maximum duration of the putting for Angle 1 and Angle 2. One-way ANOVA revealed significant differences between angles for the backswing duration ($F_{(1,598)}$ = 5.188; *p-value* = 0.023; η^2 = 0.009; *Power* = 0.623) and follow-through duration ($F_{(1,598)}$ = 78.491; *p-value* = 0.001; η^2 = 0.116; *Power* = 1.000). However, the analysis of process measures indicate no statistically significant

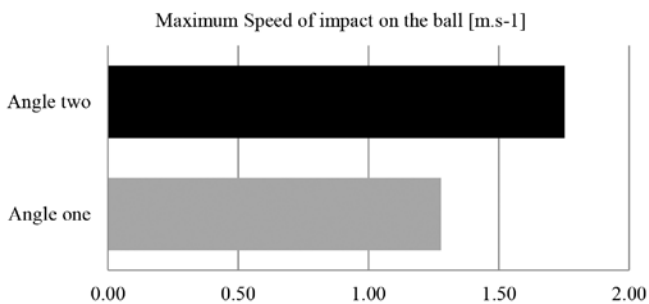

Figure 6 — Maximum speed of impact on the ball for angle 1 and 2.

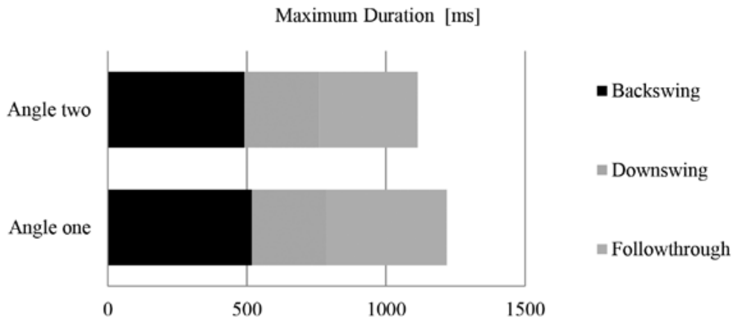

Figure 7 — Maximum duration of the putting for angle 1 and 2.

differences for the downswing duration ($F_{(1,598)}$ = 0.056; *p-value* = 0.812; η^2= 0.001; *Power* = 0.056).

Figure 8 represents the maximum acceleration of the putting for Angle 1 and Angle 2. The results suggest that the maximum acceleration of the putting showed on angle 2 is higher. Once more, significant statistical differences between angle 1 and 2 were found for the backswing maximum acceleration ($F_{(1,598)}$ = 99.270; *p-value* = 0.001; η^2 = 0.142; *Power* = 1.000) and downswing maximum acceleration ($F_{(1,598)}$ = 130.418; *p-value* = 0.001; η^2 = 0.179; *Power* = 1.000). Finally, the analysis of product measures indicate statistically significant differences between angles for the length error ($F_{(1,598)}$ = 15.402; *p-value* =0.001; η^2 = 0.025; *Power* = 0.975), lateral error ($F_{(1,598)}$ = 17.252; *p-value* = 0.001; η^2 = 0.028; *Power* = 0.986) and radial error ($F_{(1,598)}$ = 15.418; *p-value* = 0.001; η^2 = 0.25; *Power* = 0.975).

Discussion

The aim of this study was to investigate how a player responds to external constraints (slope and angle) during golf putting task. In that sense, the gathered data indicates that the characteristics of the experimental device (slope and angle) gave flexibility and plasticity to the task, so that the players' motor system could adjust

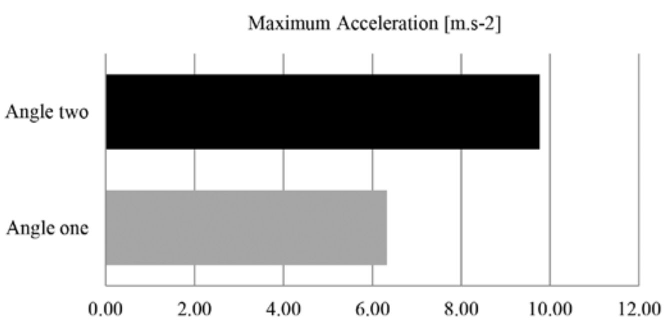

Figure 8 — Maximum acceleration of the putting for angle 1 and 2.

to the task demands. Hence, when considering that "functional variability" is associated with the way we affect the task and the player during the golf putting, and considering the fact that the player performed the putting at various distances and different trajectories (upwards and curvilinear), it is plausible that this form of "noise" contributed to a better accommodation to the demands and objectives of the putting task (Newell, 1986; Pelz, 2000; Dias et al., 2013). The data suggests that the training motor skills may be improved if different situations and difficulty degrees are explored. Bearing this in mind, we consider that the manipulation of task related constraints forced the appearance of solutions uniquely adjusted to each player, within the golf putting.

