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Comparison of Three Normalization Methods for 3D Joint Moment in the Asymmetric Rotational Human Movements in Golf Swing Analysis

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Abstract

Purpose: From the perspective of biomechanics, joint moments quantitatively show a subject's ability to perform actions. In this study, the effect of normalization in the fast and asymmetric motions of a golf swing was investigated by applying three different normalization methods to the raw joint moment. **Methods:** The study included 13 subjects with no previous history of musculoskeletal diseases. Golf swing analyses were performed with six infrared cameras and two force plates. The majority of the raw peak joint moments showed a significant correlation at $p < 0.05$. Additionally, the resulting effects after applying body weight (BW), body weight multiplied by height (BWH), and body weight multiplied by leg length (BWL) normalization methods were analyzed through correlation and regression analysis. **Results:** The BW, BWH, and BWL normalization methods normalized 8, 10, and 11 peak joint moments out of 18, respectively. The best method for normalizing the golf swing was found to be the BWL method, which showed significant statistical differences. Several raw peak joint moments showed no significant correlation with measured anthropometrics, which was considered to be related to the muscle coordination that occurs in the swing of skilled professional golfers. **Conclusions:** The results of this study show that the BWL normalization method can effectively remove differences due to physical characteristics in the golf swing analysis.

Keywords: Asymmetrical motion, Correlation regression analysis, Joint moment, Normalization, Physical characteristic

Introduction

Joint moment, which is considered as a rotational force generated at the anatomical surface of each joint during motion, is calculated using joint dynamics as influenced by ground reaction forces. From the perspective of biomechanics, joint moment quantifies the ability to perform a motion. Additionally, joint moment has been used as a joint loading parameter that is closely related to injury and has been used to analyze the differences between groups or within a group (Winter, 1990; Scott and Winter 1990; Mullineaux et al., 2006). Nevertheless, because of the anthropometrics affecting the raw joint moment, such as height and weight, which differ according to the subject, analyzing the joint motion is problematic. Therefore, performing a normalization process to reduce the differences has been recommended (Hart et al., 2010).

Joint moment is generally normalized using linear normalization but a normalization method depending on the differences in position and velocity has not been

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established. Joint moment normalization using different anthropometric values has been performed in many previous studies. Body weight (BW) (Harding et al., 2012; Choi et al., 2013; Oh et al., 2013), body weight multiplied by height (BWH) (Ferber et al., 2003; Hunt et al., 2006; Lewek et al., 2011; Silvernail et al., 2013), and body weight multiplied by leg length (BWL) (Hsu et al., 2007; Larsen et al., 2010) are typical examples of linear normalization methods. For this reason, in recent years researchers have used the human gait to find an appropriate normalization method (Moisio et al., 2003; Wannop et al., 2012). According to Moisio et al. (2003), 80% of the differences in the peak joint moments between subjects could be removed using the BWH normalization method during gait analysis. The results from previous studies, however, are difficult to apply to different motions since only a limited normalization effect is apparent in the gait, which is usually symmetrical in locomotion between left and right at normal movement speeds and has less rotation when compared to other movements.

The majority of human body movements are asymmetrical and performed in short periods of time and accompanied with large rotational forces at each joint (Buckley et al., 2006). However, there has been no related study investigating the appropriate normalization method. In this study, the effect of normalization was investigated using golf swing as an example. A golf swing is performed with continuous and complex rotational movements of each joint of the body. Of the various swing phases, the downswing phase involves the majority of the mechanical properties, which is important for maximizing club head speed (Horan et al., 2010). The joint moments generated in a downswing have been analyzed previously in a number of studies (Gatt et al., 1998; Lynn and Noffal, 2010; Somjarod et al., 2011). However, the raw joint moment data were not normalized, or were simplified by dividing the moment by the weight of the subject, in the normalization processes of the previous studies. Therefore, whether or not the different joint moment values clearly separate the experimental groups is questionable.

In this study, the effect of normalization was investigated by applying three different normalization methods to the raw peak joint moment occurring in a golf swing, which involves many rotations and fast movement. Specifically, using a correlation analysis between the normalized peak joint moments and the normalized parameters that are used for normalization, an efficient normalization method in golf swing analysis is proposed.

