THE INFLUENCE OF ADJUSTABLE PUTTER HEAD WEIGHTING ON THE STROKE

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The purpose of this study was to investigate the effects of putter head weighting towards the heel and the toe on the kinematic aspects of the putting stroke. Seven (n=7) male golfers (age 42.6 ±2.3 y) with high proficiency (handicap 9.5 ±1.4) were recruited for this study. The experiment was carried out in an indoor studio with artificial grass (Stimp 10). Two toe weight and two heel weight settings were tested and compared with the standard weighting. Results suggest that putter head weighing influences the characteristics of the putting stroke, and systematic differences were found between toe and heel weighting. It is concluded that fitting the weight and the balance of a putter head is critical for supporting each individual's stroke and putting performance.

KEY WORDS: Golf, putting stroke, golf club design, adjustability.

INTRODUCTION: Putting is considered one of the most important factors for scoring of professional Tour players (Alexander & Kern, 2005), and is accounts for 43% ±2% of the strokes per round (Pelz & Frank, 2000). Unlike the long game, where distance and dispersion are discussed, the short game, like putting, is more focused on accuracy and consistency (Hume, Keogh & Reid, 2005).
The putting stroke is divided into the Backswing phase (BACKSWING) and the Downswing phase (DS) (Delay, Nougier, Grealy, & Coello, 1997). BACKSWING is defined from address position (BA) to top of backswing (BT); DS is defined from BT to the finish position in the follow-through (FT); impact time (IMP) is defined as the time from BT to impact. Even though rhythm and timing also varies among elite players, rhythm (BACKSWINGRHYTHM, ratio of BACKSWING/IMP time) and impact timing (TIMING, ratio of IMP/DS time) are important factors for consistency and feel in a putting stroke (Marquardt, 2007).
Past research mainly focused on the putting performance between competency levels, and results have showed significant differences between handicap levels, with the better golfers having shorter BACKSWING, longer amplitude for FT, and longer stroke duration (Delay et al., 1997; Paradisis & Rees, 2002; Lee, Ishikura, Kegel, Gonzalez, & Passmore, 2008); and some studies suggested a slower velocity at impact for better players (Delay et al., 1997).
Since the rules for golf equipment on "adjustability" have been changed by the USGA and R&A in 2008/01/01, golf club designs have been coming out with innovative adjustable features that help to increase the performance of the golfers through "optimization". According studies have focused on the "long game" golf clubackswing (Neal, Abernethy, Moran, & Parker, 1990; Lindsay, Horton, & Paley, 2002; Shan, Betzler, & Dunn, 2008), other studies have examined influences of putter on shaft length (Pelz, 1990), putter shaft weight (Karlsen & Nilsson, 2007) or putter face groove design (Brouliette & Valade, 2008). The purpose of this study was to examine the influence the putter head weighting of the heel and the toe on the characteristics of the putting stroke.

METHODS: Seven advanced golfers were recruited to voluntarily participate in the study (age 42.6 ±2.3y, handicap 9.5 ±1.4). Frequency of playing was minimum of 2 rounds of golf per month. The design of the subjects own putter needed to match to the test putters design (blade-type with peripheral weighting).
The basic specification for the test putters were chosen to a blade-typed putter with peripheral weighting, loft of 4°, lie of 71°, swing weight of D2, length of 34 inches and 350 grams for head weight. Five putters of the same designs were used for this study. Weights were installed according to the test protocol in toe and heel sockets, with a combination of 30 grams of discretional weight in total. The standard putters (Std) had a balanced weighting

