DOES HAND SPEED RELATE TO CLUB HEAD SPEED OR BALL SPEED DURING A GOLF SWING?

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Many golf swing analyses use club or ball speed to indicate performance, although these are difficult to obtain using motion capture. This study examined the relationship between hand speed and club head and ball speeds to examine if hand speed can indicate performance and if different capturing frequencies affect these relationships. A 10-camera Vicon system recorded golfers performing eight golf swings (500 Hz n=11, 100 Hz n=15). A TrackMan system recorded club head and ball speed. The resultant hand speed was calculated at peak velocity, the lowest position of the hands, and at ball impact. Hand speed at ball impact and club head speed had the strongest relationship (r=0.501, p<0.001), though most correlations were r<0.400. Higher capturing frequency had better relationships with the performance outcomes, and the ball impact was the best time point for analysis.

KEYWORDS: performance, kinematics, methodology.

INTRODUCTION: The golf swing is a popular motion in biomechanics, with previous research having detailed the motions of the performer, the club, and the ball (Brown, Selbie, & Wallace, 2013; Horan, Evans, Morris, & Kavanagh, 2010). However, it is a quick movement and results in club head speeds of up to $50m\cdot s^{-1}$ and ball speeds of $70m\cdot s^{-1}$ (Horan et al., 2010). One or both of these variables are often included in biomechanical analyses although they are challenging to track accurately using traditional marker-based motion capture. Tracking the club head requires securing reflective markers that must remain in place during the swing and impact (Betzler, Kratzenstein, Schweizer, Witte, & Shan, 2006). Capturing the ball requires covering it in reflective tape (Horan et al., 2010), which may affect its flight.

Further, these fast motions require very high capturing frequencies (up to 1,000 Hz) (Horan et al., 2010), which is a limitation for many motion capture systems (Betzler et al., 2006). Alternatively, high speed video cameras (up to 5,400 Hz) (Leach, Forrester, Mears, & Roberts, 2017), or radar launch monitors (10-15 GHz) that are external to the motion capture system have been used to track club and ball parameters near impact (Leach et al., 2017). These launch monitors are gaining popularity in the golf industry and are being used by several high-level coaches. The accuracy these systems (TrackMan, https://trackmangolf.com) has been reported in the literature for ball speed (98%) and club head speed (87%) (Leach et al., 2017). However, the TrackMan system is expensive (~30,000 USD) and is not available at most biomechanics laboratories and training facilities. Therefore, researchers and coaches require access to motion capture systems capable of recording at high speeds, or specific, expensive equipment such as radars or cameras in order to obtain accurate performance.

Advances in technology have fueled the development of ‘smart coaches’, such as the Zepp golf analyzer (HUAMI Co., Beijing, China, https://www.zepp.com), which uses a Micro-Electro-Mechanical sensor attached to the performers’ hand. The sensor presents performance outcomes such as club speed, club plane and even a 3D analysis. However, the accuracy of these ‘smart coaches’ has not been validated in the literature and there is currently limited research on how the motions of the golfer’s hands relate to performance and club head speed. However, the possibility of using hand speed to indicate of golf performance is intriguing. Hand speed is easy to track with motion capture, does not require additional equipment, and has been suggested to greatly contribute to club head speed (MacKenzie & Sprigings, 2009). However, the relationships between hand speed and club head and ball speed are unknown.

While other variables also contribute to both club and ball speed (MacKenzie & Boucher, 2017; Nesbit, 2005), it would be beneficial for researchers and coaches to establish how hand speed relates to club head speed and ball speed during the golf swing.

In addition, the capturing frequency used in previous golf swing research varies considerably, with frequencies ranging between 50 Hz and 1,000 Hz (Betzler, Monk, Wallace, & Otto, 2012; Egret, Vincent, Weber, Dujardin, & Chollet, 2003), and the operating frequency of ‘smart coaches’ are rarely specified in the documentation. The capturing frequency is particularly important to track fast moving segments, such as the hands and club during a golf swing. These segments can move considerable distances between frames if the frequency is too low, and the quality of the data is therefore directly affected by the capturing frequency chosen. It is currently unknown how the capturing frequency may affect any relationships between hand speed and the club and ball speeds.

