DYNAMIC ANALYSIS OF STABILITY IN HUMAN LOADED WALKING AT DIFFERENT VELOCITIES AND HEIGHTS OF THE CENTER OF MASS, AND POSSIBLE OPTIMAL AREAS IN DIFFERENT MODES OF WALKING

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KEY WORDS: stability, dynamic analysis, optimum, center of mass (COM), height and velocity

INTRODUCTION: Loaded walking plays an important role in man's many activities, including sport, such as leisure travel and hill walking. It is known that during loaded walking the velocity and height of the body center of mass (COM) are two important factors for the stability of the whole body. This paper investigates which heights and velocities of COM lead to stable loaded and unloaded walking.

There are many authors (Alexander, 1980; Winter,1990; Cappozzo,1975; Williams and Cavanagh,1983) who have done work on the biomechanical analysis of walking. However, few authors dealt with loaded walking. Another author (Taylor et al 1970, 1980) researched the loaded walking of animals with physiological methods.

In this paper, we will discuss loaded walking in view of walking stability. It is known that ways of carrying loads are related to the center of mass (COM) of the whole body. If a load is put on the shoulder or hung on a pole, the COM of whole body will shift higher or lower. In general, the height of COM may influence the stability of walking. In addition, the velocity at COM may also have effects on the stability of walking.

How does one evaluate the stability of loaded walking? We consider a subject with a load as a whole body. When the subject is walking on the ground, he is reacted to by ground reaction forces. These forces result in angular acceleration at the COM. The product of the acceleration and inertia of moment of the whole body will be used as a criterion for the stability of loaded walking.

METHODS AND PROCEDURES: The method was as follows.

1) We considered the whole body (subject and loads) as a simple three-segment model consisting of two lower limbs (leg-foot) and one upper body (head-trunk-arm, HTA);

2) Subjects were required to walk on a long experiment lane where several cameras and a force platform were fixed. Sequences of motion and ground reaction forces can be recorded when subjects are walking. Subjects were asked to walk at self-determined 'slow', 'comfortable', 'fast' speeds and loaded in one of three different ways and with different ways of carrying;

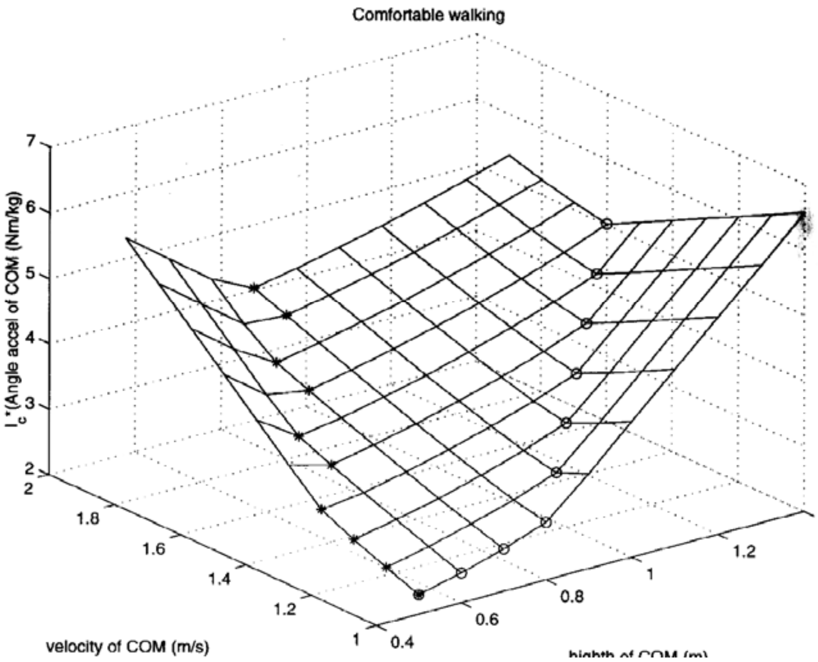
3) We applied dynamic equations to the models. According to Newton's Laws, the system (three-segment-model) and external forces have the relationship:

$$\sum F = ma_c \quad (1)$$

$$\sum M = I\beta \quad (2)$$

where m-mass, including subject-weight and carried load; I- inertia of

moment of whole system; a_c-acceleration of COM; J-angular acceleration about the COM.
When we know ground reaction forces from force plate recording, we can calculate the velocity and displacement of COM. As different loads were put on different heights, different heights of COM should be known.
4) We can get the joint motion from the analysis of motion sequences, and obtain ground reaction forces from the recording of the force platform. Inputting ground reaction force and joint motions enables us to calculate angular acceleration and moments about COM. In calculation, the reaction forces of two feet have been considered.
5) According to the general shape of the ground reaction forces, the forces may be divided into three kinds: slow, comfortable and fast modes of walking. We simulatively calculate stability under the three situations.



