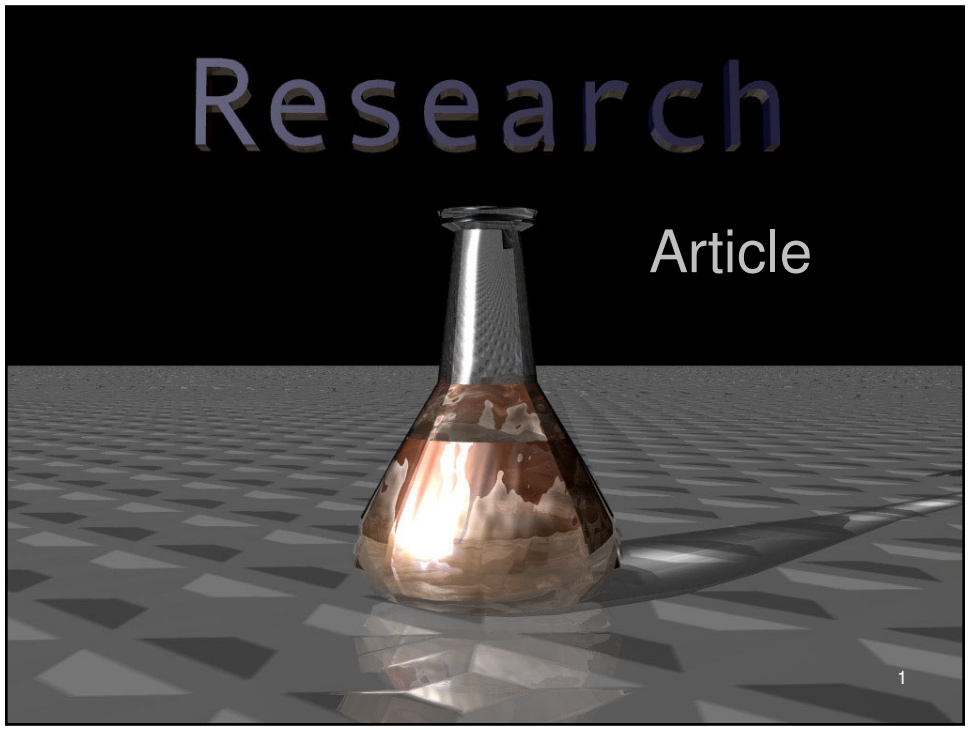
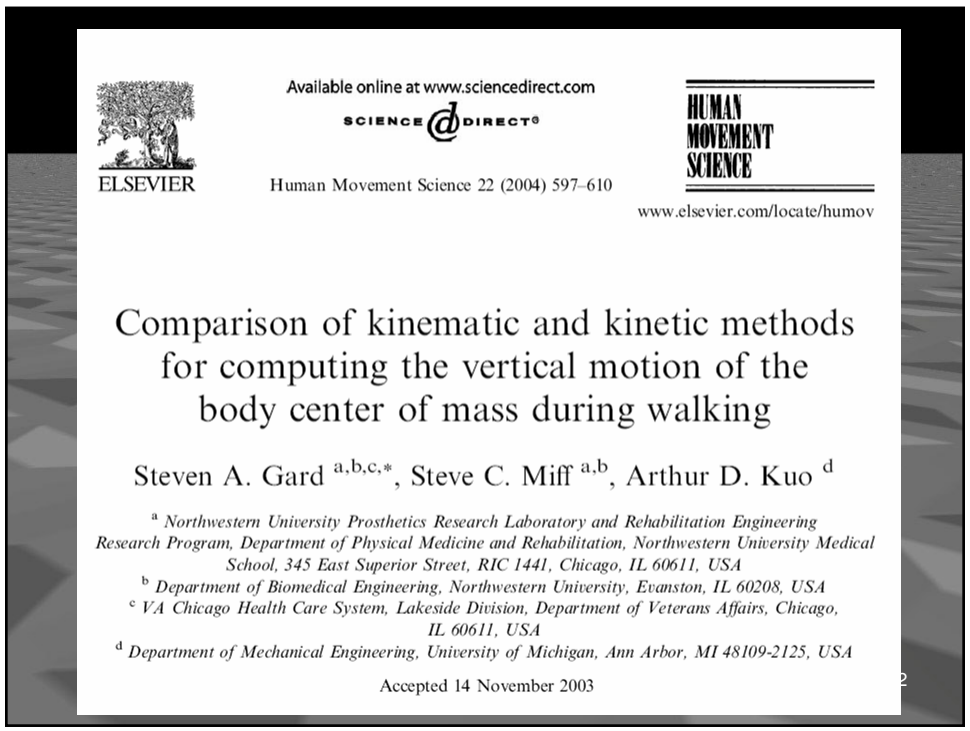
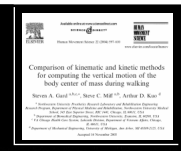

