



Performance and Kinematic Differences in Putting Between Healthy and Disabled Elite Golfers

by

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Golfers with disability are limited in the execution of the full golf swing, but their performance in putting may be comparable because this stroke does not demand significant strength, balance and range of motion. Therefore, the aim of this study was to compare putting performance, kinetic and kinematic consistency between golfers with different disabilities and healthy athletes. The participants consisted of three disabled athletes (perinatal cerebral palsy, multiple sclerosis, below knee lower limb amputee) and three healthy golfers (age 34 ± 4.5 years, body height 178 ± 3.3 cm, body mass 83 ± 6.2 kg). The golfers' movements were recorded by active 3D markers for kinematic analyses; the subjects performed 10 trials of a 6 m putting task while standing on separate force platforms placed under each lower limb. Putting performance was measured by the distance of the final ball position to the centre of the hole. ANOVA analyses did not show any differences in clubhead speed and total ball distance from the hole. The consistency of those two parameters expressed by the coefficient of variation (CV) was $CV = 0.5\%$ or better in both groups for clubhead speed and ranged from $CV = 0.40$ to 0.61% in healthy and $CV = 0.21$ to 0.55% in disabled athletes for total error distance. The main effect ANOVA showed differences in weight shift, hip and shoulder kinematics ($p < 0.05$) between healthy players and all players with disability. All disabled athletes shifted their weight toward the healthy side (towards the healthy lower limb) and alternated the end of the swing. The player with below knee amputation had the lowest range of motion in the shoulder joint during the putting stroke. The players with perinatal cerebral palsy and multiple sclerosis had the largest range of motion in the hips. Putting performance of disabled golfers was similar to healthy athletes. During training of disabled players, coaches should pay attention to the specificity of a particular disability when focused on putting performance. However, individual technique should achieve the same consistency as observed in healthy players.

Key words: golf, lower limb amputee, pendulum swing, disability.

Introduction

Performance in golf is determined by the accuracy of drives from the tee, accuracy of approach shots from the fairway, short approach shots and putting. Therefore, the most important playing clubs are the driver, wedges and a putter (McLean, 2005). In elite players it was found that about 43% of strokes were performed by the

putter (Pelz, 2000). The putting stroke is a specific kind of the golf swing (stroke), which is preferably used on the green, attempting to control both distance and lateral error, to finish either in, or as near as possible the hole. Putting has been considered the ability which determines the amount of prizes on professional tours (PGA

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Tour et al) (Alexander and Kern, 2005). Sports performance in subjects with disability is influenced by the range of deteriorated movements and body functions, which influence the range of swing motion and other variables, e.g. the information about the weight distribution (weight-shift) between the limbs (Gerych et al., 2013; Jelen et al., 2005), which causes the differences in golf swings (Stastny et al., 2015).

The golf literature gives significant attention to the technique of putting, kinesthetic feel, equipment level (stroke part of putter) and reading the putting green (initial direction choice) as the key abilities leading to successful putting (Wiren, 1990; Woods, 2001). However, an appropriate stable putting technique is the basis for a successful putt (Hurrion, 2008). Successful and consistent putting is based on a stabilized point of rotation, which allows the golfer to putt from a stable position at initial impact (contact between the head of the putter and the ball). Therefore, the golfer needs a stabilized initial position with a fixed centre of rotation to achieve high repeatability of the putting stroke. Weight transfer between both lower limbs will influence the stability or variability in postural integrity during putting (Hurrion, 2009). Although the putting stroke technique differs among players, there are several stabilizing points (mild knee flexion, hip flexion, marginal elbow flexion) aiming to produce positioning of the eyes directly over the ball (Wiren, 1990) allowing for the stroke to be performed with a pendulum movement with the rotation centre in the middle of the shoulder line. Those parameters are different from other golf swings, where the force impulse during the ball impact is reliant upon upper torso–pelvic separation called X-factor (Cheatham et al., 2001; Chu et al., 2010) and plays a crucial role. Therefore, the golfer with disability may complete the putting stroke more effectively or in a different way than with a full swing, e.g. drive.

