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The required number of trials for biomechanical analysis of a golf swing

Anna C. Severin[1], **Sally G. Barnes**[1], **Stewart A. Tackett**[1], **C. Lowry Barnes**[1], **Erin M. Mannen**[1,*]

[1]Department of Orthopaedic Surgery, University of Arkansas for Medical Sciences, Little Rock, AR, USA

Abstract

The increasing interest in the biomechanical analysis of the golf swing warrants establishing the minimum number of trials required to obtain reliable data. Several such methods have been suggested previously for other movement tasks, and it has been shown that the number of required trials depends on the method used and on the task examined. This study aimed to compare three methods of reliability; a sequential average, intraclass correlations, and a modified version of the standard error of measurement (SEM_{ind}). Kinematic and kinetic data of ten recreational golfers performing fifteen shots with both a six-iron and a driver was collected using a ten-camera motion capture system and force platforms. Range-of-motion, velocity, joint moments, and ground reaction forces were extracted and analysed using the three methods. The sequential average method yielded the highest number of required trials (12), while the intraclass correlations and SEM_{ind} both resulted in lower numbers of required trials (4). Considering the variability between subjects and strengths and limitations of the various methods, we conclude that 8 trials is sufficient for biomechanical analyses of a golf swing and recommend the SEM_{ind} method for determining how many swings should be collected.

Keywords

reliability; kinematics; kinetics; movement stability; variability

Introduction

Golf is an increasingly popular sport, with the National Golf Foundation reporting over 32 million participants in 2017 in the United States alone (The National Golf Foundation). It is therefore unsurprising that the sport is well-documented in the literature (Higdon, Finch,

*__Corresponding Author__: Erin M. Mannen, PhD, 4301 W. Markham St, Slot 531, Little Rock, AR 72205, (501) 686-5416, EMannen@uams.edu.
Anna C. Severin, 4301 W. Markham St, Slot 531, Little Rock, AR 72205
Sally G. Barnes, 4301 W. Markham St, Slot 531, Little Rock, AR 72205
Stewart A. Tackett, 4301 W. Markham St, Slot 531, Little Rock, AR 72205
C. Lowry Barnes, 4301 W. Markham St, Slot 531, Little Rock, AR 72205

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Leib, & Dugan, 2012; Nesbit, 2005; Newman, Saroki, Briggs, & Philippon, 2016). The golf swing has been of particular interest for biomechanical researchers, who traditionally collect data from volunteers performing a designated number of trials (Egret, Vincent, Weber, Dujardin, & Chollet, 2003; Gulgin, Armstrong, & Gribble, 2009; Hara et al., 2016). The number of trials collected in golf research has varied greatly, and ranges from two (Meister et al., 2011) to twelve (MacKenzie, Ryan, & Rice, 2015), with many studies using five (Horan, Evans, & Kavanagh, 2011; Horan, Evans, Morris, & Kavanagh, 2010; Zheng, Barrentine, Fleisig, & Andrews, 2008) or ten trials (Egret et al., 2003; Smith, Roberts, Kong, & Forrester, 2017; Smith, Roberts, Wallace, Kong, & Forrester, 2016).

Research has shown that a single trial of any task does not provide representative data of the participant's movement pattern (Gore, Marshall, Franklyn-Miller, Falvey, & Moran, 2016; Hamill & McNiven, 1990; James, Herman, Dufek, & Bates, 2007) and an increasing amount of studies are aiming to establish the minimum number of trials required to achieve stability and consistency in movement tasks. Both cyclic (Racic, Pavic, & Brownjohn, 2009; Riva, Bisi, & Stagni, 2014) and non-cyclic movements (Amiri-Khorasani, Osman, & Yusof, 2010; Gore et al., 2016) have been analysed using statistical measures of reliability, showing that the required number of trials depends on the task.

A common method used to determine reliability is a sequential average method, where the criterion is determined based on a standard deviation (SD) value (Bates, Osternig, Sawhill, & James, 1983; Hamill & McNiven, 1990; Rodano & Squadrone, 2002). Another common statistic is the intraclass correlation (ICC), (Amiri-Khorasani et al., 2010; Kristensen et al., 2014; Riva et al., 2014) which provides a measure of consistency of the scores of individuals (relative consistency) (Weir, 2005). These two methods are considerably different from each other and, importantly, when applied to the same data, they produce quite different results (James et al., 2007; Racic et al., 2009). Further, a more recent study by Gore et al. (2016) highlighted limitations of these methods and questioned their ability to determine the required number of trials for a given task. The authors presented an alternative method that consisted of a modified version of the standard error of measurement (SEM). The traditional SEM provides a measure of absolute consistency, which involves the consistency of the rank of individuals within a group relative to others (Weir, 2005). The modified version of the SEM method involved calculating an SEM score that was individual for each participant (SEM_{ind}) by using their individual standard deviation (Gore et al., 2016). The authors suggested that their modification always would produce more conservative criteria than the traditional SEM method.