Materials and Methods

Subject and apparatus

Thirteen professional golfers (8.2 ± 4.8 years average career; 8 males and 5 females) with no history of musculoskeletal diseases were recruited as subjects. The experimental procedures were approved by a local ethics committee and informed consent was signed by all the subjects. The participants were all right-handed, and all were members of the Professional Golfers' Association (PGA) or Ladies Professional Golf Association (LPGA). The physical characteristics of the professional golfers are given in Table 1. For the experimental apparatus, six infrared cameras (Vicon Motion Systems, Oxford, UK) along with the SB-Clinic software (SWING BANK Ltd., Korea) were used to capture swing motions with a capturing speed of 120 Hz. In addition, data of the ground reaction forces during each golf swing were collected using two force plates.

Procedure

Based on the modified Helen Hayes Hospital marker set, 16 optical markers were attached to key anatomical locations on the pelvis and lower body of each subject (Choi et al., 2014). Additionally, four optical markers were attached to the golf club to extract trajectories and coordinates. Each subject was asked to warm up through a large dynamic movement and static stretching (Fradkin et al., 2004) and perform practice swings in order to adapt to the indoor laboratory environment before the actual experiment. Each subject used their preferred driver and five golf swings were performed. Five swing phases were divided based on the vertical axis coordinate of the golf club, and the swing phase used for the analysis was limited to the downswing, during which the highest

Table 1. Subject characteristics (mean ± standard deviation)

Subjects	Age (years)	Height (cm)	Weight (kg)	Leg Length (cm)	Downswing Duration (s)
n = 13	29.1 ± 8.2	176.3 ± 7.9	69.2 ± 11.4	91.8 ± 4.5	0.31 ± 0.04

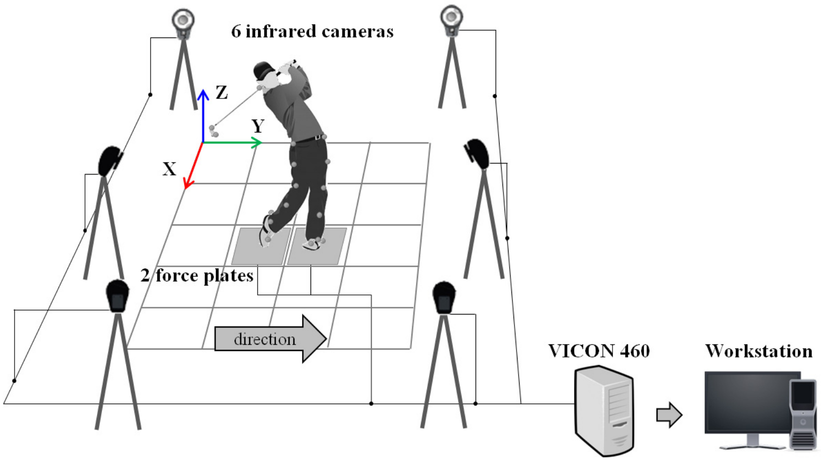

Figure 1. Experimental system schematic for golf swing analysis.

moment is generated. In terms of motion, the downswing phase was defined as beginning from the end of the backswing, where the pelvis stops the rotation from the target side, then begins to rotate toward the target, and stops at the impact when the golf club hits the ball (Wheat et al., 2007). The peak of the backswing was taken as the instant of greatest moment. The experimental setup for the swing analysis is shown in Figure 1.

Data processing and statistical analysis

The marker trajectory data acquired during the golf swing were filtered using a zero leg 4th low-pass Butter worth filter and the cutoff frequency was set at 10 Hz according to a residual analysis (Choi et al., 2015). Using the joint center calculated from the trajectory data and the ground reaction force data, the joint moment data were acquired from SB-Clinic (SWING BANK Ltd., Korea). The acquired lower body joint moments were 18 in total and were as follows: left and right ankle joint flexion/extension, abduction/adduction, and axial rotation; left and right knee joint flexion/extension, abduction/adduction, and axial rotation; left and right hip joint flexion/extension, abduction/adduction, and axial rotation. Among the joint moment data acquired for the entire golf swing, the peak joint moments during the downswing were sampled and were used to analyze the significant correlations and dependencies between the normalization parameters by correlation and regression analysis. After normalizing the raw peak joint moment using the BW, BWH, and BWL methods, the normalization effects were further analyzed through correlation and regression analysis. All the statistical processes were performed using the SAS statistical package (Version 9.13, SAS Institute, Cary, NC, USA) with the levels of statistical significance set to $p < 0.05$, $p < 0.01$.

