Journal of Biomechanics 44 (2011) 2706–2711

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

A comparison of Coulomb and pseudo-Coulomb friction implementations: Application to the table contact phase of gymnastics vaulting

M.I. Jackson, M.J. Hiley, M.R. Yeadon*

School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough LE11 3TU, United Kingdom

ARTICLE INFO

Article history:
Accepted 28 July 2011

Keywords:
Computer simulation
Friction
Stiction
Vaulting
Gymnastics

ABSTRACT

In the table contact phase of gymnastics vaulting both dynamic and static friction act. The purpose of this study was to develop a method of simulating Coulomb friction that incorporated both dynamic and static phases and to compare the results with those obtained using a pseudo-Coulomb implementation of friction when applied to the table contact phase of gymnastics vaulting. Kinematic data were obtained from an elite level gymnast performing handspring straight somersault vaults using a Vicon optoelectronic motion capture system. An angle-driven computer model of vaulting that simulated the interaction between a seven segment gymnast and a single segment vaulting table during the table contact phase of the vault was developed. Both dynamic and static friction were incorporated within the model by switching between two implementations of the tangential frictional force. Two vaulting trials were used to determine the model parameters using a genetic algorithm to match simulations to recorded performances. A third independent trial was used to evaluate the model and close agreement was found between the simulation and the recorded performance with an overall difference of 13.5%. The two-state simulation model was found to be capable of replicating performance at take-off and also of replicating key contact phase features such as the normal and tangential motion of the hands. The results of the two-state model were compared to those using a pseudo-Coulomb friction implementation within the simulation model. The two-state model achieved similar overall results to those of the pseudo-Coulomb model but obtained solutions more rapidly.

1. Introduction

In almost all examples of human movement contact with external bodies is involved and frictional forces act. For example when there is contact between a limb and the ground to arrest a fall, the force acting parallel to the ground is friction. Other examples where frictional forces are encountered are activities such as walking, running, jumping, cross-country skiing, tennis and gymnastics in which friction acts both as a driving force and as a retarding force. The motion of interest for this study was gymnastics vaulting, and in particular the table contact phase of the vault, where frictional forces act between the gymnast's hands and the vaulting table.

When two objects come into contact and there is relative motion between them (sliding) the frictional force is known as dynamic friction. On the other hand if the objects are at rest relative to each other, the frictional force is known as static friction, a state often referred to as 'stiction'. The table contact phase of gymnastics vaulting is a situation in which both sliding and stiction occur (Fig. 1).

Coulomb's law is commonly used to model frictional forces. During the sliding phase Coulomb's law states that the frictional force $F_{frictional}$ is proportional to the magnitude of the normal contact force F_{normal} :

$$|F_{frictional}| = \mu_k |F_{normal}| \tag{1}$$

where μ_k is the coefficient of kinetic friction. During the stiction phase the frictional force is equal in magnitude but opposite in direction to the net force tending to cause motion and hence no motion occurs. In this case Coulomb's law provides a threshold value for the frictional force, above which motion would occur:

$$|F_{frictional}| \leq \mu_s |F_{normal}| \tag{2}$$

Application of Coulomb friction involves transitions from stiction to sliding and vice versa. Rather than using two separate computer simulation models to simulate friction in human–ground interactions many researchers have advocated the use of pseudo-Coulomb friction models (McLean et al., 2003; Neptune et al., 2000; Wojtyra, 2003). A pseudo-Coulomb model is an approximation of Coulomb friction in that instead of having a stationary contact in the stiction phase, sliding continues but with

* Corresponding author. Tel.: +44 1509 226307; fax: +44 1509 226301.
E-mail address: M.R.Yeadon@lboro.ac.uk (M.R. Yeadon).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.07.022