Besides descriptive information about putting (Hurrion, 2009), there is a lack of literature about different putting approaches and in particular, about putting in golfers with disability. Therefore, the aim of this study was to compare putting stroke performance, kinetic and kinematic consistency between golfers with different disabilities and healthy athletes. Furthermore, we focused on the comparison of

the variability of putting to determine which movement pattern was specific to a particular disability.

Methods

Participants

The participants consisted of three disabled athletes and three healthy golfers described in Table 1. Their skill level was based on current handicap without evaluating their skills, which is suggested for elite athletes with disability (Beckman et al., 2007). Three male healthy professional golf players were included as a reference group. Informed written consent was provided by each participant and the testing protocol was approved by the local Committee of Ethics in accordance with the ethical standards of the Declaration of Helsinki of 1983.

Design and Procedures

The present research consisted of three case studies. The group of healthy golfers ($n = 3$) and the one consisting of disabled athletes ($n = 3$; each disabled participant had a different type of disability) performed 10 putting strokes in a cross-sectional design in the laboratory environment. The warm-up procedure included individual trials of putting swings for 10 minutes. Then dynamic stretching and 10 putting trials were completed. After the warm up, 3D markers were attached to the body of participants and they performed 10 putting strokes, which was the same for each player; putting stroke variables were measured by the active marker on the clubhead. A 60 s interval was allowed between trials during which time the participants renewed their initial position; strong encouragement was provided throughout testing (Hamalainen, 2016; Schücker et al., 2013). All testing was performed in the laboratory environment on an artificial green, because there are no significant biomechanical differences between the practice and competition trials besides the golf swing (Croix and Nute, 2008). The players were instructed to putt directly to the hole with a standard golf ball (Titleist ProV1). During trials, participants stood with each leg on a separate force plate.

Measures

Kinematics were measured at frequency of 200 Hz by a 3D active markers system CODA Motion System (Charmwood Dynamics Limited, Leicestershire, England) and kinetics by two force

plates Kistler 5606 (Kistler Group, Winterthur, Switzerland) with sampling frequency of 1000 Hz. The final distance of the golf ball from the centre of the hole was measured as the total distance error, i.e. lateral distance ("y" axis in the 3D system) and depth distance ("x" axis in the 3D system) (Figure 2).

For 3D measurement, active markers were attached bilaterally to the subject's skin over the following landmarks: the anterior superior iliac spine; the posterior superior iliac spine; the left acromion; right acromion. The virtual markers were placed in the middle of the crossline between the anterior superior and posterior superior iliac spine and half distance between each acromion for further calculation. Other markers were attached to the golf club at top of the club, 10 cm from the grip and the end of the club head.

3D kinematics were used to define four stroke phases:

A, initial position
B, backswing
C, impact
D, end of the swing

The initial position was defined as the moment of the beginning of the backswing, the backswing as the moment of maximal extension from the ball, the impact was the moment of the first putter / ball contact and the end of the swing

as the moment where the putter finished the pendulum forward movement. Weight transfer (shift) during the golf swing was estimated by a vertical force ratio between the right and left leg expressed in percentages. Recorded variables were the shoulder and pelvis line rotation in the XY axis (horizontal plane direction) and the XZ axis (frontal plane) and shoulder and pelvis midpoint movement in the X axis (frontal plane) direction.