Each of the three methods (sequential average, ICC, and SEM_{ind}) can help researchers determine the number of trials needed for analyses of any task. However, to our knowledge, this has not been done previously with respect to a golf swing. Biomechanical analyses of the golf swing often assess displacement, angular velocity and joint moments (Egret et al., 2003; Gulgin et al., 2009; Horan et al., 2010; Meister et al., 2011). This study therefore aimed to assess displacement, angular velocity and joint moments and (1) identify the minimal required number of trials of the golf swing and (2) compare the results of the sequential averaging analysis, ICC, and SEM_{ind} methods. It is hypothesised that the number of trials required would differ between the three methods.

Methods

Participants

Ten recreational male golfers with at least ten years of golf experience volunteered for participation (height: 1.77±0.01 m, weight: 82.6±5.8 kg, age: 39.0±17.4 yrs., self-reported handicap: 7.8±4.7). All participants were right-handed. At the time of testing, participants had been free from injury within the last six months and had no previous orthopaedic surgeries. Each participant provided written informed consent prior to data collection in agreement with the University of Arkansas for Medical Sciences Institutional Review Board approval.

Procedure

The participants were equipped with 39 low-mass 14 mm diameter retroreflective markers on designated anatomical landmarks in accordance with the Vicon Plug-In gait full body modelling (Vicon®, 2002). Markers were attached to the manubrium, xiphoid process, the seventh cervical vertebra, the tenth thoracic vertebra, the right scapula, bilaterally to the acromion process, upper arm, lateral epicondyle of the humerus, forearm, medial and lateral styloid process head of the third metacarpal, anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral epicondyle of the femur, lateral shank, lateral malleolus, calcaneus, head of the second metatarsal and anterior and posterior skull. Kinematic data were recorded using a ten-camera motion capture system (Vicon, Oxford Metrics, Oxford, UK) operating at 100Hz, and kinetic data were recorded using force platforms (AMTI, Watertown, MA, USA) operating at 1000 Hz.

Based on previous research, two types of clubs were used for this study (Egret et al., 2003; Joyce, Burnett, Cochrane, & Ball, 2013), a six-iron and a driver. Following a five-minute self-selected warm up and a static capture, participants performed fifteen successful trials with each club. The participants used their own clubs and were asked to hit the ball at maximal effort while aiming at a 1.0 × 1.0 m target attached on a net four meters from the golf ball. Any trial that the participant reported to be a miss hit or unsatisfactory in any other way were excluded from the analysis. They were allowed 30 to 60 seconds rest between shots and five minutes' rest between clubs to prevent a fatigue effect.

Data processing

The kinematic data were labelled using Vicon Nexus software (Vicon, Oxford Metrics, Oxford, UK) and then transferred into Visual 3D (C-Motion, Germantown, MD, USA) for processing. Based on a residual analysis, the kinematic and kinetic data were filtered using 2Hz and 4Hz low-pass Butterworth filters, respectively. All data were time-normalised to 100 data points starting from the initiation of the backswing movement and the peak trunk rotation at the end of the follow through (Figure 1).

The global reference system was defined using standard Euler angle conventions where the positive Y-axis pointed in the direction of ball travel, the positive X-axis pointed posteriorly from the participant's perspective, and the positive Z-axis pointed vertically. The static trial provided the 0° segment and joint orientations for the local coordinate systems (Kawamoto, Miyagi, Ohashi, & Fukashiro, 2007). Trunk and hip motions are common focus points of biomechanical analyses in golfing tasks (Gulgin et al., 2009; Hara et al., 2016; Joyce et al., 2013; Smith et al., 2016), and were therefore selected for this study. Thus, kinematic variables of interest were the three-dimensional range of motion (ROM) and velocity of the hips and trunk. Kinetic variables included ground reaction forces of both feet (GRF), and three-dimensional joint moments at the hips, which were calculated using inverse-dynamics. Wherever necessary, data were converted to comply with conventional standards where flexion, adduction, and internal rotation were defined as positive rotations about the individual segment's X, Y, and Z-axes respectively. As all participants in this study were right-handed golfers, the left leg will henceforth be referred to as the leading leg and the right leg referred to as the trailing leg.

