CHOICE OF DATA PROCESSING INFLUENCES PRACTICAL INTERPRETATION OF KICK LEG JOINT KINETICS DURING THE IMPACT PHASE OF BALL KICKING

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The aim of this study was to compare different methods processing kick leg joint moments during the ball impact phase of football instep kicking. Kicking motions of eighteen semi-professional footballers were captured by three-dimensional motion analysis (1000Hz) and joint moments were derived using four conventional, and two advanced (time-frequency filter) methods. Ankle, knee and hip moments at ball contact were all different between processing method ($P < 0.017$), with large pairwise effect sizes ($d > 0.8$). Choice of data processing influences practical interpretation of ball kicking motions. Filtering 'through' the impact phase introduces considerable error, so truncating and extrapolating joint moments before contact should be performed. Use of these methods highlight the importance of: a) training the ankle dorsiflexors for resisting forced plantarflexion upon ball contact, b) developing coaching cues that co-ordinate whole-body action to complement passive knee extension in the final stage of the downswing and c) tailoring training/ coaching of kicking skills to an individual's preferred movement strategy.

KEYWORDS: inverse dynamics, Butterworth filter, time-frequency filter, foot-to-ball contact.

INTRODUCTION: Assessment of kick leg joint kinetics are important for understanding ball kicking motions (e.g. football instep, rugby place and AFL/NFL punt kicking). Patterns of kick leg ankle, knee and hip moments (and powers) derived from inverse dynamics analyses (IDA) describe how and when specific muscle groups perform work during the kick, and can be used to inform empirically grounded training practices (Lees et al., 2010). However, while research has shown conventional low-pass filter methods can distort lower-leg kinematics near the time of foot-to-ball impact (Augustus et al., 2020; Nunome et al., 2006a), no study has evaluated data processing techniques for deriving joint moments during this phase of the kick. Given kick leg velocities and accelerations are used to derive joint moments, any error in the kinematic data will likely extend to joint kinetic estimates. For example, Nunome et al (2006b) reported hip moment reversal (to extension) in the final stages of the downswing may be the result of inadequate data filtering, but to date, it is unknown whether knee and ankle moments become distorted as well. Ultimately, flawed data processing will alter the patterns of joints kinetics and confound the practical value of investigation in this area. Research is therefore warranted to assess performance of common and novel data processing methods, with a view towards production of 'best practice' guidelines for this problem.

Since it is difficult to account for the ball reaction force in the IDA during foot-to-ball contact, studies have conventionally low-pass filtered and truncated kick leg moment data either: a) at the start of foot-to-ball impact (e.g. Atack et al., 2019), or b) ~10 ms prior to the start of impact and extrapolated the final portion of the signal (e.g. Nunome et al., 2006b) to remove distortions caused by 'ball impact artefact'. While these methods may provide valid moment estimates up until ball contact, they also inherently remove any meaningful information from the ball impact phase. Alternatively, despite evidence the derived moments will contain error (Nunome et al., 2006b), some studies continue to erroneously 'filter through' the impact phase (e.g. Clagg et al., 2009). Finally, advanced time-frequency filter methods can accurately detect kick leg motion during both the pre-impact and impact phases of ball kicking (Augustus et al., 2020; Nunome et al., 2006a), but they have not yet been used to in conjunction with an IDA. Given the aforementioned necessity of valid input kinematics, it was hypothesized time-frequency filtered joint kinetics would enhance the accuracy of kick leg moments near the time of ball contact, and the aim of this study was to compare conventional data processing techniques (a) low-pass filter through ball contact, b) truncate at ball contact, and c) truncate 10 ms before ball contact and extrapolate) with a novel time-frequency filter method of processing kick leg joint moments during football instep kicking.

METHODS: Following institutional approval and informed consent, 18 male association footballers (mean ± SD; mass 78.8 ± 7.1 kg, height 1.81 ± 0.05 m, age 23.6 ± 3.9 years; semi-professional) performed 10 instep kicks of a FIFA approved size 5 football 'as fast and accurately' as possible towards a target (0.5 m radius) placed 4 m away. Motion data (from kicking foot take off to end of the follow through) were captured at 1000Hz using a 10-camera, 3D motion analysis system (Vicon T40S, Oxford, UK). Reflective markers were attached so the position and orientation of seven segments (bilateral feet, shanks and thighs, and the pelvis) were incorporated into a 6 DOF model that were tracked using 'triad' marker clusters. Segments were rigid geometrical volumes scaled to participant height and mass, inertial characteristics were derived according to de Leva (1996) and joint centres using functional methods. Kick leg ankle, knee and hip joint moments (flexion/ extension) were estimated using a standard Newton-Euler IDA in Visual 3D (V6, C-Motion, Rockville, USA), were resolved to the joint coordinate system and expressed relative to body mass.
Kicking trials (kicking foot take off to end of follow through) were duplicated and marker trajectories were processed using six different methods (prior to calculation of joint kinetics). Four methods replicated those previously used in the literature (i.e. were variations of a Butterworth low-pass filter), and two used a novel, fractional Fourier time-frequency filter (FrFF; Augustus et al., 2020). Briefly, the FrFF uses a triangular filter boundary which raises the cut-off frequency to retain time-dependent expansions in frequency content during an impact, and thus returns more accurate kinematics near the time of foot-to-ball contact. To avoid endpoint distortions, all six filter methods were padded with 25 frames (reflection) which was removed following filter application. Full details of processing methods can be found in Table 1.