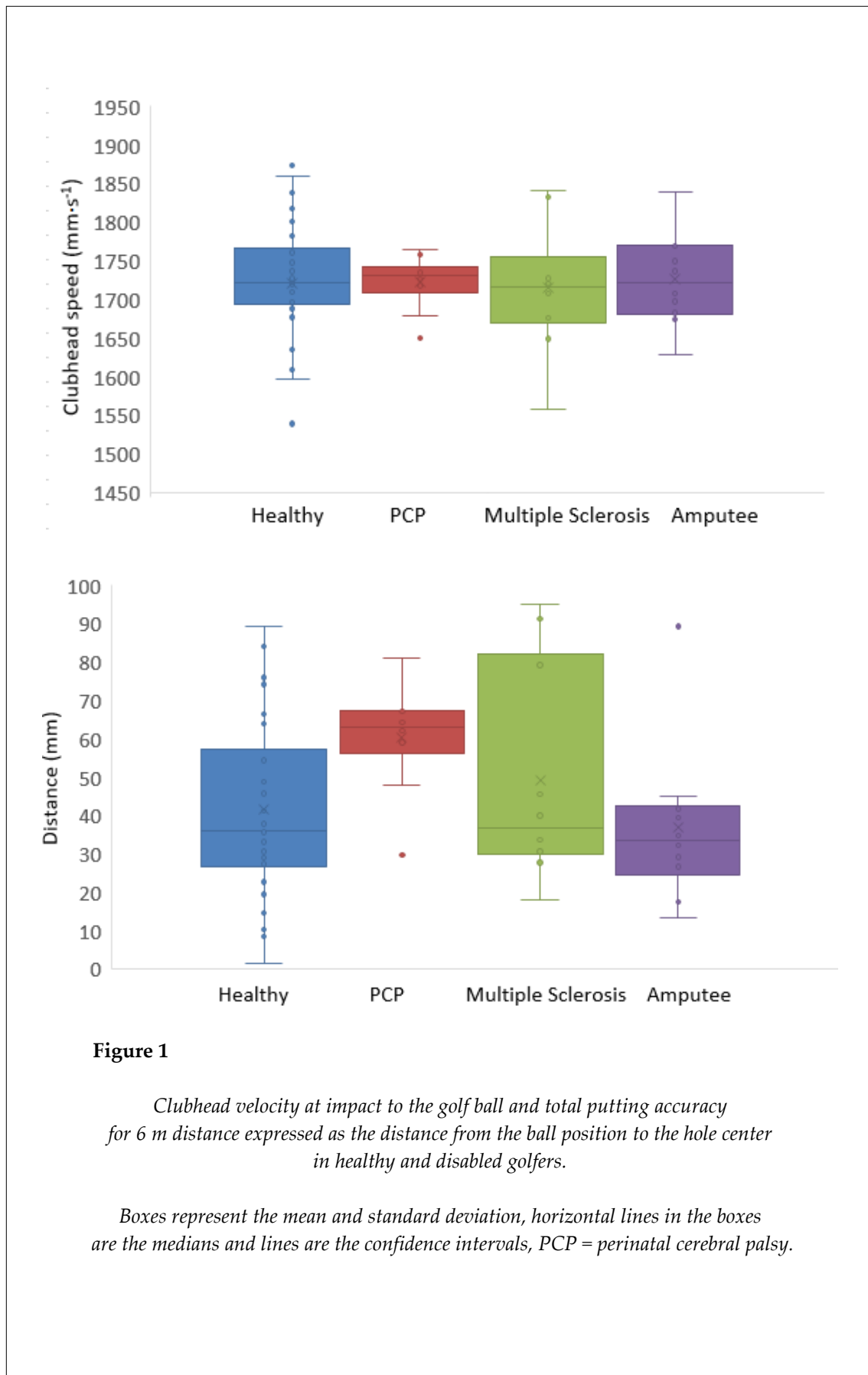
Table 1

<i>Participants Characteristics</i>				
	HLT (3)	Case 1	Case 2	Case 3
Gender	males	male	male	male
Age	34. ± 4.5	43	50	37
Body height	178.7 ± 3.3	169	194	188
Body mass	83 ± 6.2	61	105	84
Disability type	Non	perinatal cerebral palsy	Multiple sclerosis (MS)	Right under knee
Characteristics - self and medical reports	health	Sin. Hemiparesis, more expressed on the left arm.1	Right side movement ability lowered, 2	Prosthesis type - Triton Harmony System
Diagnostics length (years)	non	entire life	17	4
Golf age (years)	15 ± 2.45	6	13	4
HCP	5.4 ± 0.71	10.5	22.3	22.8

1 - left arm shortened by 10 cm, no radio ulnar movement on the left side, no movement in the left wrist and only passive movement of the thumb.