Facing this scenario, disturbances imposed to the players when performing the putting, not only put their organism to the test but also allows them to find new ways to solve motor problems. It must also be taken into consideration that the morphologic and functional characteristics of the participants, their handicap and the complexity of the task were important to find statistically significant interindividual differences in the motor performance inferred by the process variables and product measures. This enables us to hypothesize that the problem of individuality is not confined in ideal or standardized techniques, but withholds a variety of strategies that may be implemented according to the specificity of each player (Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2008).

Furthermore, we advocate the possibility that, according to the extrinsic dynamic of this task, which depends on its specificity and complexity, the player might have been influenced by the contextual information that he withdrew from the environment (Davids et al., 2008). In other words, the presence of interindividual differences that are inherent to the motor execution of this movement may be resultant not only from the individual performance, but also from the context where the task was performed (Mackenzie & Evans, 2010).

Moreover, the perception that the player withdrew from the properties of the context ("affordances") was important to perform the putting movement. This assumption is based on the fact that the golfers continuously visualized the carpet (artificial green) to analyze the slopes, putting angles and light conditions. According to this task representation ("reading" of the green), players acted in a way that enabled them explore the possibilities of golf putting, thus becoming attuned with the environment (Gibson, 1979; Pelz, 2000; Couceiro et al., 2013).

Even while performing the golf putting under task constraints, the analyzed performance variables were similar within constraint-free situations. The downswing time was around 269ms for angle 1 and 270ms for angle 2, being very similar to the values showed by Coello et al. (2000) and Delay et al. (1997) to the linear trajectories. Nevertheless, these values are smaller than the ones shown by Karlsen (2003) of approximately 305ms. Despite this, the results found in this study are in line with the ones of Karlsen, Smith and Nilsson (2008) stating that values closer to 270ms can be better to achieve the best scores on golf putting performance to the linear trajectories. The duration of the follow-through was around 431ms for Angle 1 and 353ms for Angle 2. However, no other work has studied these variables yet.

The speeds of impact on the ball were closer to 1.28 $m.s^{-1}$ for Angle 1. These values are closer to the linear trajectories studied by Coello et al. (2000) for 2 meters away from the hole (1.25 $m.s^{1}$). The values from this study are somehow larger than the ones presented by Delay et al. (1997) but still in line with the values suggested for this golf putting distance (1.3 $m.s^{-1}$).

On the other hand, the product variables suggest the best scores at Angle 1. This can be explained by the kind of movement. The players at Angle 2 perform the putting with their backs toward the hole, thus partially constraining their vision. Nevertheless, the final scores are closer to those suggested by the literature (Dias, Couceiro, Barreiros, Clemente, Mendes, & Martins, *in press*; Dias, Mendes, Couceiro, Figueiredo, & Luz, 2013). At Angle 2, the depth notion can be severely constrained, thus constraining the perception about the tridimensional environment. This may be explained by the necessary adjustment of the head position to overcome the constraint, hence providing them erroneous information about the depth. This can be justified by an ambiguous volume of information captured by each eye. Therefore, each player adjusted their movements (process variables) to find new solutions and achieve the final goal, obtain the high score in the golf putting performance (Steinberg, Frehlich, & Tennant, 1995; Sugiyama, Nishizono, Takeshita, & Yamada, 2002; Sugiyama & Lee, 2005).

Finally, the constraints used for this study showed a high impact on the golfer's performance, mainly in the angle trajectories. We identify significant differences among the movement of the golfers, using two different types of task constraints. Moreover, the constraint applied by Angle 2 suggests a strong way to increase the process adjustment.

In brief, the task constraints are strongly recommended for golf training to increase the variability and improve the performance adjustments. This brings implications to the area of sports coaching and training, considering that the athlete can optimize his performance if he explores different couplings of information-movement, in different levels of complexity.

Applications for Sport Training

The experimental apparatus of this work can be used to train putting while exploring different conditions of practice (slope and angle). Through it, it allows the study of the player's upward, downward and curvilinear trajectories, thus developing skills in different contexts. This aspect is particularly important not only for the athlete but also for the coach. In agreement with Newel (1986), we consider that task constraints are a fundamental resource for the coach to optimize the performance of his or her athletes. To do so, it is necessary that these constraints guarantee the complexity, variability and dynamics of the competition.

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