Table 1: Details of the six data processing methods.

Method Name	Low-Pass Filter Type	Filter Cut-Off Frequency (Hz)	Ball Impact Phase Treatment	Example Paper
BW-12	4th order, dual pass Butterworth	12	None - filtered through	Clagg et al., 2009
BW-18	4th order, dual pass Butterworth	18	None - filtered through	
BW-EXT	4th order, dual pass Butterworth	18	Truncated 10 ms before ball contact and extrapolated using 1st order polynomial	Nunome et al., 2006b
BW-BC	4th order, dual pass Butterworth	18	Truncated one frame before ball contact	Atack et al., 2019
FrFF	Fractional Fourier domain	Variable	None - filtered through	Augustus et al., 2020 (kinematics only)
FrFF-EXT	Fractional Fourier domain	Variable	Truncated 10 ms before ball contact and extrapolated using 1st order polynomial	

Bonferroni adjusted, repeated measures ANOVAs compared ankle, knee and hip joint moments at the start of ball contact between the six processing conditions (N = 3; α = 0.017) in SPSS (V23, IBM, New York, USA). If a significant main effect was identified, Bonferroni adjusted planned contrasts examined pairwise differences of each processing method compared to the FrFF (N = 5; α = 0.017), and pairwise effect sizes were calculated according to Cohen (1988).

RESULTS: Kick leg ankle, knee and hip moments at the start of foot-to-ball contact were all significantly different between data processing condition ($P < 0.017$). Mean ± SD joint moments are shown in Table 2. The FrFF showed distinct ankle plantarflexion moments, filtering through the impact with a conventional filter (BW-12 and BW-18) showed negligible ankle moments, whereas extrapolating ankle moments for the final 10 ms (BW-EXT and FrFF-EXT) showed dorsiflexion moments. All conditions displayed knee flexion moments, but filtering through impact (BW-12, BW-18 and FrFF) exacerbated the magnitude of flexion moments compared to extrapolation methods (BW-BC, BW-EXT and FrFF-EXT). This pattern was also evident for hip extension moments. A representative example of time-series moments during the kicking motion are shown in Figure 1.

Table 2. Mean ± SD joint moments at ball contact, and pairwise contrasts with FrFF.

		FrFF	BW-12	BW-18	BW-EXT	BW-BC	FrFF-EXT
Ankle Dorsi/ Plantarflexion Moment (Nm/kg)	Mean ± SD	**-0.14 ± 0.18**	0.05 ± 0.04	-0.03 ± 0.08	0.19 ± 0.02	-0.02 ± 0.03	0.21 ± 0.05
	p-value		<0.001*	0.002*	<0.001*	0.007*	<0.001*
	Effect Size (*d*)		1.5	0.8	2.6	0.9	2.7
Knee Flexion Moment (Nm/kg)	Mean ± SD	**-3.1 ± 0.6**	-2.2 ± 0.3	-3.0 ± 0.4	-0.4 ± 0.2	-0.4 ± 0.1	-0.4 ± 0.2
	p-value		<0.001*	0.638	<0.001*	<0.001*	<0.001*
	Effect Size (*d*)		1.9	0.2	6.0	6.2	6.0
Hip Extension Moment (Nm/kg)	Mean ± SD	**-3.9 ± 0.8**	-2.9 ± 0.5	-4.4 ± 0.5	-0.4 ± 0.3	-0.9 ± 0.4	-0.5 ± 0.4
	p-value		<0.001*	0.045	<0.001*	<0.001*	<0.001*
	Effect Size (*d*)		1.5	0.7	5.8	4.7	5.4

Dorsiflexion moments = +ve. 0 - 0.2 = trivial effect, 0.2 - 0.5 = small effect, 0.5 - 0.8 = medium effect, >0.8 large effect.

