ACCURACY OF SIX DOF JOINT KINEMATICS DURING NORMAL AND PATHOLOGICAL GAIT: A SIMULATION STUDY

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INTRODUCTION

The conventional gait model (CGM) uses a minimal marker configuration to track three-dimensional lower extremity motion[1]. However, the CGM relies on shared markers between segments, which may adversely affect the reliability of non-sagittal joint angles[2]. A number of researchers have opted to use clusters of three or more markers on each segment to independently assess all 6 segmental degrees of freedom (DOF)[3]. A prior study by our group showed that gait measures derived using redundant marker sets differ significantly from those obtained using a CGM approach in normal subjects, particularly in the non-sagittal plane[4]. However, it is unknown whether the differences found actually reflect greater accuracy, or whether comparable differences would be observed in pathological gait. The goal of this study was to compare the accuracy of non-sagittal joint kinematics derived from inverse kinematic models based on shared and independent marker sets.

CLINICAL SIGNIFICANCE

Pathological gait often includes substantial non-sagittal motion. However, a lack of confidence in non-sagittal gait measures diminishes the usage of such data for treating movement disorders. The results of this study suggest that use of independent marker sets on each limb may improve the accuracy of transverse plane joint angles, and hence may allow for greater consideration of non-sagittal motion in treatment planning.

METHODS

We generated gait simulations of six healthy children (4 males, 2 females; age, 9 ± 1.5 yrs) and two cerebral palsy (CP) patients (1 male age 10 yrs with apparent equinus, 1 female age 14 yrs with Winters type 4 gait pattern) walking over ground at a preferred speed. To generate the simulations, we first scaled a generic three-dimensional, whole body model (with 34 degrees of freedom) to match the measured segment lengths of each subject. We then used a least squares forward dynamics algorithm to compute the pelvic motion and joint angular trajectories over a gait cycle that were optimally consistent with the measured marker kinematics and ground reactions, while also satisfying the overall equations of motion of the system[5]. The results were a set of joint torque-actuated forward dynamic simulations that closely resembled subject-specific gait patterns. Simulated angles were generally within 1 deg of those obtained using more conventional inverse kinematic approaches.

Ideal marker trajectories were then generated assuming that the markers were rigidly fixed to each segment in the simulations. Both random equipment noise (Gaussian noise with 1 mm s.d.) and soft tissue artefact (continuous noise model with random amplitude<10 mm, frequency f<4 Hz, and phase[6]) were then added to the noise free marker trajectories. We computed the joint angles from both the corrupted marker trajectories using six degree of freedom inverse kinematic analyses with two marker sets: 1) A shared marker set in which a virtual hip joint center, and the lateral knee and ankle markers were shared by both the proximal and distal segments, 2) An independent marker set in which 4 tracking markers on each segment were used to compute 6 dof segmental position. We quantified accuracy as the root-mean-squared (RMS) difference between the reconstructed and actual joint angles over a full gait cycle.

RESULTS

Use of an independent marker set resulted in smaller RMS errors for hip, knee, and ankle internal/external rotation angles, and ankle ab/adduction when compared to a shared marker set (Table 1). However, errors in hip ab/adduction were slightly larger using an independent marker set. Model effects on accuracy were similar whether processing normal or pathological gait.

DISCUSSION

Our results suggest that the use of independent marker sets, in which 3 or more markers are placed on a rigid plate attached mid-segment, may enhance the accuracy of 3D joint angles. The most noteworthy improvements were internal-external rotation angles and likely result from using redundant non-collinear markers displaced from the long axis of the joint. Our analyses considered the effect of equipment noise and soft-tissue artefact. However, implementation also requires consideration of how soft tissue noise can vary systematically with marker placement. We conclude that the development and use of optimized, independent marker sets may enhance the confidence that practitioners have in using non-sagittal biomechanical measures to plan treatment.

Table 1: Root mean square (RMS) errors for non-sagittal joint angles using shared and independent marker sets on each segment.