6) From these experiments and simulation, we can analyze possible optimum areas at different velocities and heights of COM.

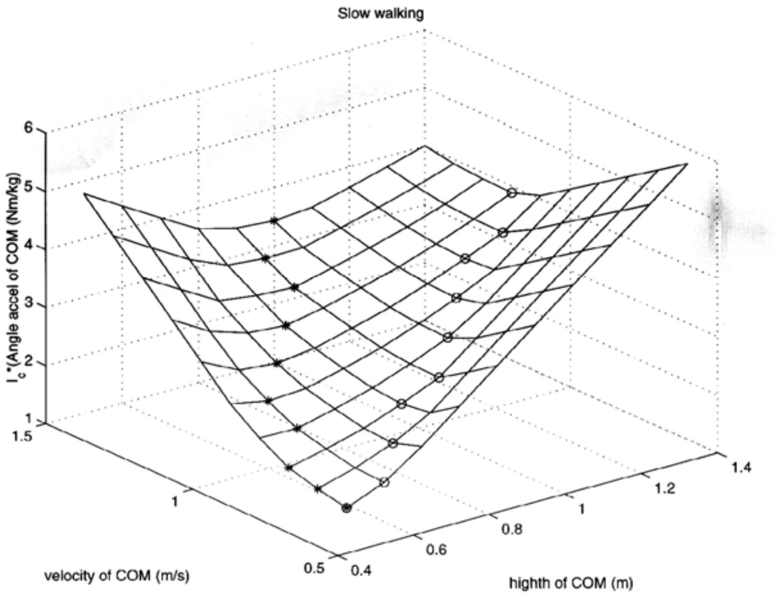


Figure 2 Simulation of the stability of loaded walking at slow walking.

RESULTS AND DISCUSSION: Results (see Figures 1-3) show that there are different dynamic responses for different modes of walking. In general, taking the stability of the center of mass as our criterion, stability in loaded walking decreases with an increase in the height and velocity of COM. However, a lower height of COM does not always satisfy the criterion of stability. Neither does a greater height of COM always lead to reduced stability. If COM is lower and velocity is higher, this will result in an decrease in stability (see Fig. 1-3). Rather, it is apparent that different modes of loaded walking each have a characteristic height/velocity area, beyond which stability decreases. From Figure 1-3, comfortable walking can form a larger stability area, and fast walking has a smaller stability area. The differences of stability areas result from the differences of ground reaction forces. So it is discovered that a special stability area may exist for a relative walking way.

CONCLUSIONS: In fact, for different carried walking ways, there are some suitable areas where optimum stability may be obtained and beyond which the stability of human walking may decrease. For a different height of COM, this paper recommends a relative walking velocity which may be referenced to human leisure, sport and transport activities.

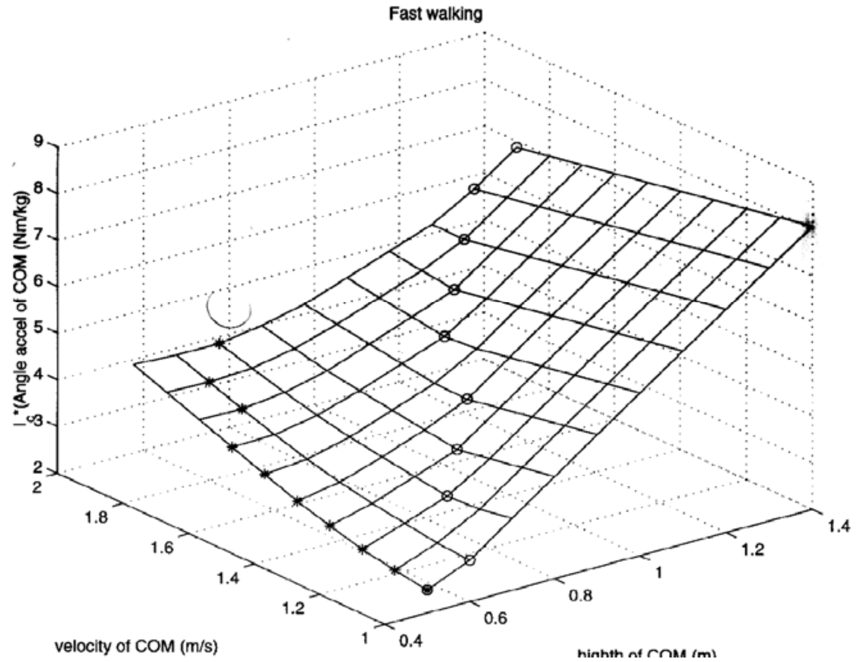


Figure 3 Simulation of the stability of loaded walking at fast walking

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Acknowledgments:

This research is funded and supported by grants from the Natural Environment Research Council, Biotechnology and Biological Sciences Research Council, the Royal Society, and the Erna and Victor Hasselblad Foundation.