Results and Discussion

Table 2 gives the correlation and regression analysis results between the normalized parameters and the peak joint moments occurring in the joints during the downswing of the 13 golfers. The 18 different peak joint moments occurring in the lower body joint during the downswing phase were linearly correlated with body weight, height, and leg length between 0.09~0.94. In addition, the results of the regression analysis between the peak joint moments and normalization parameters showed a dependency of the peak joint moment on the weight, height, and leg length with $p < 0.05$ and $p < 0.01$ except for the left ankle joint abduction/adduction moment, left knee joint abduction/adduction moment, left hip joint axial rotation moment, right ankle flexion/extension, and right hip joint axial rotation moment.

According to the results in Table 2, the left ankle joint abduction/adduction moment, left knee joint abduction/adduction moment, left hip joint axial rotation moment, and right hip joint axial rotation moment that occurs during a golf swing did not show significant dependencies on normalization parameters in the regression analysis. Contrary to the results of previous studies that were based on gait movement and showed statistical significance ($p < 0.05$) between the normalization parameters and joint moment variables (Moisio et al., 2003), the low normalization parameter dependencies in golf swing are considered to

Table 2. Correlation and regression analysis results between raw peak joint moment and normalization parameter. Bold values represent significant correlations

Raw peak joint moment		Normalization parameter		
		Body weight	Body weight × height	Body weight × leg length
		r^2	r^2	r^2
Left ankle	Flexion/extension	0.67**	0.71**	0.70**
	Abduction/adduction	0.04	0.04	0.07
	Axial rotation	0.53**	0.49**	0.40**
Left knee	Flexion/extension	0.30*	0.24*	0.18**
	Abduction/adduction	0.07	0.08	0.13
	Axial rotation	0.78**	0.74**	0.62**
Left hip	Flexion/extension	0.50**	0.49**	0.46**
	Abduction/adduction	0.17*	0.18*	0.09*
	Axial rotation	0.11	0.1	0.03
Right ankle	Flexion/extension	0.10*	0.12	0.21
	Abduction/adduction	0.22*	0.18*	0.23*
	Axial rotation	0.85**	0.81**	0.74**
Right knee	Flexion/extension	0.29**	0.28**	0.28**
	Abduction/adduction	0.23*	0.20*	0.09*
	Axial rotation	0.94**	0.90**	0.85**
Right hip	Flexion/extension	0.53**	0.56**	0.57**
	Abduction/adduction	0.92**	0.89**	0.83**
	Axial rotation	0.02	<0.01	<0.01

* $p < 0.05$, ** $p < 0.01$

be related to the muscle cooperation that occurs in the swing of skilled professional golfers (Demircan et al., 2012).

Table 3 describes the effect of normalization on the peak joint moments for the downswing phase for the 13 golfers. All peak moments were normalized using the BW, BWH, and BWL methods. Correlation and regression analysis was performed subsequently. When applying the BW normalization method, which is the mostly used method in golf analysis, only 8 out of 18 peak joint moments were normalized (left knee flexion/extension, all three left hip joint moments, right knee flexion/extension and adduction/abduction, and right hip flexion/extension and rotational moment). The results from the BW normalization indicate that eight peak moments showed statistical nonlinear relationship with and dependency on weight, height, or leg length ($p > 0.05$). Among the normalized peak joint moments when applying the BWH method, a total of 10 peak joint moments (left ankle axial rotation moment, left knee flexion/extension and axial rotation, all three left hip joint moments, right knee flexion/extension and adduction/abduction, and right hip flexion/extension and rotational moment) no longer exhibited significant correlation with or dependency on the normalization parameter. In addition, as a result of the BWL normalization, the following 11 peak joint moments exhibited the best normalization effect: left ankle axial rotation moment, left knee flexion/extension and axial rotation, all three left hip joint moments, right ankle adduction/abduction, right knee flexion/extension and adduction/abduction, and right hip flexion/extension and rotational moment.

