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Three-dimensional kinematic correlates of ball velocity during maximal instep football kicking.

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Abstract

Achieving a high ball velocity is important during soccer shooting, as at gives the goalkeeper less time to react, thus improving a player's chance of scoring and is also fundamental to long passes and goalkicks. This study aimed to identify important technical aspects of kicking linked to the generation of ball velocity using regression analyses. Maximal in-step kicks were obtained from twenty-two academy level soccer players using a ten camera motion capture system sampling at 500 Hz. Three-dimensional kinematics of the lower extremity segments were obtained. Regression analysis was used to identify the kinematic parameters associated with the development of ball velocity. A single biomechanical parameter; knee extension velocity of the kicking limb at ball contact Adj R^2=0.37, $p \leq 0.01$ was obtained as a significant predictor of ball-velocity. This study suggests that sagittal plane knee extension velocity is the strongest contributor to ball velocity and potentially overall kicking performance. It is conceivable therefore, that players may benefit from exposure to coaching and strength techniques geared towards the improvement of knee extensors strength as highlighted in this study.

Introduction

Kicking is a fundamental motor skill in soccer (Lees & Nolan, 1998) and the in-step soccer kick is the most frequently analysed action in soccer (Zernicke & Roberts, 1976; Asami & Nolte, 1983; Putnam & Dunn, 1987; Dorge et al., 1999; Kellis & Katis, 2007; Lees et al., 2010; De Witt & Hinrichs, 2012). It is important to achieve a high ball velocity in soccer goal kicking, since first and foremost this gives the goalkeeper less time to react thus improving a player's chance of scoring but is also fundamental to long passes and goalkicks (Dorge, Anderson, Sorensen, & Simonsen, 2002).

The velocity of the ball subsequent to the kicking action is therefore considered a central biomechanical indicator of kicking performance and it is the consequence of several factors such as kicking technique/ kinematics (Lees & Nolan, 1998), approach velocity/ angulation (Isokawa & Lees, 1988; Kellis, Katis & Gissis, 2004), skill level (Commetti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Luhtanen, 1988), kicking limb (Barfield, 1995; Dorge et al., 2002; Narici, Sirtori, & Mognoni, 1988; Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006), and age (Lees & Nolan, 1998). However, although previous analyses have attempted to relate the resultant ball velocity to several determining factors, the majority have been comparative in nature in that they have aimed to identify similarities and differences between in-step kicking conditions. Therefore, despite the wealth of research into the mechanics of in-step kicking, the specific factors associated with the generation of ball velocity are not yet fully established.

During in-step kicking the lower extremity segments interact via a proximal to distal mechanism along the kinematic chain in order to transfer momentum to the kicking foot (Putnam, 1993; De Witt & Hinrichs 2012). Thus far De Witt & Hinrichs (2012) have performed the only investigation using correlational analyses in an attempt to determine the mechanical factors associated with the development of ball velocity. Velocity of the foot centre of mass, velocity of the foot centre of mass relative to the knee and peak velocity of the knee relative to the hip at ball impact were shown to be significantly correlated with ball velocity. However De Witt & Hinrichs (2012) were more concerned with the mechanical determinants of ball velocity and thus examined few kinematic parameters that were limited primarily to the sagittal plane. Furthermore, this investigation utilized single correlational analyses rather than multiple regression; thus the weighted influence of the discrete kinematic parameters on ball velocity was not determined.

Whilst the importance of maximal instep kicking has been well documented in terms of its influence on performance, there has been little attention paid to the kinematic elements pertinent to the development of ball velocity. This study therefore aimed to identify important lower extremity rotational aspects of in-step kicking pertinent to the generation of high ball velocity using three dimensional (3-D) kinematic modelling and regression analyses.

Methods

Participants

Twenty-two male soccer players (age = 16.8 ± 0.71 years; height = 1.80 ± 0.07 m; mass = 76.73 ± 8.31 kg) were examined whilst kicking a stationary soccer ball (size 5) as hard as possible into a regulation sized goal using their right (dominant) foot. Participants were academy level players contracted to a top-division professional soccer club in England. Participants were all free from musculoskeletal pathology at the time of data collection and provided written informed consent in accordance with the predetermined guidelines outlined in the declaration of Helsinki. Ethical approval was provided by a University ethical board.