with 15g each at the heel and the toe, the two heel-weighted putters had 10g (H1) and 20g (H2) heavier weighted towards the heel, and the toe-weighted putters were 10g (T1) and 20g (T2) heavier weighted towards the toe.
The putting strokes were measured using a three-dimensional kinematic ultrasound system (SAM PuttLab system, Science & Motion Sports GmbH) where a triplet with three sensors has to be attached to the shaft. The sampling rate of the positional data was 70 Hz per marker. The analysis was done with SAM Puttlab 2010 software which includes specific data analysis and filtering techniques for processing human movement data (Marquardt & Mai, 1994). The experiment took place in an indoor studio on an artificial turf surface with a Stimp reading of 10. Golfers warmed-up before practicing with their own putter prior to experiment.
The weights were covered with tape and the putters were randomly given to the subjects to minimize the effects on the learning progress (Fairweather, 2002). The golfers were encouraged to go through their normal pre-shot routine prior to each putt, and ten putts were collected per setting. After recording the strokes, parameters like BACKSWING's displacement and timing, DS's displacement, timing before impact and after impact, velocity at impact, maximum acceleration, stroke rhythm and timing of impact, were calculated and used to analyze the different dimensions of the putting stroke.
Data were processed with SPSS 19.0 software. ANOVA and post-hoc tests were used to test differences at α=0.5 level.

RESULTS: Table 1 shows the results for the different weight settings for Backswing's (BACKSWING) and Downswing's (DS) displacement and timing (Table 1). Kinematic parameters in the DS, velocity at impact (IMP) and maximum acceleration (AMAX) are shown in Table 2. Lastly, the stroke's rhythm (BACKSWINGRHYTHM) and timing are shown in Table 3.

Table 1: Summary for backswing and downswing stroke parameters with various adjustable weighting (mean±SD).

Definition	Parameters	Std Standard	H1 More- Heel	H2 Most- Heel	T1 More- Toe	T2 Most- Toe
Backswing:	Displacement (m)	0.22±0.01	0.22±0.01	0.21±0.01	0.21±0.01	0.19±0.01**
	Time(sec)	0.63±0.03	0.64±0.02	0.63±0.04	0.66±0.03	0.67±0.04**
Downswing	Displacement (m)	0.59±0.01	0.53±0.01	0.57±0.03	0.61±0.02	0.60±0.02
	Time(sec)	0.77±0.03	0.78±0.02	0.77±0.02	0.81±0.04**	0.82±0.01**
Top of Backswing to Impact	Time(sec)	0.36±0.01	0.37±0.02	0.36±0.01	0.35±0.01	0.37±0.01
Impact to Follow-through	Displacement (m)	0.37±0.01	0.31±0.02	0.36±0.02	0.40±0.01	0.41±0.01
	Time(sec)	0.40±0.03	0.40±0.15	0.41±0.03	0.46±0.04**	0.44±0.04**

Significant level relative to Std (standard setting): *α=0.05, **α=0.01
Std (Standard weight setting, both 15g); **H1** (more-heel, 20g in heel, 10g in toe), **H2** (most-heel, heel 25g, toe 5g); **T1** (more-toe, 10g in heel, 20g in toe), **T2** (most-toe, 5g in heel, 25g in toe).

Table 2: Downswing's kinematics parameters with various adjustable weightings (mean±SD).

Definition	Parameters	Std Standard	H1 More- Heel	H2 Most- Heel	T1 More- Toe	T2 Most- Toe
Downswing Kinematics	IMP Velocity (m/s)	1.43±0.65	1.40±0.04	1.27±0.04**	1.45±0.03	1.47±0.02
	AMAX (m^2/sec)	5.28±0.65	5.66±0.21*	5.65±0.29*	5.07±0.51**	4.91±0.59**

Significant level relative to Std (standard setting): *α=0.05, **α=0.01
IMP velocity (Velocity at Impact); **AMAX** (Maximum Acceleration)
Std (Standard weight setting, both 15g); **H1** (more-heel, 20g in heel, 10g in toe), **H2**(most-heel, heel 25g, toe 5g); **T1**(more-toe, 10g in heel, 20g in toe), **T2**(most-toe, 5g in heel, 25g in toe).

Table 3: Summary for Stroke's Rhythm with various adjustable weightings (mean±SD).

