FULL BODY MODEL – DESCRIPTION

Table S1. Model Fundamentals

Design	In house developed full body model and location protocol.
Degrees of freedom	All joints/segments : 6
Optimisation	Segment optimisation - Software generic. See Visual 3D documentation at *http://www.c-motion.com/v3dwiki/index.php?title=Six_Degrees_of_Freedom* and [1]
Kinetic calculations	Mass, moments of inertia and center of gravity calculated according to [2] (see Visual 3D documentation at *http://c-motion.com/v3dwiki/index.php/Segment_Geometry*

Table S2. Landmarks

Landmark ID (^bilateral/side)	Location	Location method	Function		Type
			Definition	Tracking	
^ASI	Superficial on skin surface such that marker body is anterior to prominent anterior edge of iliac crest.	Palpation	Yes	Yes	Marker
^PSI	Superficial to palpable prominence at posterior edge of iliac crest.	Palpation	No	Yes	Marker
^ASI2	Superficial and lateral to proximal border of iliac crest.	Palpation	No	Yes	Marker
^VPSI	PSI projected by half marker radius perpendicular to contralateral PSI in plane connecting PSIs and mid point between ASIs.	Calculation	Yes	No	Derived
^VASI	ASI projected by half marker radius perpendicular to contralateral ASI in plane connecting ASIs and mid point between PSIs.	Calculation	Yes	No	Derived
^HJC	Hip joint centre – at the following distances from mid-point between VASI markers (Pelvis origin) in pelvis coordinate system (see Pelvis): AP (in mm) = -0.24PD - 9.9 ML (in mm) = 0.28PD + 0.16PW +7.9 Axial (in mm) = -0.16PW-0.04LL-7.1 Where PD = Pelvic depth: the distance between the mid points of VASIs and VPSIs PW = Pelvic width : distance between left and right VASIs LL = Leg Length : distance between the ASI and VANM via the VKNM [3]	Calculation	Yes	No	Derived

Journal of Experimental Biology • Supplementary information

Landmark ID (^bilateral/side)	Location	Location method	Function		Type
			Definition	Tracking	
^TRO	Lateral and superficial to the centre of the palpated prominence of the greater trochanter when standing in calibration posture.	Palpation	No	Yes	Marker
^TH1	Anteriorly on thigh, approximately 1/3 distance between hip and knee.	Visualisation	No	Yes	Marker
^TH2	Anteriorly on thigh, 50mm (approx.) above the patella when relaxed in standing.	Visualisation	No	Yes	Marker
^TH3	Laterally on thigh, approximately mid distance between hip and knee	Visualisation	No	Yes	Marker
^TH4	Lateral on thigh, between TH3 and TRO	Visualisation	No	Yes	Marker
^KNL	At the bony prominence of the lateral femoral condyle, to form the lateral end of a 'knee axis' with ^KNM.	Palpation	Yes	Yes	Marker
^KNM	At the bony prominence of the medial femoral condyle, to form the medial end of a 'knee axis' with ^KNL.	Palpation	Yes	No	Marker *
^VKNL	KNL projected by half marker radius in direction of KNM.	Calculation	Yes	No	Derived
^VKNM	KNM projected by half marker radius in direction of KNL.	Calculation	Yes	No	Derived
^KJC	Mid point between KNL and KNM.	Calculation	Yes	No	Derived
^SHA1-4	Set of four markers placed anteriorly and posteriorly on lower 1/3 of the shank positioned to avoid excessive rotation due to individual tendon/muscle protrusion on dorsi/plantar flexion.	Visualisation	No	Yes	Marker
^ANL	At most lateral point on lateral malleolus, to form the lateral end of the 'ankle' axis with ^ANM.	Palpation	Yes	No	Marker
^ANM	At most medial point on medial malleolus, to form the medial end of the 'ankle' axis with ^ANL.	Palpation	Yes	No	Marker*
^VANL	ANL projected by half marker radius in direction of ANM.	Calculation	Yes	No	Derived
^VANM	ANM projected by half marker radius in direction of ANL.	Calculation	Yes	No	Derived
^AJC	Mid point between ANL and ANM				
^TOE	At a point approximating position of second metatarsal head on dorsum of shoe	Palpation /Visualisation	Yes	Yes	Marker
^MT1	On dorsum of shoe at a point approximating position of first metatarsal head.	Palpation /Visualisation	Kinetic only	Yes	Marker
^MT5	On dorsum of shoe at a point approximating position of fifth metatarsal head.	Palpation /Visualisation	Kinetic only	Yes	Marker
^FT3	On dorsum of shoe proximal to MT1 and MT5.	Palpation /Visualisation	No	Yes	Marker