Procedures

A ten camera motion analysis system (Qualisys ™ Medical AB, Gothenburg, Sweden) captured 3-D kinematic data from the lower extremities at 500 Hz from each participant performing maximal instep kicks with a 5m run up and an approach angle of 45° in accordance with Isokawa & Lees (1988). The ball was positioned such that it allowed the support foot to land on a piezoelectric force platform (Kistler Instruments, Model 9281CA) which sampled at 1000 Hz. In accordance with the protocol outlined by Shan & Westerhoff

(2005) the camera system also tracked the soccer ball using three reflective markers, thus allowing ball release speed to be quantified. Dynamic calibration of the motion analysis system was performed before each data collection session using predefined acceptance criteria with an identical motion capture system (Sinclair et al., 2013).

The calibrated anatomical systems technique (CAST) marker configuration was utilized for this study (Cappozzo, Catani, Leardini, Benedeti, & Della, 1995). Retro reflective markers were positioned on the following anatomical locations; bilaterally to the 1st and 5th metatarsal heads, calcaneus, medial and lateral malleoli, medial and lateral epicondyle of the femur, greater trochanter, posterior super iliac spine (PSIS) and right and left anterior super iliac spine (ASIS). Tracking clusters were positioned on the right and left thigh and right and left shank. The tracking clusters were comprised of four 19mm spherical reflective markers mounted to a thin sheath of lightweight carbon fiber with a length to width ratios of 1.5:1 and 2.05:1, in accordance with the previously established guidelines (Cappozzo, Cappello, Della-Croche & Pensalfini, 1997). This allowed the pelvis, bilateral foot, shank and thigh segments to be defined and tracked. The proximal joint centre for the thigh segment was quantified using regression equations via the positions of the ASIS markers (Bell, Brand, & Pedersen, 1989). A static trial was captured to define the pelvis, thighs, feet and shank segments of both the left and right limbs, following which markers used only to define the segments, were removed prior to the collection of dynamic information.

Data Processing

3-D Kinematic measures were calculated using Visual 3-D (C-Motion Inc, Germantown, USA) and filtered at 100 Hz using a zero-lag low-pass Butterworth 4th order filter. Ten trials of maximal instep kicking were averaged for each participant. Trials were defined by the instances of stance limb footstrike with a force platform (Sinclair et al., 2011) to ball contact. Ball contact was determined using retro-reflective marker tape attached to the ball (Shan & Westerhoff, 2005). Angular kinematics from the hip, knee and ankle joints were created about an XYZ cardan sequence referenced to co-ordinate systems created about the proximal end of the segment, where X = sagittal plane rotations; Y = coronal plane rotations and Z = transverse plane rotations (Lees et al., 2010). Three-dimensional kinematic measures of both stance and kicking limbs from the hip, knee and ankle which were extracted for statistical analysis were 1) angle at footstrike, 2) angle at ball impact, 3) range of motion during stance, 4)peak angle during stance, 5) relative range of motion from footstrike to peak angle, 6) angular velocity at footstrike, 7) angular velocity at ball impact and 8) peak angular velocity.

Statistical analyses

A factor analysis was used to select a smaller number of variables to be included in the regression analysis. This preliminary analysis yielded 10 separate factors, and the variables with the highest loading for each factor were extracted. These factors were then entered into the multiple regression analyses which was conducted with ball velocity as criterion and the 3-D kinematic parameters as independent variables. The significance level for the regression model was set at the $p \leq 0.05$ level. The independent variables were examined for co-linearity prior to entry into the regression model using a Pearson's correlation coefficient matrix and those exhibiting high co-linearity $R \geq 0.7$ were removed. All statistical procedures were conducted using SPSS 20.0 (SPSS Inc, Chicago, USA).

Results

Ball velocities and Regression analyses

Tables 1-2 present the mean ± standard deviation 3-D kinematic parameters from both the stance and kicking limbs. The results revealed mean ± standard deviation ball velocities of 26.73 ± 6.47 $m.s^{-1}$. The overall regression model was significant and yielded an Adj R^2 of 0.37, p≤0.01. A single biomechanical parameter, peak knee extension velocity of the kicking limb in the sagittal plane was obtained as a significant predictor of ball velocity (*B*=0.55, t=3.86) Adj R^2=0.37, p≤0.01.

@@@ Table 1 near here @@@

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Discussion

The aim of the current investigation was to determine the lower extremity 3-D kinematic parameters pertinent to the development of ball velocity during maximal in-step kicking. This study represents the first to examine these factors during maximal in-step kicking in soccer.