The results of the present study, which was based on a professional golfer's swing and which had a maximum club-head speed of 44.7 m/s, were compared with the study on gait, which had an average speed of 1.2 m/s. It was found that the normalization effect improved dramatically from 40% (BW) to 80% (BWH) in the gait experiments (Moisio et al., 2003; Mullineaux et al., 2006), whereas 44.4% (BW), 55.6% (BWH), and 61.1% (BWL) normalization effects were observed for the golf swing experiment. There were no existing normalization methods that could significantly normalize the 18 peak joint moments. Most of the previous golf swing related research has utilized

Table 3. Correlation and regression analysis results for the normalization effect quantification. Bold values represent effective normalization, which implies no significant correlation

Normalized peak joint moment		Normalization parameter					
		Body weight		Body weight x height		Body weight x leg length	
		r^2	p-value	r^2	p-value	r^2	p-value
Left ankle	Flexion/extension	0.45	<0.01**	0.35	<0.01**	0.45	<0.01**
	Abduction/adduction	0.25	<0.01**	0.19	<0.01**	0.33	<0.01**
	Axial rotation	0.27	0.018*	<0.01	0.978	<0.01	0.964
Left knee	Flexion/extension	<0.01	0.860	0.11	0.300	0.03	0.403
	Abduction/adduction	0.35	<0.01**	0.26	<0.01**	0.46	<0.01**
	Axial rotation	0.31	<0.01**	0.04	0.237	0.05	0.279
Left hip	Flexion/extension	<0.01	0.798	0.06	0.236	0.02	0.511
	Abduction/adduction	0.02	0.542	<0.01	0.283	0.09	0.156
	Axial rotation	0.04	0.308	0.03	0.097	0.15	0.054
Right ankle	Flexion/extension	0.18	0.033*	0.34	<0.01**	0.20	0.023*
	Abduction/adduction	0.27	0.017*	0.22	0.016*	0.13	0.069
	Axial rotation	0.68	<0.01**	0.34	<0.01**	0.45	<0.01**
Right knee	Flexion/extension	0.06	0.247	0.05	0.515	0.03	0.407
	Abduction/adduction	<0.01	0.989	<0.01	0.416	0.06	0.234
	Axial rotation	0.87	<0.01**	0.62	<0.01**	0.69	<0.01**
Right hip	Flexion/extension	0.04	0.325	<0.01	0.879	<0.01	0.637
	Abduction/adduction	0.80	<0.01**	0.56	<0.01**	0.62	<0.01**
	Axial rotation	0.03	0.392	<0.01	0.245	0.09	0.146

* $p < 0.05$, ** $p < 0.01$

the least effective BW normalization method (Gatt et al., 1998; Lynn and Noffal, 2010; Somjarod et al., 2011). The relatively low normalization effect in the golf swing experiment is considered to be due to the following reasons: the particular body motion required for a proper golf swing, which requires two feet fixed to the ground; the external forces generated from the golf club-head mass while in motion; and the swing having an aperiodic motion. The low normalization effect implies that the absolute standard in gait is not applicable to golf swing experiments and it suggests that a new normalization method needs to be developed.

Conclusions

In biomechanics, motion analysis using joint moments allows for quantitative comparisons of motion performance between subjects. For a more meaningful analysis, a normalization process that eliminates the effect of the subject's anthropometrics on joint moments is recommended. A correlation and regression analysis showed that the BWL normalization method is the most effective, followed by the BWH and BW methods, in that order. Numerically speaking, BWL was the best normalization method. The more complete normalizing effect between the BWL and BWH methods was difficult to determine as both had similar numerical values.

Studies analyzing the effect of normalization on different motions (other than gait) are nonexistent, and the existing research related to golf has only focused on the phenomenological analysis of the swing motion. This study, which used the golf swing as an example, proposes the effect of application of normalization methods derived from the existing gait analysis and provides basic information for the establishment of a new normalization parameter selection and method for efficient data analysis. However, no method could normalize all the 18 peak joint moments. Therefore, future studies analyzing the precise motion control mechanism of asymmetrical motion should be carried out with different types of human locomotion and different subject groups. Based on an in-depth review of the motion control mechanism, extracting variables maintaining simultaneous independencies between the variables and the dependencies of joint moments is required in order to establish an effective normalization method.

Conflict of Interest

The authors have no conflicting financial or other interests.

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