Paresis of brachial plexus. Balance impairment - positive Romberg test.

2 - using orthosis on the right leg on the golf course, did not use orthosis during testing. All participants were right handed (dominant) playing with the right side golf club.



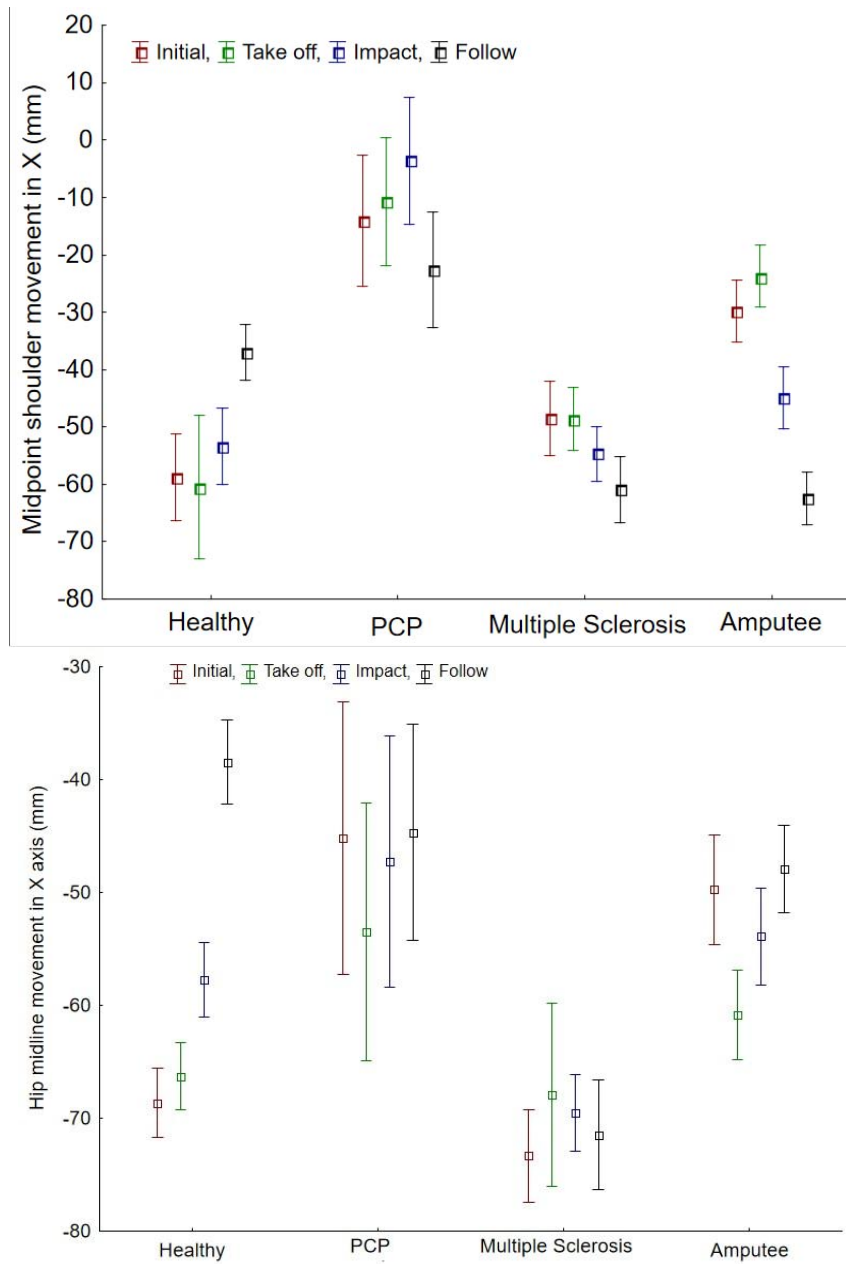


Figure 2

Shoulder and pelvis kinematics in healthy and disabled golfers

Boxes represent the mean and standard error of measurement, and the lines represent the confidence interval. PCP = perinatal cerebral palsy.

Table 2
Putting accuracy and clubhead speed in healthy and disabled golfers.

	Forward distance (mm)			Horizontal distance (mm)			Total distance (mm)			Clubhead Speed		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
	HLT	-5.6	18.7	-1.3	-1.9	35.9	-1.9	41.7	22.3	0.5	1721.1	70.0
PCP	-23.7	50.5	-2.1	0.6	26.2	43.6	60.2	12.9	0.2	1722.2	33.0	0.02
MS	-1.1	49.5	-45.0	-16.9	20.1	-1.2	49.1	26.9	0.5	1714.6	77.8	0.05
Amputee	-11.0	32.8	-3.0	-4.1	23.4	-5.7	36.9	19.9	0.5	1725.6	57.2	0.03

HLT = Healthy participants, PCP = perinatal cerebral palsy
MS = multiple sclerosis AM = below knee lower limb amputee.

Table 3
Kinematic variables of the putting stroke in all study participants

Swing Phase		SetUp			Backswing			Impact			EoS			
		Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%	
Shoulders rotation	XY (°)	HLT	-1.41	1.75	24.33	2.99	1.88	63.00	-2.99	0.87	-29.00	15.33	2.76	-18.00
		PCP	-6.70	0.80	-11.89	-1.93	0.76	-39.57	11.15	1.05	-9.38	29.10	21.67	-74.48
		MS	-6.36	0.34	-5.36	-1.03	0.53	-51.37	-6.41	0.54	-8.38	21.03	1.61	-7.66
		AM	-6.81	0.63	-9.20	3.07	1.24	40.37	-3.68	0.79	-21.47	11.85	1.25	-10.58