The regression analysis revealed that knee extension angular velocity of the kicking limb at ball impact was the only significant predictor of ball velocity. The fit of the multiple regression analysis (R^2 = 0.37) suggests that variance in ball velocity may be significantly influenced by the kicking technique employed by the player. This concurs with the Lees & Nolan (1996) proposition that variations in ball velocity during in-step kicking are influenced by alterations in kicking kinematics.

That knee extension angular velocity at ball contact served as a significant predictor of ball velocity is unsurprising and is in line with the observations of Ball (2008) who found that peak knee angular velocity was significantly related to ball velocity during Australian Rules soccer punt kicking. This finding reinforces the notion that the velocity of the foot centre of mass which ultimately governs the resultant ball velocity is a function of the angular velocity of the shank in the sagittal plane (Ball, 2008). The linear velocity of the rotating foot which makes contact with the ball is proportional to the product of the angular velocity and radius rotation of the proximal body segments (Ball, 2008) thus the significant relationship between shank angular velocity and ball velocity appears logical.

The findings of this study may allow recommendations for specific training modifications to be made with the goal order of improving ball velocity during in-step soccer kicking. It has been recognized that performing training drills that promote greater foot velocities and shank angular velocities, are useful methods of training this skill (Ball, 2007). Therefore to improve ball velocity it is recommended that coaching practices be implemented with the purpose of increasing sagittal plane knee angular velocity. There is further indication an effective strength training program which encompasses both concentric and eccentric training modalities also improves kicking distance and power (DeProft, Cabri, Dufour, & Clarys, 1988). Cabri, De Proft, Dufour, & Clarys (1988) detected significant correlations between knee flexor and extensor strength and kick distance. Correspondingly Poulmedis (1988) and Narici et al. (1988) also found strong correlations between lower extremity muscle strength and resultant ball velocity. Therefore as the principal contributor to knee extension, the quadriceps muscle group generates high intensity forces during the in-step kick (Lees, Bartona, & Robinson, 2010). Hence, from a biomechanical perspective, strength training of the quadriceps muscle group may be of particular importance to soccer players wishing to improve their scoring potential through increases in ball velocity. It is also recommended based on this observation that the hamstrings also receive strength training as not to negatively influence the quadriceps: hamstrings strength ratio which has been linked to the development of injury when it falls outside the recommended 3:2 ratio (Coombs & Garbutt, 2002).

Although statistically significant the regression model suggests that there remains variance in ball velocity that was not accounted for by the discrete kinematic measures that were entered into the multiple regression analysis. Some of the remaining variance may be attributable to the collision mechanics between foot and ball which have been reported by various authors as pertinent to kicking tasks (Nunome et al., 2006). Bull-Andersen, Dorge, & Thomsen (1999) noted that ball velocity during soccer in-step kicking was a product of foot velocity and the coefficient of restitution between foot and ball. Lastly, whilst this investigation examined the influence of the lower extremities kinematics on resultant ball velocity, no information was examined regarding the influence of upper body kinematics on the resultant ball velocity. Chen & Chang (2010) showed that arm swing can significantly influence the resultant ball velocity. Similarly Shan & Westerhoff (2005) showed that effective upper-body movement to be a key factor in creating better initial conditions for a more explosive muscle contraction during kicking. It permits a more powerful quasi whip-like movement of the kicking leg. As such it is recommended that future examinations be conducted to investigate the upper body contribution to ball velocity during in-step kicking.

A limitation of the present study was the all-male sample may limit its generalizability as Barfield, Kirkendall, & Yu (2002) documented kinematic differences in kicking kinematics during the maximal instep soccer kick. There remains currently a noticeable paucity of research regarding the mechanics of in-step kicking in females, and the growth in female participation in soccer has failed to lead to a corresponding growth in the study of the mechanics of kicking in females. It is therefore recommended that the current investigation be repeated using a female sample.