Definition	Parameters	Std Standard	H1 More- Heel	H2 Most- Heel	T1 More- Toe	T2 Most- Toe
Rhythm	Backswing Rhythm	1.74±0.04	1.71±0.06 **	1.74±0.05	1.87±0.06 **	1.82±0.05 **
	Timing	0.47±0.02	0.48±0.02	0.47±0.02	0.43±0.01 **	0.45±0.02 **

Significant level relative to Std (standard setting): *α=0.05, **α=0.01
BACKSWINGRHYTHM (relation of BACKSWING / IMP time);TIMING (relation of Impact time / DS time)
Std (Standard weight setting, both 15g); **H1** (more-heel, 20g in heel, 10g in toe), **H2**(most-heel, heel 25g, toe 5g); **T1**(more-toe, 10g in heel, 20g in toe), **T2**(most-toe, 5g in heel, 25g in toe).

DISCUSSION: During backswing phase, the toe-weighted were shorter and had longer duration, while the heel-weighted condition showed no differences. Significant differences were found with T2, both the backswing displacement was shorter (p<.001) and backswing duration was longer (p<.001) which was not found for the long game (Shan et al., 2008). The shorter displacement but longer duration could suggest a more smooth putting stroke. The velocity at impact still maintains higher speed than other weightings which suggest better efficiency and trait of higher proficiency (Delay et al., 1997).
From top of backswing to impact phase, there were no significant differences were found and impact timings were all close the typical range also found in Tour players of 317ms ±35 ms (Marquardt, 2007). At impact position, the toe-weighted conditions showed comparably more efficiency, similarity trend with other racquet sport (Cross, 2001), even with a shorter backswing; H2 showed significantly slower velocity at impact (p<.001) even with a larger maximum acceleration. This could even suggest that the golfers were voluntarily increasing the speed, which could also lead to inconsistency (Karlsen et al., 2007). From impact to end of follow-through, no significant effects were found for displacement while toe-weighting showed significantly longer duration (p<.001). The toe-weighting might cause larger momentum on the downswing which has been seen in better players with a longer follow-through (Craig et al., 2000). Looking at the downswing phase as a whole, the displacement tends to be shorter for heel-weighting while displacement for toe-weighting tends to be slightly longer. Duration for T1 and T2 were significantly longer (p<.001), and were closer to Tour player's duration of 810ms±31ms (Marquardt, 2007). While toe-weighting results in longer downswing duration, heel-weighting seems to creates a larger moment of inertia similar to a heavier shaft (Karlsen et al., 2007).
Looking at the acceleration during the downswing phase, the heel-weighted condition a significantly larger magnitude of acceleration (AMAX) was found (p<.05), however the toe-weighted condition showed the opposite (p<.001). Looking at backswing rhythm, toe weighting resulted in significant longer rhythm (p<.001), whereas heel weighting resulted in a slightly shorter rhythm, but all were shorter than the Tour players rhythm of 2.2±0.11 (Marquardt, 2007). Looking at timing of the downswing phase, toe-weighting showed significant shorter timing (p<.001), and are closer to the Tour players timing of 0.39±0.04 (Marquardt, 2007). Overall, the toe-weighting shows characteristics of the putting stroke comparable to skilled players, like shorter backswing, longer follow-through and longer rhythm; heel-balanced on the other hand seems to result in a larger moment of inertia that affects the putting stroke.

CONCLUSION: The results of this study suggest that adjusting the putter head balance with additional weighting offers an effective method to influence the characteristics of the putting stroke even for skilled golfers. Significant effects were mostly found for moving more weight to the toe of the putter. Toe-balanced putters seem to promote a more efficient stroke in at least some golfers, which also tend to result in longer duration. In contrast, heel-balance might even impair the stroke, but this will depend on the stroke types, i.e. rotational versus straight path. Subjects' own putters were similar to the standard putter used in the test, but the findings might also depend on the individual putting style.
The findings suggest that a more precise fitting of the head balance and weighting of a putter according to his/her putting stroke and skill level could help to improve the performance on the green. Putter designs should reflect preferred mechanical properties, but more focus should be set on identifying the best biomechanical fit for a player. Thus the study confirms

the importance of putter fitting in general and underpins the value of biomechanical testing for sport equipment optimization.
Further studies should evaluate the relation between individual stroke types and relevant fitting parameters, which also might be adjusted to different lengths of putts.

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