Shoulders tilt	XZ (°)	HLT	6.28	1.38	22.00	-2.26	1.60	70.63	8.22	0.87	10.62	24.53	2.45	10.00
		PCP	7.17	0.92	12.77	-5.41	1.50	-27.82	8.85	1.05	11.83	25.11	1.65	6.58
		MS	4.92	0.59	12.01	-0.93	0.56	-60.00	7.48	0.87	11.68	23.17	1.29	5.58
		AM	10.69	0.67	6.27	-5.27	1.08	-20.56	11.48	0.56	4.86	22.75	0.90	3.96
Shoulders movement X (mm)		HLT	58.72	19.90	33.89	60.48	32.97	54.52	53.39	17.60	32.97	37.03	12.76	-34.45
		PCP	14.13	15.17	107.32	10.78	14.74	136.81	-3.62	14.64	404.43	22.60	13.26	-58.69
		MS	48.56	8.59	-17.70	48.62	7.35	-15.12	54.70	6.25	-11.43	60.90	7.55	-12.40
		AM	29.79	7.20	-24.17	23.77	7.16	-30.14	44.95	7.18	-15.97	62.40	6.04	-9.68
Hips rotation	XY (°)	HLT	4.40	2.03	46.16	6.08	2.09	34.37	1.97	2.46	125.11	-3.57	4.43	123.98
		PCP	-0.68	1.22	180.54	3.12	0.78	25.06	-4.04	1.07	-26.43	10.83	0.76	-7.05
		MS	-4.25	0.28	-6.59	-0.33	0.99	305.17	-4.69	0.42	-8.85	-9.37	1.36	-14.52
		AM	-4.18	0.65	-15.52	-3.20	0.73	-22.93	-5.04	0.92	-18.22	-7.04	0.89	-12.60
Hips tilt	XZ (°)	HLT	-2.53	1.25	49.38	-2.33	1.55	-66.71	-1.97	1.90	-96.36	-1.06	2.04	192.74
		PCP	0.47	0.51	109.95	-0.28	0.43	151.26	0.81	0.39	48.47	3.88	0.69	17.81
		MS	0.06	0.53	926.48	1.05	0.88	83.83	0.31	0.39	123.38	2.44	0.38	15.46
		AM	3.61	0.36	9.93	3.55	0.37	10.35	3.50	0.26	7.57	4.02	0.33	8.33
Hips movement	X (mm)	HLT	68.63	7.98	-11.62	66.27	7.78	-11.75	57.71	8.77	-15.20	38.44	9.86	-25.66
		PCP	45.15	16.00	-35.43	53.49	15.14	-28.30	47.26	14.72	-31.14	44.69	12.70	-28.43
		MS	73.33	5.48	-7.48	67.87	10.75	-15.84	69.53	4.49	-6.45	71.49	6.44	-9.01
		AM	49.75	6.40	-12.87	60.86	5.27	-8.67	53.88	5.68	-10.54	47.92	5.08	-10.59