In addition, although ball velocity has been the focus of a number of examinations in soccer, there is currently a lack of published studies examining the discrete 3-D kinematic parameters associated with accuracy during in-step kicking. It was proposed by Godik, Fales, & Blashak (1993) that kicks with the greatest ball velocity are also associated with the highest degree of accuracy, and conversely Teixeira (1999) showed that that higher ball velocities were linked to reductions in accuracy. Lees & Nolan, (1998) comparing the mechanics of in-step kicking with a focus on both accuracy and ball velocity, found that when accuracy is paramount there is a decrease in lower extremity joint angular velocities and ball velocity compared to maximal velocity kicking. This leads to the notion that a trade-off exists between accuracy and ball velocity. Whilst ball velocity has been linked to performance, the accuracy of in-step kicking is also clearly pertinent as the kick still has to hit a specific target in order for a goal to be scored. Given the lack of published work investigating the mechanics of accurate kicking it is recommended therefore that future analyses consider the discrete kinematic factors associated with the development of accuracy during in-step soccer kicking.

In conclusion this study provides new information regarding the 3-D kinematic parameters associated with the development of ball velocity during in-step kicking. The current investigation documents that knee extension angular velocity is most pertinent to the development of ball velocity during in-step kicking. It is recommended that training modalities be modified towards increasing this measure for those wishing to improve their kicking performance.

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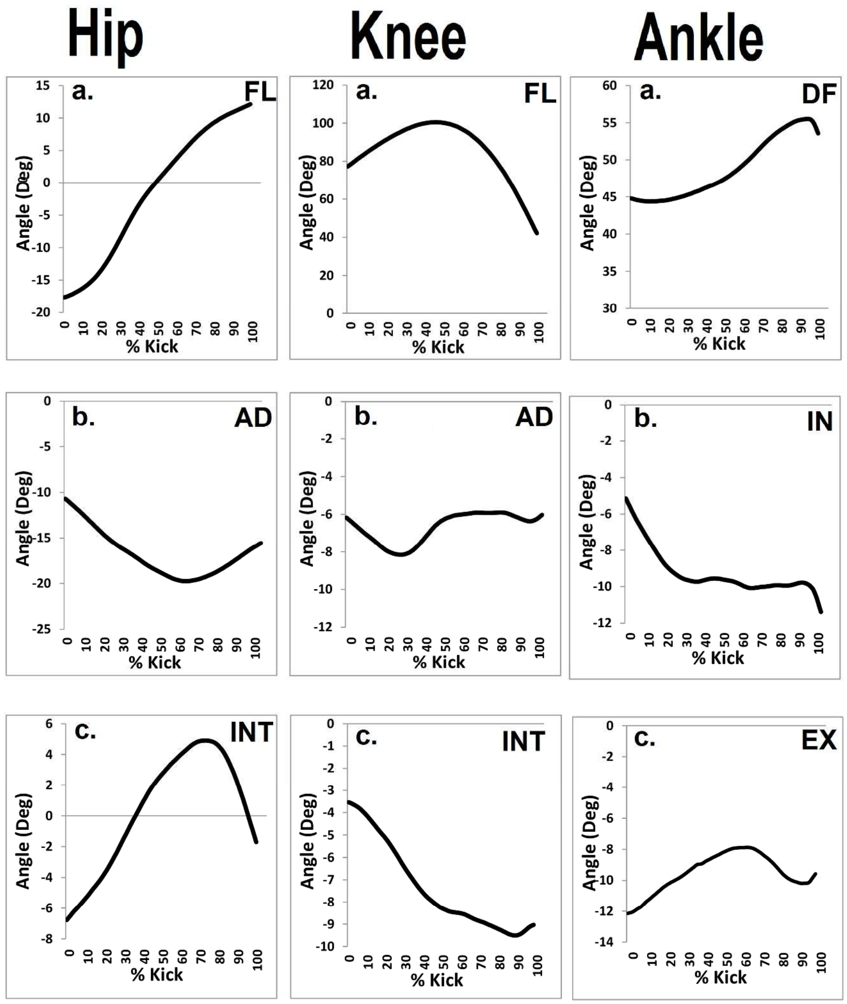
Table 1: Hip, knee and ankle joint angular parameters (means ±SD) from the kicking and stance limbs limb.

Table 2: Hip, knee and ankle joint angular velocities (means ±SD from the kicking and stance limbs limb.