Landmark ID (^bilateral/side)	Location	Location method	Function		Type
			Definition	Tracking	
^HEE	On heel counter, approximately 15mm from ground, centrally when viewing from a posterior position along the long axis of the shoe to form the longitudinal axis of the foot with TOE	Measurement /Visualisation	Yes	Yes	Marker
^TOEvert	Projection of TOE onto laboratory floor.	Calculation	Yes	No	Derived
^HEEvert	Projection of HEE onto laboratory floor.	Calculation	Yes	No	Derived
^HEElat	Projection of HEEvert laterally in pelvis coordinate system.	Calculation	Yes	No	Derived
STRN	Anterior and superficial to sternal notch	Palpation	Yes	Yes	Marker
XYPH	Superficial to xyphoid process	Palpation	Yes	Yes	Marker
C7	Superficial to seventh cervical vertebra	Palpation	Yes	Yes	Marker
LUM	Lumbar region, superficial to the spine at point of maximum curvature.	Palpation	Yes	Yes	Marker
LowerTorso	Mid point between XYPH and LUM	Palpation	Yes	No	Marker
UpperTorso	Mid point between STRN and C7	Palpation	Yes	No	Marker
^SHA	Anterior to the approximate shoulder joint centre.	Palpation/ Visualisation	Yes	Yes	Marker
^ACR	Vertically above the acromium process	Palpation	Yes	No	Marker *
^SJC	Projection of SHA onto the plane made by R & LACR and the vertical projection of RACR.	Calculation	Yes	No	Derived
^UPA	On the posterior upper arm approximately half way between the shoulder and elbow.	Visualisation	No	Yes	Marker
^ELL	Superficial to the lateral condyle, placed with the arm hanging to the side of the body	Palpation	Yes	Yes	Marker
^ELM	Approximately superficial to the medial condyle, placed with the arm hanging to the side of the body to form an axis through the elbow with ELL	Palpation	Yes	No	Marker *
^VELL	ELL projected by half marker radius in direction of ELM	Calculation	Yes	No	Derived
^VELM	ELM projected by half marker radius in direction of ELL	Calculation	Yes	No	Derived
^EJC	Mid point between ELL and ELM	Calculation	Yes	No	Derived
^HA1	Between 1st and 2nd metacarpals, approximately 15mm from the metacarpal heads.	Palpation	Yes	Yes	Marker
^HA2	On the radial process of the wrist, to form a ‘wrist axis’ through the joint with HA3.	Palpation	Yes	Yes	Marker
^HA3	On the ulnar process of the wrist, to form a ‘wrist axis’ through the joint with HA2.	Palpation	Yes	Yes	Marker
^VHA2	HA2 projected by half marker radius in direction of HA3	Calculation	Yes	No	Derived

Landmark ID (^bilateral/side)	Location	Location method	Function		Type
			Definition	Tracking	
^VHA3	HA3 projected by half marker radius in direction of HA2	Calculation	Yes	No	Derived
^FIN	HA1 projected distally 0.5*distance between HA1 and midpoint of HA2 and HA3, along the line formed by HA1 and then midpoint of HA2 and HA3	Calculation	Yes	No	Derived
^FHD	On band approximately 2 cm above brow line, vertically above corner of eye	Visualisation	Yes	Yes	Marker
^BHD	On band approximately 2 cm laterally of bony protrusion on back of head	Palpation/ Visualisation	Yes	Yes	Marker
^HEC	Mid point of line between FHD and BHD	Calculation	Yes	No	Derived
LFHD_proj	LFHD projected backwards in global coordinate system by 0.05m	Calculation	Yes	No	Derived
^HEP	HEC projected (upwards) onto plane defined by RFHD, LFHD and LFHD_proj	Calculation	Yes	No	Derived