This study therefore aimed to (1) determine the relationship between hand velocity as measured with a motion analysis system and club and ball speed measured with a launch monitor during a golf swing, and (2) to examine the effect of different capturing frequencies on the relationships.

METHODS: Male golfers, all right-handed with over 10 years of golfing experience and a self-reported handicap of ≤15, volunteered for participation. All participants provided written informed consent in agreement with the institutional review board approval. The sampling frequency used in the first cohort (n=15, 1.76±0.06 m, 84.3±5.6 kg, 40.1±18.6 years) was 100 Hz, and in the second cohort (n=11, 1.78±0.08 m, 94.6±11.8 kg, 44.9±19.0 years) was 500 Hz. Both groups were fitted with retroreflective markers for a full-body kinematic capture and performed eight swings with their own driver (Severin, Barnes, Tackett, Barnes, & Mannen, 2019). All kinematic data was captured using a 10-camera Vicon system with a 50 Hz digital video camera (Vicon, Oxford, UK). A dual radar TrackMan launch monitor system (TrackMan 4, TrackMan A/S, Vedbæk, Denmark) recorded club and ball parameters. Kinematic data was imported into Visual3D (C-motion, Germantown, MD, USA) and processed using a fourth order Butterworth filter with a cut-off frequency of 2 Hz based on a residual analysis (Winter, 2009). The speed of the right hand was extracted at three time points; peak velocity, its lowest position in the swing, and at ball impact, which was identified based on the digital video footage. The resultant 3D velocities were calculated to generate the hand speed at the three time points. The club head speed and ball launch speed were extracted from the TrackMan data, and Parsons’s correlation analyses determined the relationships between the kinematic and performance outcomes at each time point.

RESULTS: The analysis showed that the relationship between the hand speed and club head speed differed depending which time point in the swing was used for the analysis and that the capturing frequencies affected the relationship (Table 1). The strongest relationship with the club head speed existed with the hand speed at ball impact at 500 Hz ($r=0.501$, $p<0.001$). When the capturing frequency was 100 Hz, the strength of all relationships decreased and the strongest relationship occurred at the lowest point of the swing ($r=0.302$, $p=0.002$).

Table 1. Statistical relationships between the hand speed and the club head speed

	100 Hz			500 Hz		
	r	r^2	p	r	r^2	p
Peak velocity	0.241	0.058	0.013	0.306	0.094	0.007
Velocity at lowest point in swing	0.302	0.091	0.002	0.487	0.237	<0.001
Velocity at ball impact	0.251	0.063	0.010	0.501	0.251	<0.001

r - Pearson’s correlation coefficient, r^2- correlation of determination

The relationships between the hand speed and ball speed were even weaker than those with the club head speed (Table 2). Like with club head speed, the strongest relationship between the ball speed and hand speed existed at ball impact at 500 Hz (r=0.400, p<0.001). For data collected at 100 Hz, the correlation coefficients between hand speed and ball speed were consistently poor (r<0.300) at all the analyzed time points.

Table 2. Statistical relationships between the hand speed and the ball speed

	100 Hz			500 Hz		
	r	r^2	p	*r*	r^2	p
Peak velocity	0.175	0.031	0.073	0.259	0.067	0.025
Velocity at lowest point in swing	0.261	0.068	0.007	0.383	0.147	0.001
Velocity at ball impact	0.187	0.035	0.054	0.400	0.160	<0.001

r - Pearson's correlation coefficient, r^2- correlation of determination

DISCUSSION: This study examined the extent to which hand speed, measured with a motion capture system, correlates with performance outcomes (ball speed and club head speed) measured with a launch monitor. The findings show that hand speed at ball contact has, at best, moderate relationships with ball and club head speed when the data is collected at 500 Hz. The data also showed that both the capturing frequency and the time point used in the analysis affected the relationships, which highlights the need for careful design of research methodologies when golf performance is of importance. This also suggests caution is warranted for coaches and practitioners using hand-based sensors.