Statistical analysis

The statistical analyses were performed using SPSS statistical software (IBM, Chicago, IL, USA) and Microsoft Excel (Microsoft Corp., Redmond, WA, USA). Mean and SD values for the kinetic and kinematic variables were calculated for both clubs over all fifteen trials. A sequential averaging analysis was performed using the method described by James et al. (2007), using a bandwidth of ±0.25 SD (SD_{25}). Reliability analyses were performed on the variables of interest using the ICC (3,1) model in accordance with previous research (Gore et al., 2016; James et al., 2007; Racic et al., 2009). The ICC (3,1) scores were classified according to Portney and Watkins (2015) where <0.500 represented poor stability, 0.500–0.750 indicated moderate stability, and >0.750 indicated good stability. The trial number with the highest ICC (3,1) score represented the required number of trials (Gore et al., 2016; James et al., 2007; Racic et al., 2009).

Finally, the SEM_{ind} method proposed by Gore et al. (2016) was used, where one SEM_{ind} score was calculated for each participant using the individual's SD and the ICC (3,1) score for all fifteen trials. In addition, a paired t-test was used to test for differences in swing time from peak backswing to the end of the swing between the first and last trials to indicate the presence of fatigue as a possible covariate (Gore et al., 2016).

Results

The t-test showed no difference in swing time between the first and last swings with either club (six iron p= 0.379; driver p=0.698). The mean and SD values for the kinematic and kinetic variables over all fifteen trials are presented in Table 1.

The analysis showed that the minimal required numbers of trials varied depending on the method used (Table 2) and ranged from four to twelve. The SD_{25} method consistently indicated that at least ten trials were needed to reach stability in the golf swing, and was therefore the most conservative method of the three. The ICC scores were all larger than 0.750 thereby indicating good stability (ROM: 0.901, velocity: 0.945, GRF; 0.844 and joint moments: 0.858). The analysis suggested that the SEM_{ind} method often required six to eight trials, which was similar to the ICC (3,1) method. The SEM_{ind} method also had the lowest trial number of all methods, and indicated stability in joint moments after only four trials.

The analysis showed that the number of trials needed varied between the different biomechanical variables, although the variations were minimal.

Discussion and Implications

This study used three different methods to determine the minimal required number of trials required for biomechanical analyses of the golf swing. To the authors' knowledge, this is the first of such analyses on the biomechanical variables of golf swings, although researchers have previously highlighted the importance of such analyses for increased reliability of biomechanical data (James et al., 2007). The results from this study support previous studies in that the number of trials varies depending on the reliability method used and the biomechanical variable of interest (Gore et al., 2016; James et al., 2007; Racic et al., 2009), and thereby support the hypothesis. Our data indicated a required trial number ranging between four and twelve.

Agreeing with previous studies, our results indicate that the SD_{25} method is the most conservative out of the three methods, requiring ten to twelve trials to reach stability. The ICC method indicated that six to eight trials was needed, which was similar to earlier studies that examined jumping and landing tasks (James et al., 2007; Racic et al., 2009). The SEM_{ind} analysis resulted in trial numbers that were similar to those indicated with the ICC method. This partially supports previous research that reported the SEM_{ind} as the least conservative out of the three methods during a hurdle hop task (Gore et al., 2016). The trial numbers indicated by the ICC method in this study were smaller than those reported by Gore et al. (2016) while the SEM_{ind} scores of both studies were similar. As mentioned previously, the ICC calculation provides a measure of relative consistency, and therefore reflects between-subject variability. The participants in this study were recreational golfers, and the study design did not specifically require a certain handicap. It is therefore possible that the between-subject variability was quite large in our study, and thereby resulted in larger ICC scores after fewer trials (Weir, 2005).

The susceptibility of the ICC method to between-subject variability is another reason why the SEM_{ind} method has been recommended over both the traditional sequential averages and ICC methods, as it is the only technique that considers the individual error (Gore et al., 2016). It has been highlighted that the ICC method provides a measurement error that is relative to the heterogeneity of the subjects (Weir, 2005), and while the SEM_{ind} method is not completely unaffected by this limitation, the effect is lessened by using each subjects' individual SD (Gore et al., 2016). Therefore, in populations that are likely to have greater between-subject variability, like in this study, the SEM_{ind} method should be used in favour of the other techniques.

Researchers agree that numerous trials are required in biomechanical analyses (Amiri-Khorasani et al., 2010; Kristensen et al., 2014; Robinson & Gribble, 2008), and that the different reliability methods produce varying results (Gore et al., 2016; James et al., 2007; Racic et al., 2009). The number of trials in any biomechanical analysis should be based on the study task and how factors such as fatigue, testing duration and cost may affect the experiment. Participants in this study did not exhibit signs of fatigue after fifteen trials, and the reliability analysis suggests that for biomechanical analyses of people performing golf swing, researchers should consider using seven or eight trials. This study also estimated low numbers of required trials when using the SEM_{ind} method and due to limitations discussed previously regarding the ICC method, we agree with the SEM_{ind} is the most practical method for human movement tasks (Gore et al., 2016), especially when fatigue might be an issue.