* Marker removed following static calibration trial

Table S3. Segment definitions

Segment (^bilateral/ side)	**Landmarks** (derived landmarks in parentheses)	**Origin**	**Axes**			**Geometry* Joint radii**	**Tracking markers**
			Flex/ext	**Add/abd**	**Axial**		
Pelvis (V3D Composite[a])	LASI, RASI, LPSI, RPSI, LAS2, RAS2, (LVASI), (RVASI), (LVPSI), (RVPSI)	Midpoint between LVASI and RVASI markers	Parallel to line from origin to RVASI	Orthogonal to the flex/ext and axial axes.	Perpendicular to the plane defined by LVASI, RVASI & the midpoint between LVPSI and RVPSI	See [a]	LASI, RASI, LPSI, RPSI, LAS2, RAS2, VSAC
^ Thigh	(VKNL), (VKNM), TRO, TH1, TH2, TH3, KNL (HJC)	HJC	Perpendicular to axial axis in plane defined by HJC, VKNL and VKNM	Orthogonal to axial and flex/ext axes	Line joining HJC and midpoint between VKNL and VKNM	Proximal: half distance between RTRO and LTRO	TRO, TH1-4, KNL[b]
^ Shank	(KJC), (VANL), (VANM), ANL, SK1-4	KJC	Perpendicular to axial axis in plane defined by KJC, VANL and VANM	Orthogonal to Axial and Flex/Ext axes	Line joining KJC and midpoint between VANL and VANM	Proximal: half distance between VANL and VANM	SK1-4, KNL, ANL[b]
^ Foot	(AJC), (VANL), TOE, LHL, HEE, MT5	AJC	Perpendicular to axial axis in plane defined by AJC, VANL and TOE	Orthogonal to Axial and Flex/Ext axes	Line joining AJC and TOE	Proximal : distance between AJC and VANL, Distal : half distance between MT1 and MT5	TOE, HEE, MT1, MT5, FT3
^ KMAT Foot	(HEEvert), (TOEvert), (HEElat), TOE, LHL, HEE, MT5	HEEvert	Perpendicular to axial axis in plane defined by HEEvert, TOEvert and HEElat	Line joining HEEvert and TOEvert	Orthogonal to Add/Abd and Flex/Ext axes	NA	TOE, HEE, MT1, MT5, FT3

Segment (^bilateral/ side)	**Landmarks** (derived landmarks in parentheses)	**Origin**	**Axes**			**Geometry* Joint radii**	**Tracking markers**
			Flex/ext	**Add/abd**	**Axial**		
Thorax	(UpperTorso), (LowerTorso), STRN, XYPH, C7, LUM.	Upper Torso	Perpendicular to axial axis, orthogonal to plane defined by UpperTorso, LowerTorso and STRN.	Orthogonal to Axial and Flex/Ext axes	Line joining UpperTorso and LowerTorso	Proximal : half distance between RSJC and LSJC Distal : half distance between RASI and LASI	STRN, XYPH, C7, LUM
^ Upper Arm	(SJC), UPA, (VELL), (VELM), SHA, ELL	SJC	Perpendicular to axial axis in plane defined by SJC, VELL and VELM	Orthogonal to Axial and Flex/Ext axes	Line joining SJC to mid point between VELL and VELM	Proximal : distance between SJC and ACR	SHA, UPA, ELL
^ Forearm	(EJC), (VHA2), (VHA3), ELL, HA2, HA3	EJC	Perpendicular to axial axis in plane defined by EJC, VHA2 and VHA3	Orthogonal to Axial and Flex/Ext axes	Line joining EJC to mid point between VHA2 and VHA3	Proximal : distance between VELL and VELM	ELL, HA2, HA3
Hand	(FIN), HA1, HA2, HA3, (VHA2), (VHA3)	Midpoint between VHA2 and VHA3	Perpendicular to axial axis in plane defined by FIN, VHA2 and VHA3	Orthogonal to Axial and Flex/Ext axes	Line joining FIN and midpoint between VHA2 and VHA3	Distal : half distance between VHA2 and VHA3	HA1, HA2, HA3
Head	(RHE),(LHE), (Upper Torso), LFHD, RFHD, LBHD, RBHD	Mid point between RHE and LHE	Perpendicular to axial axis in plane defined by RHE, LHE and Upper Torso	Orthogonal to Axial and Flex/Ext axes	Line joining mid point between RHE and LHE and Upper Torso	Proximal : Half distance between LFHD and LBHD minus 1 marker diameter. Depth : half distance between LFHD and LBHD minus 1 marker diameter	LFHD, RFHD, LBHD, RBHD