It is not surprising that the relationships were stronger when the data was collected at 500 Hz rather than at 100 Hz. Gaps between frames are longer during the fast golf swing motion when captured at 100 Hz, thereby making it more difficult to reconstruct the three-dimensional marker coordinates (Betzler et al., 2006). Capturing frequency is always an important consideration for biomechanical analyses, especially when measuring fast motions, and should be selected carefully in the study design. It is therefore also advised that individuals using any atomized 'smart coach' systems consider the operating frequency of the system.

It is also unsurprising that the best time point for correlation analysis was the point of ball impact. The kinematic-based time points included in this analysis (peak velocity and velocity at the lowest point in the swing) are easy to identify based on the kinematic data and do not require additional equipment or markers on the ball. The poor correlations for these variables can likely be attributed to a lack of synchronization between the motion capture and launch monitor. The launch monitor uses a high frequency radar to identify ball impact, and the club and ball speeds were generated at that time point, while the hand speed variables do not necessarily represent this point accurately. The hands may decelerate before impact (Betzler et al., 2006; Nesbit, 2005) and the club head may lag behind the hands (MacKenzie & Sprigings, 2009) causing it to not impact the ball when the hands are at their lowest point. The point of ball impact provided the strongest relationships between hand speed and both club head and ball speed when 500 Hz was used. This was likely because the time synchronization of both the motion capture data and the TrackMan data were the closest at this time point.

The time synchronization between the systems at ball impact is a limitation with this study, as the time point was identified using the proprietary video camera in the Vicon system, and was therefore subject to hardware limitations (i.e. 50 Hz). A method, such as synchronized high frequency video, that can identify the ball impact moment more accurately may have yielded stronger correlations in our data. However, the exact moment of ball impact is difficult to establish with traditional motion capture, even with markers added to the ball and high capture frequencies (Betzler et al., 2012). This study highlighted the importance of identifying the time of ball impact accurately for determining the performance outcomes. To date, the most accurate method to do so is likely to use a high-speed video camera (Leach et al., 2017), however, both high-speed cameras and radars are external to the motion capture system and require manual synchronization with the motion data to identify the point of impact in the kinematic data accurately.

Although the moment of ball impact for the hand speed likely differed slightly from the launch monitor data, the moderate relationships suggests that the method used may be adequate to identify ball contact for laboratories lacking high speed synchronized systems. It is possible that a more exact identification of the ball impact event would have improved the relationships, and this should be a focus for future research.

Several factors contribute to club head and ball speed in addition to the kinematics (MacKenzie & Boucher, 2017; Nesbit, 2005). For example, the participants used their own clubs which may have had different shaft stiffness and length, and thereby affected the results. However, this experimental design choice was made to minimize changes to their normal golf kinematics.

CONCLUSION: This study evaluated how hand speed measured via motion capture correlates with club head and ball speeds during a golf swing. Hand speed had moderate relationships with both club head (r=0.501) and ball speed (r=0.400) and may provide limited information on performance. In particular, hand speed may be adequate when biomechanical alterations are the main interest point, but should not be used as an indicator of golfing performance. It is therefore recommended that coaches do not solely rely on measurements of hand speed, or devices attached to the hand, to evaluate performance. Further, researchers focusing on performance should include equipment that provides the ball or club head speed, or collect club and/or ball parameters along with the exact moment of ball impact using motion capture.

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ACKNOWLEDGEMENTS: This project was financially supported by the National Institute of General Medical Sciences of the National Institutes of Health under Award Number P20GM125503. The authors would like to thank the HipKnee Arkansas foundation for contributing with facilities and testing equipment for this study.