Research
Article
1


ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT®
Human Movement Science 22 (2004) 597–610
HUMAN MOVEMENT SCIENCE
www.elsevier.com/locate/humov
Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking
Steven A. Gard [a,b,c,*], Steve C. Miff [a,b], Arthur D. Kuo [d]
[a] Northwestern University Prosthetics Research Laboratory and Rehabilitation Engineering Research Program, Department of Physical Medicine and Rehabilitation, Northwestern University Medical School, 345 East Superior Street, RIC 1441, Chicago, IL 60611, USA
[b] Department of Biomedical Engineering, Northwestern University, Evanston, IL 60208, USA
[c] VA Chicago Health Care System, Lakeside Division, Department of Veterans Affairs, Chicago, IL 60611, USA
[d] Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109-2125, USA
Accepted 14 November 2003
2

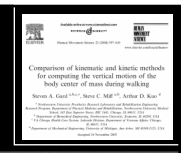
1. BCoM Introduction


Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking

- BCoM Vertical Excursion ~ 4-5 cm;
- Used in:
  - mechanical energy changes estimation;
  - gauge of Efficiency;
  - estimator of Quality of Gait;
  - to estimate Work;
  - to describe Asymmetry;

3

1. Introduction


Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking

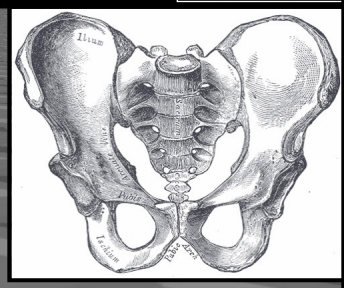
Purpose of study: to account for differences in vertical BCOM excursion calculated from kinematic data and kinetic data in:

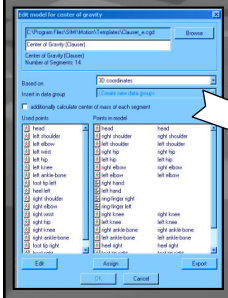
- Sacral Marker Method
- Body Segmental Analysis Method
- Force Platform Data Method

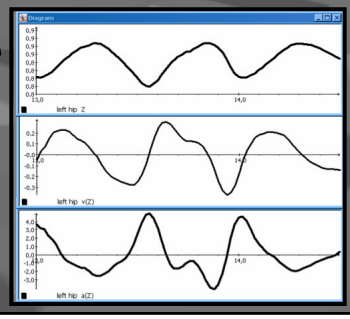
4

Sacral Marker Method

- simplest kinematic method;
- 1 marker placed on sacrum (middle of the 2 PSIS's);



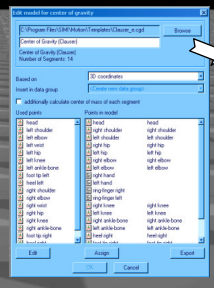


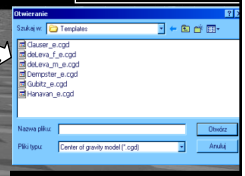


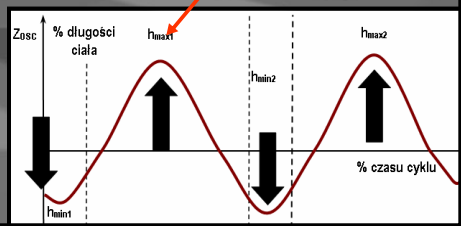
5

Body Segmental Analysis Method

- more sophisticated kinematic method;
- multiple markers;
- anthropometric model to calculate the CoM of each segment;
- BCoM = weighted average of vertical displacements

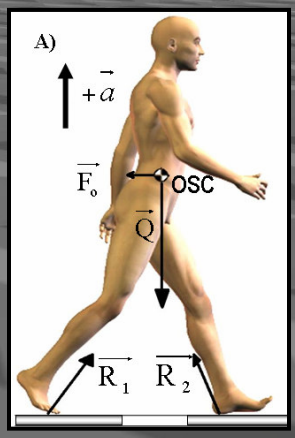






Force Platform Data Method

- use of GRF;
- Newton's 2nd Law;
- double integration of the acceleration term with proper consideration for the integration constants