Variable	Normal		Cerebral Palsy		
	Shared Marker Set	Independent Marker Set	Shared Marker Set	Independent Marker Set	Model Effect Significant?
Hip Ab/adduction	2.6 (0.7)	4.3 (1.0)	1.9 (0.8)	4.9 (0.3)	*
Hip Rotation	7.8 (3.7)	4.8 (1.5)	6.7 (2.1)	4.6 (1.6)	*
Knee Ab/adduction	3.3 (1.2)	4.4 (0.8)	4.9 (1.7)	5.2 (0.8)	
Knee Rotation	18.6 (7.0)	6.5 (1.6)	16.5 (4.1)	5.6 (0.6)	*
Ankle Ab/adduction	7.1 (2.6)	3.4 (0.9)	6.2 (1.3)	4.1 (0.6)	*
Ankle Rotation	16.0 (7.7)	4.8 (0.9)	13.9 (4.4)	4.0 (1.4)	*

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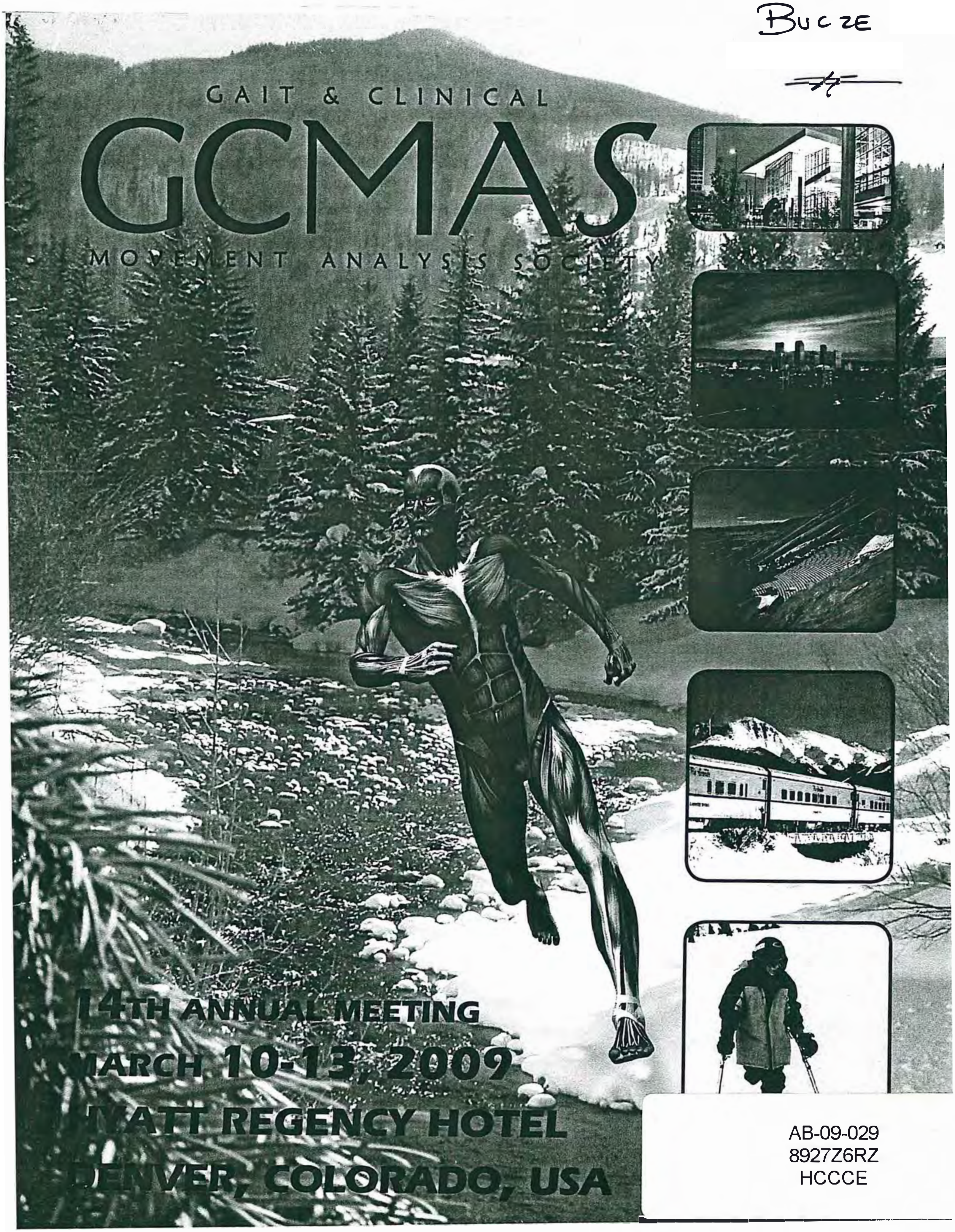
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