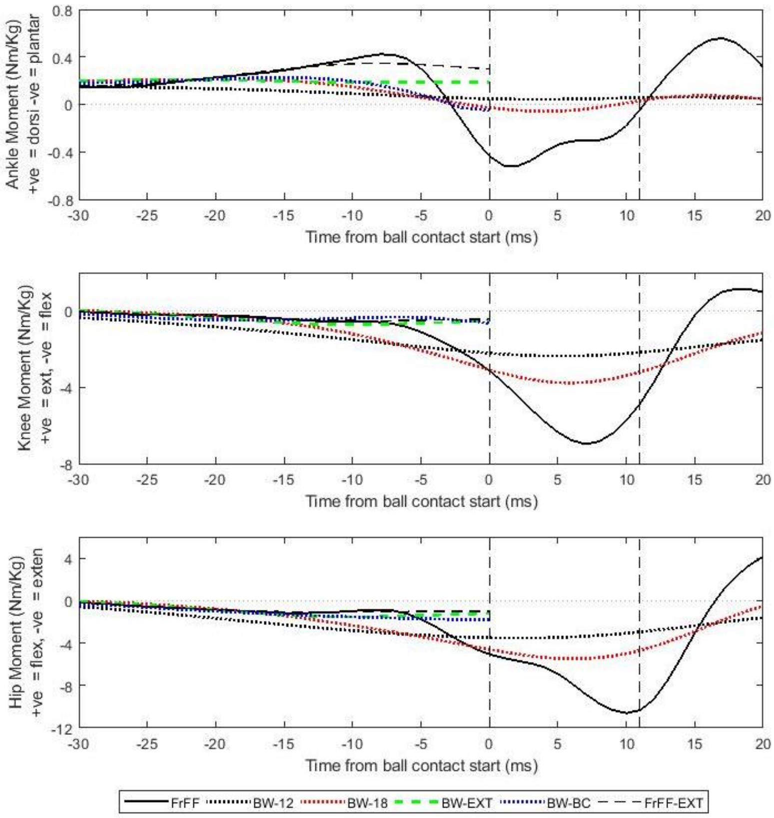

Figure 1. Time-series joint moments in each of the six data processing methods. Vertical dashed lines show start and end of ball contact, respectively.

DISCUSSION: Contrary to the hypothesis that time-frequency filtered kinematic data would reduce error in derived joint kinetics at ball contact, the FrFF distorted ankle, knee and hip moments towards a more negative value for the final 5 -10 ms of the downswing (Figure 1). This has previously been shown by Nunome et al. (2006b) and was also evident for the other conditions which 'filtered through' the impact (BW-12 & BW-18). These exacerbated negative moments were likely caused by larger lower-leg decelerations maintained in the FrFF condition (i.e. high frequency motion content; Augustus et al., 2020). This effect was lessened, but still

problematic, when those decelerations were attenuated in BW-12 and BW-18 conditions (i.e. were removed due to over filtering). Since IDA assumes segmental and joint motion are from internal forces and moments (i.e. muscle and other joint tissues), the calculations do not account for the influence of the external reaction force between the foot and ball. Thus, the IDA erroneously attributes any lower-leg deceleration to neuromuscular sources. In contrast, the three methods that truncated data before contact (BW-EXT, BW-BC and FrFF-EXT) were free from these errors as the decelerations owing to ball impact were removed. In lieu of accounting for the ball force in the IDA, such methods should be adopted for future study.
From a practical perspective, choice of data processing will influence practical interpretation of kick leg joint kinetics. For example, extrapolation methods (BW-EXT and FrFF-EXT) showed distinct ankle dorsiflexion moments at ball contact. This seems logical given increasing ankle rigidity (i.e. resisting force plantarflexion) has recently been proposed to enhance impact efficiency during AFL punt kicking (Peacock & Ball, 2018). Reversal to plantarflexion moments seems less intuitive (e.g. as shown by BW-12, BW-18 and FrFF), but could be indicative of co-contraction of antagonist muscles to enhance the effective mass of the foot (Lees et al., 2010). Moreover, correctly identifying the timing of knee moment reversal (to flexion) is important as it indicates when the joint switches from active (i.e. concentric quadricep force) to passive (i.e. from motion-dependent forces) extension towards the ball (Lees et al., 2010). If this instance is misrepresented due to over-filtering or distortion in the signal (e.g. BW-12 and BW-18 showed earlier reversal than FrFF and FrFF-EXT; Figure 1), then attempts to clarify kinetic interactions (e.g. energy/ power transfers) between the kick leg and distant segments (e.g. pelvis and support leg) are difficult. Finally, the current study showed hip moments reversed to extension before ball contact, irrespective of whether an erroneous filter through or valid extrapolation method was used. Nunome et al. (2006b) previously suggested hip moment reversal was exclusively due to ball impact artefact, and hip moments remained in flexion for the entirety of the kick. This discrepancy may be explained by the current participants using a different strategy to perform kicks. Ball (2008) previously differentiated between 'hip' and 'knee' dominant strategies. Maintaining hip flexion moments until ball contact might be indicative of a hip dominant strategy and reversing to extension of a knee dominant strategy. Understanding such strategies might help inform training/ conditioning practices for individual kickers. For example, hip flexor dominant kickers might benefit from training concentric capabilities of the hip flexors. However, it should also be noted that while extrapolation methods seemed to perform better than filtering through ball contact, limitations of IDA mean it is difficult to validate these patterns of joint moments with the real loads experienced by the kicking leg during ball kicking motions (i.e. compare to reference values).

CONCLUSION: In lieu of accounting for the ball reaction force, extrapolation methods should be used to derive kick leg joint moments near the instance of foot-to-ball contact. Use of these methods can help prevent erroneous practical interpretation of kicking skills. For example, removing error near to ball contact highlights the importance of: a) maintaining a dorsiflexion moment upon foo-to-ball contact (i.e. resisting forced plantarflexion upon contact), b) ensuring the timing of knee joint reversal is not distorted (i.e. the transition from active concentric to passive eccentric knee extension) and c) determining hip strategy at ball contact (i.e. flexor or extensor dominance) and subsequent strategy-dependent training practices.

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