EFFECT OF SMOOTHING ON IMPACT VARIABLES IN SOCCER KICKING

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This technical note examined the effect of smoothing on calculation on several impact effectiveness variables in soccer kicking. A skilled male soccer player performed 10 maximum effort place kicks with a regulation soccer ball. Two-dimensional foot and ball motion were recorded by high-speed (210 Hz) for the 0.4 seconds around impact. Kinematic data were smoothed either through impact or using a separation and five-point linear interpolation technique (Knudson, 2005). Smoothing protocol had a significant effect on three of five impact effectiveness variables (e, foot-to-ball speed ratio, V_{Fpre}). Smoothing protocol did not affect V_{Bpost} and effective striking mass. The results supported previous studies reporting distortions of velocities near impact in striking objects, however these distortions inconsistently affected more complex impact parameters. More research is needed on smoothing techniques for impact kinematic variables, particularly parameters utilizing both pre- and post-impact velocity values.

KEY WORDS: filtering, football, impulse, interpolation, momentum.

INTRODUCTION: Biomechanical studies of striking sports often focus on t limb/implement and object velocity before and after impact to document the effectiveness of performance (Ishii et al., 2012). Maximizing the transfer of impulse to change the objects momentum is a primary objective of many striking sports. The elasticity and mass of the striking segment/implement interacts with the elasticity and mass of the object in determining the transfer of momentum.
Previous studies of combative (Smith & Hamill, 1986: Lenetsky et al., 2015; Neto et al., 2007) and ball sports (Asami & Nolte, 1983; Southard, 2014; Shinkai et al., 2009) have utilized the concept of effective striking mass to examine the transfer of momentum in striking. For example, it has been hypothesized that the activation of muscles across the ankle joint, can increase the stiffness and effective mass of the foot, increasing the transfer of momentum from the foot to the ball in a soccer kick. Impacting the ball nearer the ankle, minimizing the forced plantar flexion of the foot by the ball during impact (Nunome et al., 2006; Peacock & Ball, 2018; Sterzing & Hennig, 2008) is also hypothesized to result in better momentum transfer to the ball, however some studies refute that the mass of the foot influences kicking (Bull-Anderson et al., 1999). Peacock and Ball (2018) have recently shown with a mechanical kicking machine that a more rigid ankle/foot can increase the striking mass over a more compliant one.
The results of studies calculating effective striking mass of the foot in kicking also vary considerably with many of these studies not using data smoothing techniques that account for the distortion of kinematics data for objects near impacts. This distortion of kinematics near impacts and special extrapolation and smoothing strategies to reduce this problem have been well documented in batting (Tabuchi et al., 2004), kicking (Nunome et al., 2006; Shinkai et al., 2009) and in tennis (Knudson, 1990; Knudson & Bahamonde, 2001; Reid, Campbell, & Elliott, 2012; Tanabe & Ito, 2007). Signal distortions from smoothing through impact are not affected by the mass of the object in striking (Knudson, 2005) and remain even at very high (1000 Hz) sampling rates (Knudson & Bahamonde, 2001; Tanabe & Ito, 2007). Errors in the velocities of the striking limb and the object before and after impact, however, likely distort the calculation of impact effectiveness variables, contributing to inconsistent results and correlations with post-impact ball speed (Nunome et al., 2006). The purpose of this technical note was to determine if smoothing techniques near impact effect the calculation of effectiveness variables in a soccer kick using high-speed kinematic data collection and smoothing techniques common in sports biomechanics.