The sample population in this study consisted of recreational golfers, and the lack of control for their skill level is a limitation to the design. It is likely that the differences in the participants' skills affected the results when using the ICC (3,1) method, and it is also possible that it affected number of trials each individual needed to obtain stability in their golf swing. However, research is yet to establish how individual skill levels may affect the number of trials required for stability to occur in recreational study subjects. This should be a focus in future investigations as an increased understanding of the implications of the level of skill on movement stability would benefit researchers across several fields. However, because we included golfers with a range of skill levels, our results may be more conservative than a study on only elite golfers.

Conclusions

In summary, this study suggests that the number of trials that should be collected for biomechanical research on participants during a golf swing ranges between four and twelve, and that seven or eight trials will suffice for most research projects. It also supports previous research in that the SEM_{ind} probably is the method most suitable for human movement tasks as it has fewer limitations and suggests a lower number of trials, which reduces the time required during testing and limits the risk for fatigue and injuries.

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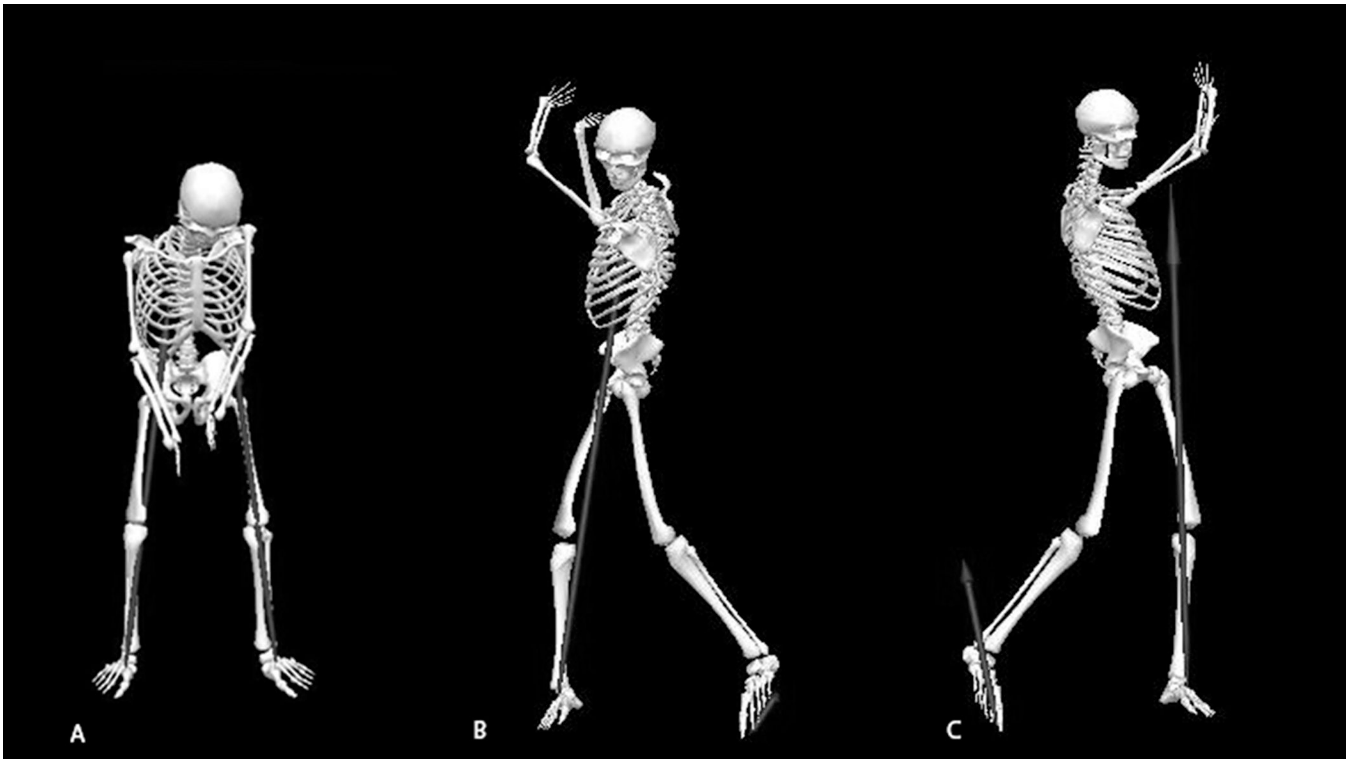

Figure 1.
Image of a motion analysis model showing the key positions used in this study; A – start of backswing, B – end of backswing, and C – end of swing.