EoS = End of Swing, HLT = Healthy participants, PCP = perinatal cerebral palsy MS = multiple sclerosis
AM = below knee lower limb amputee, ShXY = shoulder rotation in XY axis,
ShXZ = shoulder rotation in XZ axis, ShXY = shoulder centre displacement, HXY = hip rotation in XY axis,
HXZ = hip rotation in XZ axis, ShXY = pelvis centre displacement

Statistical Analyses

All statistical analyses were performed with STATISTICA version 12 (StatSoft, Inc., Tulsa, OK, USA) with $\alpha = 0.05$. Within subject reliability was estimated by the individual coefficient of variation (CV) across 10 repetitions of all trials of each participant. This CV was used to determine whether the putting stroke was stable within each subject. The T test score of each student was used to establish differences between stroke accuracy and clubhead speed measured in healthy subjects and each person with disability. The differences in kinematics and weight transfer were analyzed by 2×4 (athlete condition \times movement phase) ANOVA, where one athlete condition was always represented by healthy athlete values and the second condition was the one of each of the three disabilities.

Results

The CV did not differ between healthy athletes in kinematic variables (Table 3), clubhead speed and total putting accuracy (Table 2); however, there were differences in the depth error and lateral error (Table 2). The T test did not show any significant differences in clubhead speed (Figure 1) and accuracy of the putting stroke (Figure 1). The kinematic variables differed between the healthy athletes and the player with perinatal cerebral palsy (PCP) ($p < 0.01$), multiple sclerosis ($p < 0.05$) and the disabled amputee ($p < 0.05$), (Figure 2). The weight transfer differed significantly between the healthy athletes and players with PCP ($p < 0.01$), multiple sclerosis ($p < 0.01$) and the disabled amputee ($p < 0.01$). The healthy players had greater loading of the left lower limb (Left, $54 \pm 4\%$), which was lower in multiple sclerosis (Left, $51 \pm 1\%$) and below knee amputee (Left, $63 \pm 1\%$). On the other hand, the player with PCP loaded the right leg to a greater extent (Right, $57 \pm 1\%$).