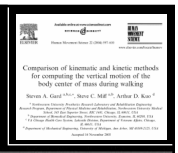
$$a_z(t) = \frac{F_z(t) - m \cdot g}{m}$$

$$v_z(t) = v_0 + \int_0^t a_z(\tau)\,\mathrm{d}\tau = v_0 + \frac{1}{m}\int_0^t (F_z(\tau) - m \cdot g)\,\mathrm{d}\tau$$

$$z_{\mathrm{BCOM}}(t) = z_0 + \int_0^t v_z(\tau)\,\mathrm{d}\tau$$

7

2. Theoretical Model



- 3 rigid link model (trunk & 2 legs);
- 2 rocker legs – effective lengthening;
- Leg CoM causes BCoM to change its position relative to sacral marker;

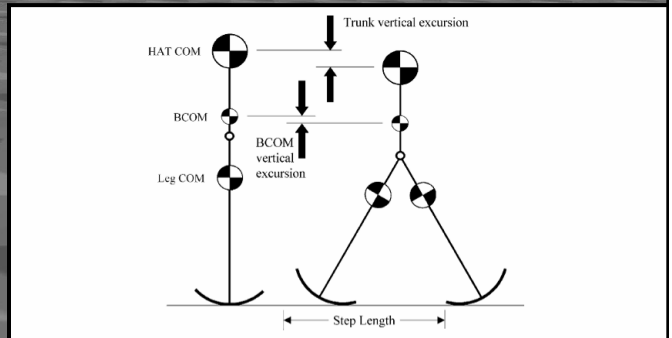
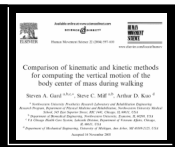


Fig. 1. A simple model can be used to explain the differences observed when calculating the vertical excursion of the BCOM using the sacral marker method, the segmental analysis method, and the force platform method. In the model, the trunk COM and the BCOM are at their highest elevations in midstance when the legs are vertical (figure at left), and they are at their lowest elevations in the middle of double support (figure at right). As step length increases, the trunk COM and BCOM both undergo greater vertical excursions during the step. However, reciprocal action of the legs effectively raises the BCOM position within the trunk, thereby causing the vertical excursion of the BCOM over the gait cycle to be less than that of the trunk.

3. Methods



- 10 healthy adults (5M, 5F);
- 4 walking speeds (0.8, 1.2, 1.6, 2.0 m\s);
- 8 cams (MAC, Santa Rosa, USA); 6 F-plates (AMTI, Watertown, USA)

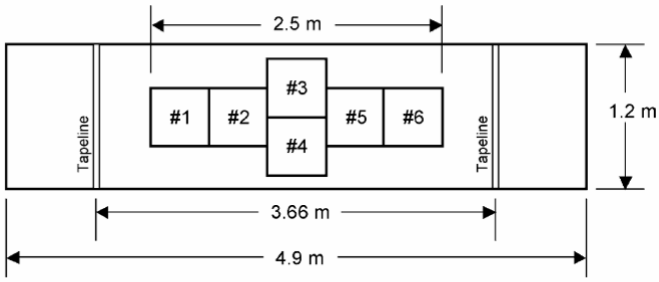
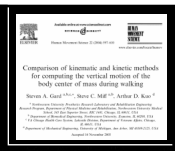
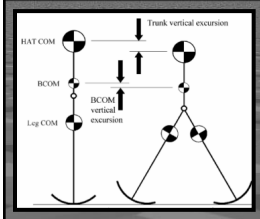


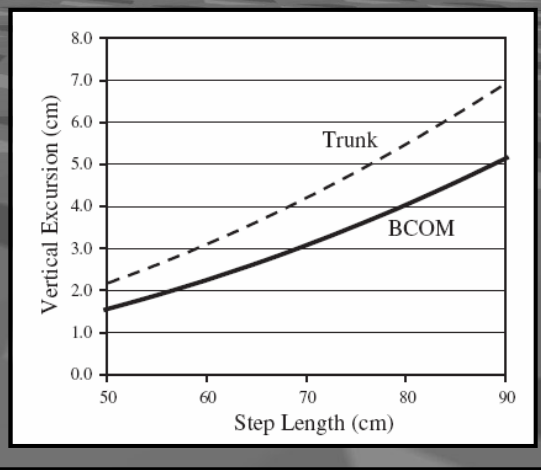
Fig. 3. The measurement volume of the kinematic measurement system occupies an area on the walkway of 4.9 m×1.2 m, with a height of approximately 1.8 m. The six platforms, numbered 1–6, are arranged along the walkway such that the array measures 2.5 m end-to-end, which enables a minimum of three foot strikes (one stride) to be captured at the fastest walking speeds of able-bodied subjects. The total length of the walkway is approximately 11 m.