	Hip		Knee		Ankle	
Sagittal Plane (+ =flexion/ - =extension)	**Kick**	**Stance**	**Kick**	**Stance**	**Kick**	**Stance**
Angle at Footstrike (°)	-16.56 + 12.93	54.52 + 12.27	77.26 + 15.52	26.01 + 7.02	44.78 + 14.06	83.64 + 10.29
Angle Ball impact (°)	12.97 + 14.27	13.10 + 10.84	42.03 + 13.48	40.56 + 9.61	53.55 + 22.42	78.89 + 12.51
Range of Motion (°)	29.79 + 6.19	41.42 + 7.10	35.23 + 10.61	14.55 + 5.52	8.78 + 4.17	4.75 + 3.77
Peak Range of Motion (°)	29.78 + 9.19	0.13 + 1.12	23.22 + 7.16	19.04 + 5.03	10.75 + 5.06	17.55 + 10.76
Peak Angle (°)	13.49 + 8.57	54.52 + 21.70	100.48 + 13.80	45.04 + 17.57	55.26 + 21.51	65.89 + 24.41
Coronal plane (+ =adduction/ - =abduction)						
Angle at Footstrike (°)	-10.69 + 4.91	-7.73 + 6.99	-6.17 + 13.61	6.59 + 7.14	-5.14 + 10.41	0.42 + 8.75
Angle Ball impact (°)	-15.55 + 4.74	11.28 + 7.95	-6.02 + 9.45	5.20 + 10.44	-11.38 + 13.15	-9.59 + 8.68
Range of Motion (°)	4.86 + 5.01	18.51 + 3.62	0.15 + 1.60	1.38 + 3.17	6.25 + 5.31	10.02 + 6.17
Peak Range of Motion (°)	9.05 + 6.60	18.51 + 4.11	-8.16 + 11.34	3.65 + 4.77	6.24 + 5.48	13.61 + 4.78
Peak Angle (°)	-19.74 + 4.96	11.27 + 8.54	1.99 + 3.89	2.94 + 8.50	-11.38 + 13.14	-13.61 + 4.78
Transverse plane (+ =internal/ - =external)						
Angle at Footstrike (°)	-6.78 + 16.18	-4.04 + 15.95	-3.53 + 6.14	-20.17 + 14.61	-12.15 + 7.78	-20.17 + 14.61
Angle Ball impact (°)	-1.70 + 15.95	-10.13 + 16.54	-9.04 + 9.22	-8.56 + 11.89	-9.58 + 10.46	-8.56 + 11.89
Range of Motion (°)	5.09 + 6.19	6.09 + 7.70	5.20 + 3.17	11.60 + 9.18	2.58 + 3.69	11.61 + 8.89
Peak Range of Motion (°)	11.70 + 7.11	9.69 + 6.68	5.98 + 2.97	14.96 + 8.97	4.28 + 5.01	14.96 + 7.98
Peak Angle (°)	4.92 + 15.88	-13.74 + 16.43	-9.52 + 6.51	-5.21 + 10.55	-7.87 + 8.01	-5.21 + 10.55