Discussion

Putting is the least physically demanding golf swing, in which we can observe the highest variation between individual movement technique in professional and amateur golfers. During the putting task, the total distance error from the hole is determined by a combination of the lateral error and depth error. In straight putts, the lateral error is estimated by the initial ball

direction and the initial speed of the ball determines the depth error. Initial direction of the ball after impact is dependent on the face angle, stroke path and impact spot (Mackenzie and Evans, 2010). The initial velocity of the ball is determined by the clubhead speed at impact and the impact spot. The similarity in putting clubhead speed between healthy and disabled golfers in our study indicates that they should have similar performances. This is in agreement with a previous study (Pelz, 2000), where the velocity of the ball post impact had four times higher importance than initial ball direction for putting accuracy in breaking putts. Moreover, the putting training intervention by different techniques resulted in lowering the variability of clubhead speed in impact along with putting accuracy (Mackenzie and Evans, 2010; Mackenzie, et al., 2011). Therefore we may assume that low variability in clubhead speed leads to better putting performance.

The finding that CV kinematics during putting did not vary between the golfers with and without disability pointed to a sufficient level of individual technique in disabled golfers (Table 2). The consistency and repeatability of the golf swing has been considered one of the key factors in golf performance (Meister et al., 2011), which was not dependent on the disability level in this study and a previous study performed on a disabled group (Stastny et al., 2015). If the golfers had low swing variability (a fluent and consistent swing), their rotational variables of shoulder and pelvic orientation should correlate with clubhead speed at impact (Meister et al., 2011; Myers et al., 2008), yet this dependence was not confirmed in the study of Kwon et al. (2013) Therefore our study did not analyze this relationship. However, the repeatability of the same clubhead speed and putting performance was similar across all athletes, and the variability in those variables was lowest in the PCP golfer. Therefore, putting performance may be characterized by a technique, where golfers with disability can achieve a high level of efficiency.

The results of kinematic analyses show that disabled players move after impact in the opposite direction of the stroke, which is probably connected to their one limb preference (Figures 3 and 4). This weight-shift was recognized by the right and left foot vertical force ratio throughout

the putting stroke, which was influenced by the level and type of disability. Thus, the decreased possibility of proprioception and movement coordination in disabled golfers is evident after the impact rather than set up, back swing and club head impact. Although the importance of weight-shift and the need for its frequent training is one of the foundations of golf (Chu et al., 2010), this variable does not seem to be critical for putting performance. On the other hand, the weight-shift was the most variable parameter among different disabilities during the putting stroke.

Previous studies showed that putting stroke performance and putter movement parameters, such as club head speed variability, could be impacted by specific practice without the need to change technique even in less skilled golfers (Mackenzie and Evans, 2010; Mackenzie et al., 2011). Based on the results of our study, we suggest that different putting techniques in different disabilities do not lead to less accurate putting. Therefore, each player (disabled or healthy) should be looking for their specific repetitive motion of the body, which leads to consistent movement. The consistent body movement should result in repeatable club head movements during the impact in terms of clubhead speed, path and face angle to control initial ball direction and speed, which allows to reach maximal putting performance.

The limitations of the study are in small numbers of participants, as our sample was based on single case studies. The movement variability might have been significantly different if there was comparison of stroke conditions with specially adopted equipment for different kinds of disabilities. This study also did not estimate differences in the force momentum in the knee joints, which might be useful for golf training (McHardy et al., 2006). Since the study sample was low, we did not estimate how the players learned the consistent putting stroke/action (Oliveira et al., 2013).

Conclusion

The fluency and consistency of putting stroke kinematics and accuracy are not dependent on the specific type of disability. The most variable parameter among each disability is weight-shift, where disabled golfers prefer the healthy limb during movement stabilization. The course of stroke movement was performed specifically with individual technique rather than imitation of movement observed in healthy athletes, thus its modification by training is difficult. Therefore, disabled players should find their own putting technique. Putting performance in disabled golfers should be similar to healthy players, which means that partial handicap should be resolved by high reproduction of movement.

Acknowledgements

Programme for the Development of Fields of Study at Charles University under Grant UNCE 032, and Czech science foundation GAČR 16-21791S, and Higher Education of Poland under Grant NRSA3 03953 and NRSA4 040 54.

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