[a] See http://www.c-motion.com/v3dwiki/index.php?title=V3D_Composite_Pelvis

[b] Data from repeatedly obscured markers excluded. Segments tracked with at least 3 non-collinear markers including at least 1 anterior and 1 posterior placed marker.

Table S4. Joint definitions / rotation sequences

Joint / Segment angle name[a] (*bilateral)	Segment[b]	Reference segment[b]	Cardan sequence	Positive direction
Pelvis	Pelvis	Laboratory	Flex/ext - add/abd - int/ext rotation	Tilt – anterior Obliquity – right down Twist – right forwards
Hip*	Thigh	Pelvis	Flex/ext - add/abd - int/ext rotation	Flexion Adduction Internal rotation
Knee*	Shank	Thigh	Flex/ext - add/abd - int/ext rotation	Flexion Adduction Internal rotation
Ankle*	Foot	Shank	Flex/ext-add/abd-inv/ev rotation	Dorsiflexion Adduction Inversion
Virtual Ankle*	Virtual Foot	Virtual Shank	Flex/ext-inv/ev-add/abd	Dorsiflexion Inversion Adduction

[a] Virtual segments are used for joint kinematics only.

[b] Angles are calculated within the co-ordinate system of the reference segment.

Table S5. System

Capture system / software	Motion Analysis Corporation [a]: 17-camera Raptor/ Cortex version 6 [a]
Medium	Passive retro-reflective markers : 12.7mm with thin fabric base
Sampling frequency	100Hz

Table S6. Processing

	Software	Details
Eventing	Visual 3D[b]	Kinematic algorithm (velocity-based, from [4])
Filtering	Visual 3D[b]	7Hz-12Hz 4th order Butterworth, by marker [5]
Interpolation	Cortex [a]	Cubic spline / software-based virtual join [a]

[a] Motion Analysis Corporation, Santa Rosa, CA, USA
[b] C-Motion, Germantown, MD, USA
[c] Mathworks, Natick, MA, USA

References

[1] Spoor CW. Rigid body motion calculated from spatial co-ordinates of markers. J. Biomech 1980; 13: 391-393.

[2] Hanavan Jr, EP. A mathematical model of the human body (No. AFIT-GA-PHYS-64-3). Air Force Aerospace Medical Research Lab Wright-Patterson Afb Oh, 1964.

[3] Harrington ME, Zavatsky AB, Lawson SE, Yuan Z, Theologis TN. Prediction of the hip joint centre in adults, children, and patients with cerebral palsy based on magnetic resonance imaging. J Biomech. 2007;40(3):595-602.

[4] Zeni Jr, JA., Richards, JG, & Higginson, JS. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. Gait Posture 2008, 27(4), 710-714.

[5] Giakas, G. Power spectrum analysis and filtering. Innovative Analyses of Human Movement, Champaign, IL: Human Kinetics, 2004.