	Hip		Knee		Ankle	
Sagittal Plane (+ =flexion/ - =extension)	**Kick**	**Stance**	**Kick**	**Stance**	**Kick**	**Stance**
Velocity at Footstrike (°.s^{-1})	40.32 + 130.38	-302.91 + 148.47	575.32 + 168.96	-38.31 + 168.56	-59.16 + 191.12	-375.81 + 187.42
Velocity at Ball impact (°.s^{-1})	161.93 + 201.04	-255.52 + 178.14	-1563.13 + 579.19	-157.98 + 133.35	-627.64 + 445.07	-36.32 + 116.18
Peak Velocity (°.s^{-1})	367.15 + 160.68	-595.42 + 342.91	-1563.13 + 579.19	751.36 + 424.55	169.98 + 262.88	-750.40 + 508.18
Coronal plane (+ =adduction/ - =abduction)						
Velocity at Footstrike (°.s^{-1})	-73.00 + 99.26	166.12 + 154.74	-41.25 + 147.25	-23.34 + 94.94	-139.20 + 187.92	-119.68 + 202.63
Velocity at Ball impact (°.s^{-1})	174.98 + 166.15	78.84 + 99.63	92.67 + 353.16	-23.88 + 81.40	-201.51 + 273.98	70.92 + 90.35
Peak Velocity (°.s^{-1})	-113.97 + 119.83	300.32 + 265.11	-110.04 + 195.82	157.05 + 245.18	38.33 + 145.34	657.21 + 704.27
Transverse plane (+ =internal/ - =external)						
Velocity at Footstrike (°.s^{-1})	156.67 + 148.10	-27.60 + 111.65	43.52 + 119.31	191.33 + 227.09	-130.41 + 190.88	2.87 + 151.67
Velocity at Ball impact (°.s^{-1})	-222.57 + 285.59	75.94 + 140.26	5.23 + 345.90	-75.67 + 165.32	-244.97 + 441.74	46.48 + 141.09
Peak Velocity (°.s^{-1})	190.88 + 120.09	175.39 + 206.66	-86.03 + 214.60	342.12 + 386.52	49.86 + 159.13	-315.81 + 344.54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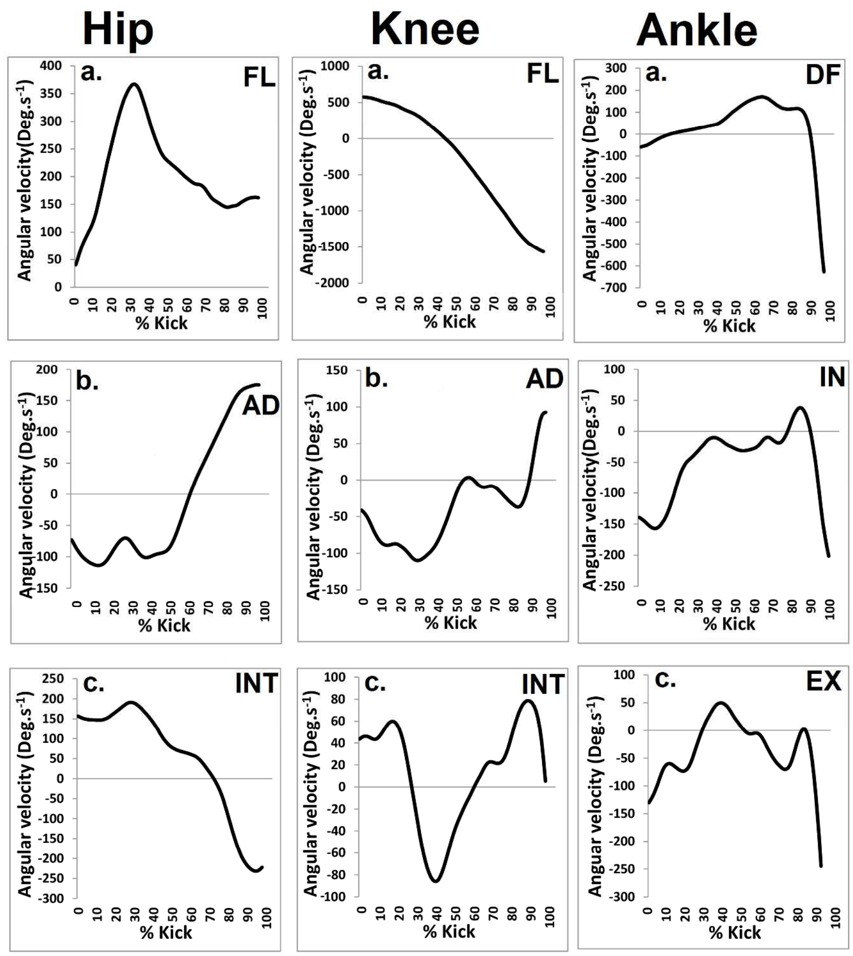
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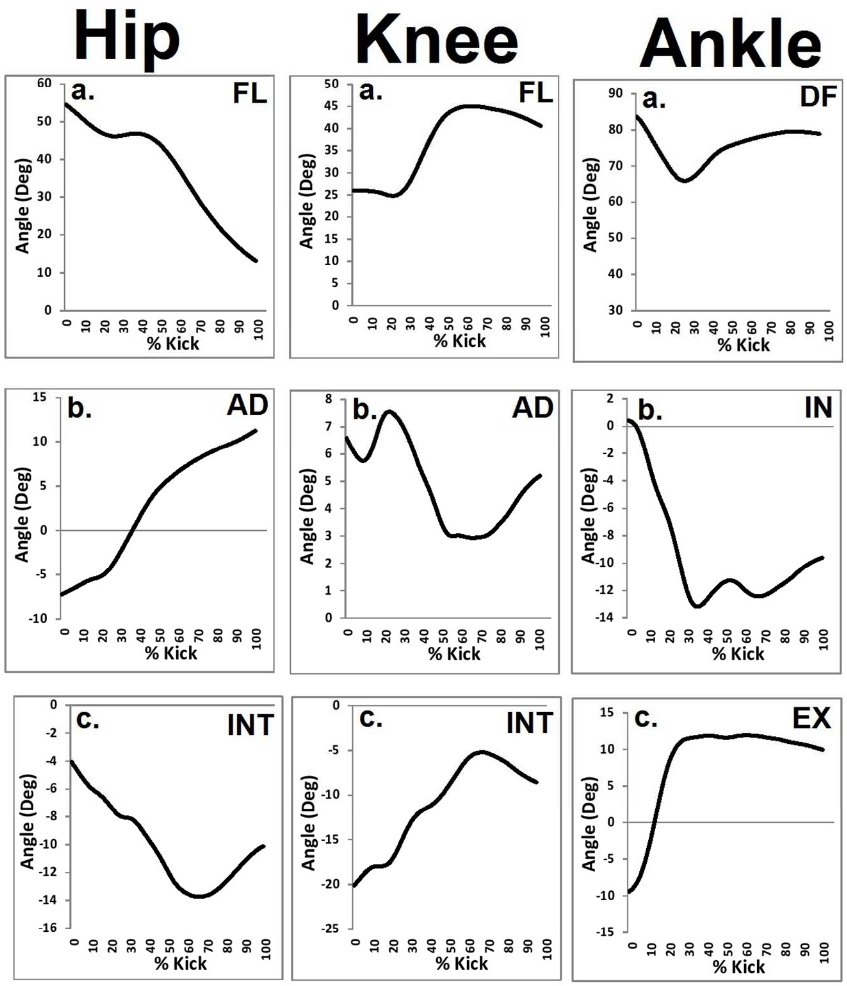