4. Results





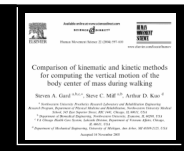
from theoretical model:



as step length increases, the reciprocal action of the legs raise the position of BCOM relative to trunk, causing its vertical excursion to be less

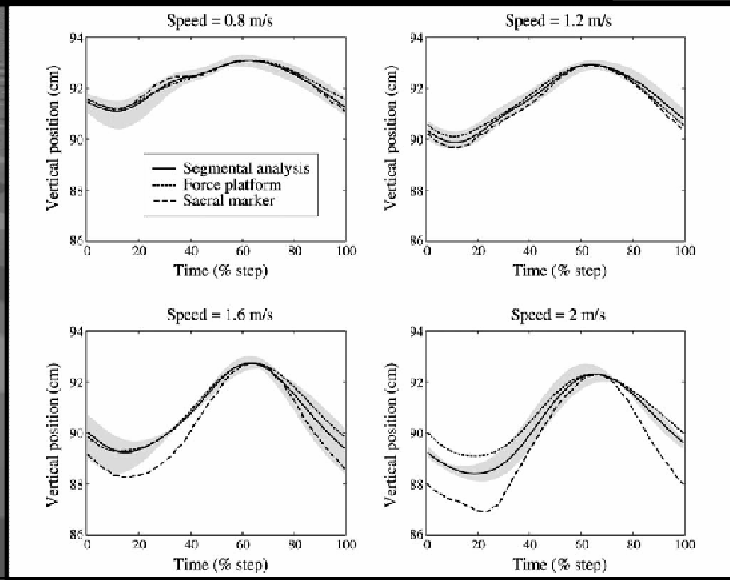
10

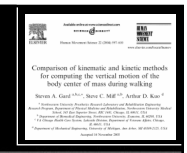
4. Results



Vertical displacement vs time for each gait speed

Average BCoM trials of one representative sub.





Vertical excursion vs gait speed:

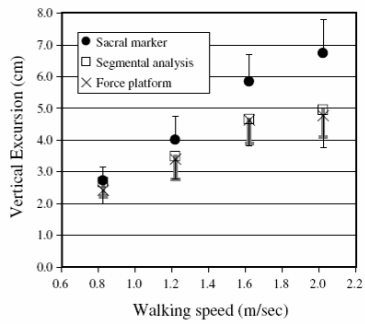
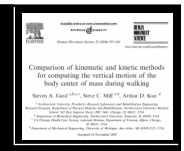


Fig. 5. The vertical excursion of the BCOM for the sacral marker method, the segmental analysis method, and the force platform method, plotted as a function of walking speed. All three methods yield comparable results at the slowest walking speed of 0.8 m/s, but the sacral marker method appears to overestimate the BCOM vertical excursion at faster speeds. The vertical bars represent one standard deviation from the mean; the thicker, gray error bars correspond with the segmental analysis data.

12

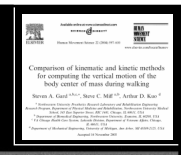
5. Discussions & Conclusions:


Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking

- discrepancies between the sacral marker method and the other two techniques were explained using a simple model;
- the reciprocal configuration of the legs during double support phase significantly raises the position of the BCOM within the trunk at longer step lengths, corresponding to faster walking speeds;
- the theoretical model predicts that the sacral marker method, which tracks trunk motion, will tend to over-estimate vertical trunk excursion compared to the segmental analysis and force platform methods;

13

5. Discussions & Conclusions


Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking

- at the slowest walking speed the vertical excursions calculated by all three techniques were similar
- the body segmental analysis and force platform techniques were in agreement at all walking speeds

- the sacral marker method may provide a reasonable approximation of vertical BCOM motion at slow and freely selected speeds of able-bodied walking;
- the body segmental analysis or force platform techniques will yield better estimates at faster walking speeds or in persons with gait pathologies

14