METHOD: One skilled male (70.5 kg) soccer player/coach gave informed consent to participate in the study. The athlete wore regular athletic clothes and soccer shoes. The kicking shoe was masked with black tape and small (8 mm) white reflective markers were placed on the lateral side of the ankle and center of mass of the kicking foot. Following a warm-up, the athlete made 10 maximum effort instep kicks of a regulation soccer ball on grass toward a goal 17 m away. After each kick the subject rated the quality of the impact with a 10 cm visual analog scale (VAS) with endpoints anchored from "poor/soft" to "firm/solid" impact.
A high-speed video camera (210 Hz) positioned 8 m lateral to the intended direction of the instep soccer kicks. Two-dimensional coordinates of the foot center of mass and front center of the soccer ball were acquired from 0.4 seconds before to after impact using Vicon Motus® 10.0 software. Two smoothing protocols using identical Butterworth low-pass filtering (f_c = 10 Hz horizontal and 10 Hz vertical coordinates: Nunome et al., 2006). One protocol likely induced biased by smoothing through the impact phase (TIM), while the other protocol involved separating pre- and post-impact data and plus 5-point linear extension (LEX) technique (Knudson, 2005). Following visual identification of the frame before foot/ball contact, the coordinates for the horizontal position of the foot at impact and the next 5 frames were established with linear extension. Foot vertical coordinates were not interpolated given the downward to upward transition of foot motion at impact. Impact distortion from smoothing of horizontal and vertical coordinates of the ball was reduced by adding 5-point linear extension forward in time for both the horizontal and vertical coordinates.
Six impact effectiveness dependent variables were calculated following the two smoothing protocols: foot resultant velocity one frame before impact (V_{Fpre}), maximum ball resultant velocity in the 0.04 seconds after impact (V_{Bpost}), coefficient of restitution (e), foot-to-ball speed ratio (FBSR: Peacock & Ball, 2018), and effective striking mass (ESM). The ESM was calculated using the formula by Southard (2014), where ESM = $(m \bullet (V_{Bpost}/V_{Fpre}) \bullet (1+e)) - V_{Bpost}$ assuming e = 0.43. The resultant velocity of the ball pre-impact was set at 0 for all trials and conditions for calculation of e and ESM. These variables were compared across smoothing condition by five dependent t tests (Table 1) and effect sizes calculated. The experiment-wise type I error rate was set at $p < 0.05$ and alpha inflation controlled over multiple comparisons using a Holms correction.

RESULTS: Smoothing had a significant effect ($p < 0.05$) on three impact effectiveness variables: V_{Fpre}, e, and FSBR (Table 1). Smoothing had no significant effect on V_{Bpost} and ESM. Smoothing through impact systematically underestimated foot resultant velocity at impact by 9 percent, but overestimated e and FBSR, 19 and 9 percent respectively. Figure 1 illustrates that V_{Fpre} was slowed before impact with TIM smoothing, with LEX smoothing created a more realistic foot resultant velocity profile slowing 20% through impact, close to the 33% reported using higher sampling rates (Nunome et al., 2006). Note, however, that both TIM and LEX could not accurately model pre-impact and during impact ball velocity. Both smoothing protocols resulted in similar V_{Bpost} values for frames at least 15 ms beyond impact (Figure 1).

DISCUSSION: Smoothing through impact created significant and large ($d > 1.6$) distortions of three impact effectiveness variables for the maximum effort kicks of a skilled soccer player. The 9% underestimation of the resultant velocity of the foot at impact in this study was consistent with previous studies of soccer kicking (Nunome et al., 2006; Shinkai et al., 2009) and other striking activities (Knudson, 1990; Knudson & Bahamonde, 2001; Reid, Campbell, & Elliott, 2012; Tabuchi et al., 2004; Tanabe & Ito, 2007).
The distortion of the velocity of the foot at impact likely contributed the 9% overestimation the FBSR when smoothing through impact. The mean FBSR in the interpolated condition was closer to more recent values (1.2 – 1.6) using higher sampling rates and more appropriate smoothing protocols for impacts (Peacock & Ball, 2018; Nunome et al., 2006; Shinkai et al., 2009, 2013). Impact coefficient of restitution (e) was also overestimated (19%) when data were

smoothed through impact. The observed e (0.70 – 0.83) and ESM (3.1 – 3.5) for impacts were qualitatively larger than previously reported (0.4 and 2.2, respectively) values (Shinaki et al., 2013). Higher values would indicate greater transfer of energy to the ball for the athlete studied, however this is unlikely given the higher level of skill and training in subjects in previous studies. This unusual observation and the inconsistent results seen in this and previous studies for more complex impact variables like e and ESM, using a combination of inconsistent and smoothing distorted pre- and post-impact velocities, indicate likely poor reliability of these impact variables. Future studies should more closely examine the reliability of these complex impact variables and the effect of smoothing on the velocities near impact needed for these calculations.