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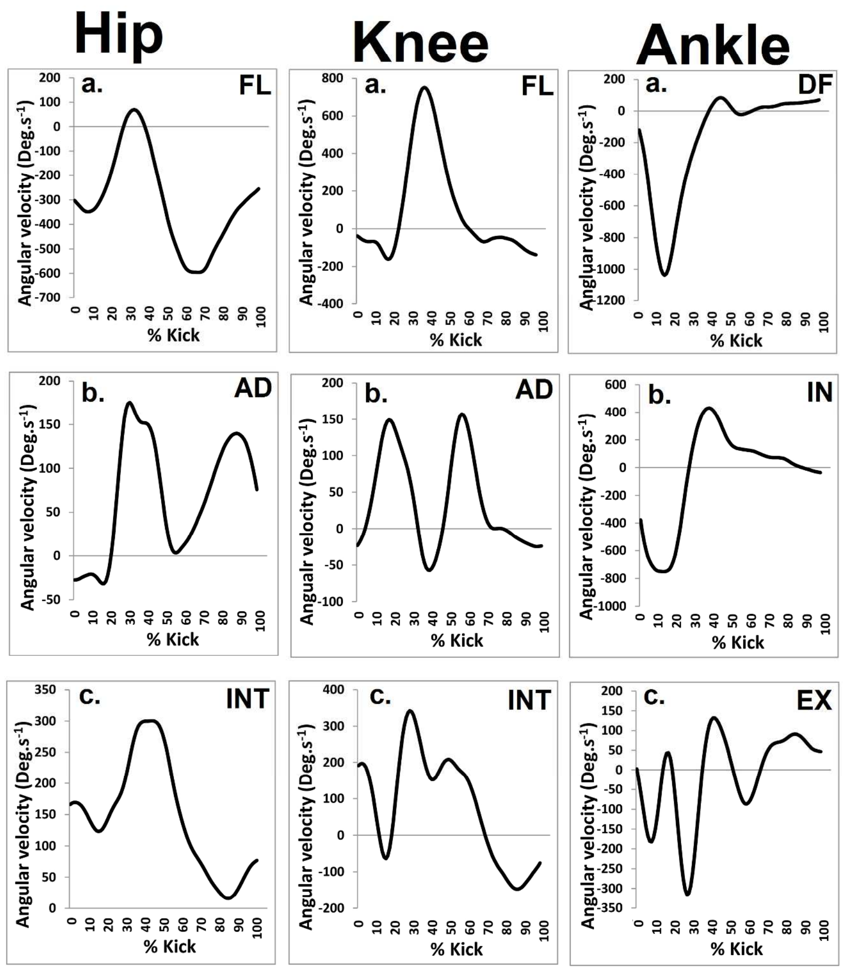
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