Table 1.

Mean (SD) of the analysed variables for both clubs.

Variable		Six-Iron	Driver
Trunk	Flexion/Extension ROM (°)	25.22 (7.69)	19.95 (8.09)
	Lateral tilt ROM (°)	26.64 (8.71)	22.60 (8.73)
	Axial rotation ROM (°)	56.21 (12.13)	53.47 (10.53)
	Peak flexion angular velocity (°/s)	126.26 (36.52)	112.82 (32.61)
	Peak lateral angular velocity (°/s)	182.60 (42.37)	206.88 (62.26)
	Peak axial rotation angular velocity (°/s)	388.24 (59.50)	452.45 (65.66)
Leading leg	Vertical GRF (N/Bw)	1.37 (0.18)	1.41 (0.23)
	Anteroposterior GRF (N/Bw)	0.22 (0.05)	0.24 (0.08)
	Mediolateral GRF (N/Bw)	0.07 (0.02)	0.06 (0.02)
	Hip flexion/extension ROM (°)	35.79 (8.58)	34.07 (10.53)
	Hip adduction/abduction ROM (°)	47.30 (8.50)	43.44 (9.48)
	Hip internal/external rotation ROM (°)	20.14 (6.38)	21.13 (6.82)
	Hip flexion angular velocity (°/s)	293.37 (79.02)	276.24 (61.41)
	Hip abduction angular velocity (°/s)	179.40 (55.6)	153.25 (72.78)
	Hip internal rotation angular velocity (°/s)	138.57 (39.00)	132.42 (51.12)
	Hip flexion moment (Nm/kg)	1.06 (0.29)	1.25 (0.37)
	Hip abduction moment (Nm/kg)	1.29 (0.34)	0.86 (0.31)
	Hip internal rotation moment (Nm/kg)	0.54 (0.19)	0.63 (0.23)
Trailing leg	Vertical GRF (N/Bw)	0.79 (0.10)	0.84 (0.10)
	Anteroposterior GRF (N/Bw)	0.19 (0.05)	0.21 (0.04)
	Mediolateral GRF (N/Bw)	0.15 (0.04)	0.18 (0.03)
	Hip flexion/extension ROM (°)	47.72 (10.0)	51.83 (10.61)
	Hip adduction/abduction ROM (°)	42.23 (7.28)	38.19 (5.99)
	Hip internal/external rotation ROM (°)	19.69 (5.76)	21.40 (8.78)
	Hip extension angular velocity (°/s)	60.66 (20.15)	229 (63.48)
	Hip abduction angular velocity (°/s)	233.94 (53.36)	234.00 (97.22)
	Hip external rotation angular velocity (°/s)	187.76 (72.10)	195.86 (89.82)
	Hip extension moment (Nm/kg)	2.03 (0.42)	0.93 (0.43)
	Hip abduction moment (Nm/kg)	1.18 (0.31)	1.15 (0.30)
	Hip external rotation moment (Nm/kg)	0.42 (0.15)	0.45 (0.15)

ROM – range of motion, GRF – ground reaction force, Bw – body weight.

Table 2.

Mean (SD) required trials for different biomechanical variables for each club as suggested by the different methods.

		ROM (°)	Angular velocity (°/s)	GRF (N/Bw)	Moments (Nm/kg)
Six-Iron	SD_{25}	10.7 (2.9)	9.6 (3.0)	10.2 (3.3)	9.5 (3.4)
	ICC (3,1)	7	7	8	6
	SEM_{ind}	6.7 (2.7)	8.0 (2.2)	7.2 (2.7)	6.3 (2.8)
Driver	SD_{25}	10.5 (2.7)	11.4 (2.4)	10.9 (2.7)	10.8 (2.7)
	ICC (3,1)	7	4	6	7
	SEM_{ind}	6.0 (2.5)	6.6 (2.1)	5.5 (2.5)	3.5 (2.1)
Overall	SD_{25}	10.5 (2.8)	10.5 (2.7)	10.5 (3.0)	10.2 (3.1)
	ICC (3,1)	7	6	7	7
	SEM_{ind}	6.5 (2.6)	7.3 (2.1)	6.5 (2.6)	5.5 (2.5)

ROM – range of motion; ICC (3,1) – intraclass correlation model 3,1; SD_{25} – the sequential averaging method used; SEM_{ind} – the individual standard error of measurement method used, Bw – body weight.