Table 1
Mean (SD) Kicking Kinematics at Impact Across Smoothing Protocols

	TIM	LEX	*d*
V_{Bpost} (m/s)	25.0 (1.4)	25.0 (1.3)	
V_{Fpre} (m/s)	15.4 (0.5)	16.9 (1.0)*	2.0
e	0.83 (0.08)	0.70 (0.08)*	1.6
FBSR	1.62 (0.10)	1.48 (0.08)*	1.6
ESM (kg)	3.52 (0.80)	3.10 (0.86)	

Note: See text for variable abbreviations and * indicates significant $p < 0.05$ difference between smoothing protocols.

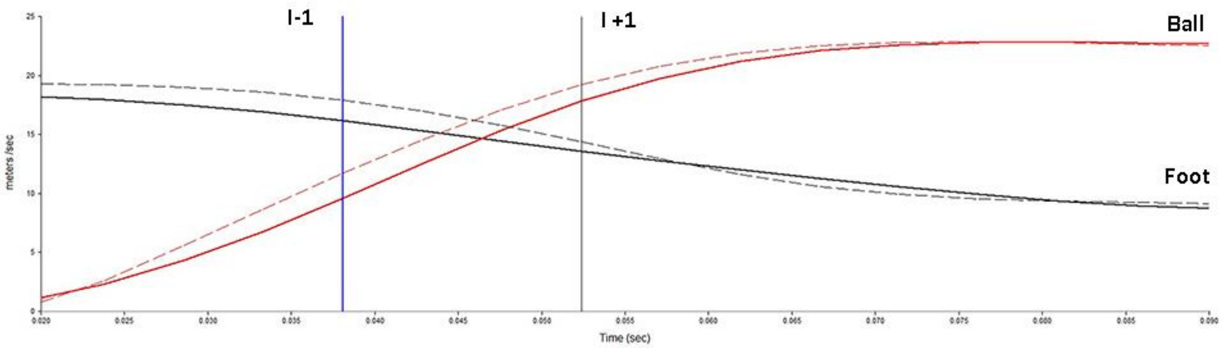

Figure 1. Representative trial illustrating significant underestimation of V_{Fpre} (——) but negligible effect on $V_{Bpost.}$ (——) with TIM smoothing. Smoothed data with LEX are in dashed lines. The frames before (I-1) and after (I+1) the impact phase (middle 10 ms) are indicated.

The limitations of this study included the two-dimensional analysis and the use of a single skilled athlete. It is possible that the extent of the bias introduced by smoothing through impact in soccer kicking varies across skill levels, so this should be examined in future studies. These limitations have a negligible effect on the validity of the results to most studies of kinematic variables near impact in soccer, primarily because the results were consistent with numerous studies of smoothing effects on kinematics near impact in soccer (Nunome et al., 2006; Shinkai et al., 2009). This distortion has been reported across different masses of balls in tennis (Knudson, 2005) and for higher (1000 Hz) sampling rates (Knudson & Bahamonde, 1999; Tanabe & Ito, 2007) in tennis.

CONCLUSION: Smoothing protocol significantly influenced three of five common impact effectiveness variables in soccer kicks of a skilled player. Systematic distortion of velocities near impact may contribute to inconsistent results impact effectiveness variables (e, FBSR) that use pre- and post-impact measures. These results should be confirmed with more athletes and additional sampling rates and amounts of smoothing.

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