BIOMECHANICAL SIMULATION OF HUMAN LIFTING

COLOBERT B. MULTON F., CRETUAL A. and DELAMARCHE P.

Laboratoire de Physiologie et Biomécanique de l'Exercice Musculaire
Address : av. Charles Tillon, Université Rennes 2,UFRAPS ,35044 Rennes, France
Tèl : (+33) 02 99 14 17 78- Fax : (+33) 02 9914 17 74
Mail : briac.colobert@uhb.fr

Abstract: The aim of this paper is to simulate several levels of lifting strategies from parameters depending on the subject's centre of mass movements. Usually, symmetrical lifting strategies were categorized in two major solutions (Chaffin and Andersson, 1991): the squat lift that mainly involves a knee flexion and the back lift that mainly involves hip flexions. In the literature two main indexes (Zhang et al. 2000) were introduced to evaluate the natural selected strategy. These indexes either did not take all the articulations into account or did not consider the evolution of posture depending on time. We propose a new index based on kinematic simulation obtained through a blending of the two extreme strategies. This work was based on the motion blending technique introduced in computer animation (Witkin and Popovic, 1995). To parameterise this simulation method, five squat lifts, five back lifts and five freestyle lifts were performed by one subject. A para sagittal model with five body segments was used to describe the posture of the subject. We captured the angular trajectories of the different lifts to abstract the natural lift movement as a blending of the two extreme strategies. To this end, a blending coefficient, considered as the strategy index, was introduced to minimize the set of control parameters of such a model. Indeed, instead of specifying a blending coefficient to each joint separately, we introduced a unique blending coefficient based on the displacement of the centre of mass. This choice enabled us to use only a force plate system to generate the inputs of our model. Hence, the angular trajectories could be simulated only thanks to the displacement of the centre of mass and to the blending coefficients identified in this paper. Our results showed a constant pattern of the angular trajectories for each joint and each strategy. The resulting blending coefficient remained constant for each joint during the movement. However depending on the joint, different values of blending coefficients were computed. For the ankle, we found that back lift was very attractive (the same behaviour whatever the strategy used) whereas for the knee and the shoulder different behaviours were found. On the opposite, the hip and the elbow trajectories were not influenced by the strategy. This work has potential applications in computer animation and in clinical biomechanics. To conclude, this approach could be applied to all kinds of movements involving a compromise between two extreme strategies, such as lifting.

Keywords: biomedical simulation, human lifting, motion blending

1. INTRODUCTION

Lifting is a daily activity and its modelling is of interest for several areas. Several authors developed biomechanical models to evaluate and predict the effect of the weight of the load, position of load, body posture, or the strength capability of the human body on the way people lift weights. (Chaffin and Andersson, 1991; Hsiang et al. 1999).

Computer animation modelled human motion in order to generate realistic synthetic motions. These models were created to avoid motion capture and heavy manual motion editing, more expensive and difficult to reemploy. Most biomechanists (Hsiang et al. 1999, Chaffin and Andersson, 1991) referred to the principle of two pure lift strategies. In case of back lift, leg remains in extension and only the hip joint, the spine and the upper limbs are used. Squat lift uses a flexion at the knee that decreases spinal constraints. Two authors presented indexes to quantify the strategy employed. Burgess-Limerick and Abernethy, (1997) proposed to quantify lifting strategy by the ratio between the knee flexion and the sum of ankle, hip and lumbar vertebral flexion. Unfortunately this index was only based on two postures: the standing posture and the one that occurred at the beginning of the lift, when the weight was held. Another index (Zhang et al., 2000) was based on leg and back velocity during

Proceedings 17th European Simulation Multiconference
(c) SCS Europe BVBA, 2003 ISBN 3-936150-25-7

the lift. Nevertheless this model did not include the arms that contributed to the lift. Another problem was that the index was supposed time-invariant which is not true.

Kinematic simulation was widely used in computer animation (Multon et al. 1999). Especially, Frame Space Interpolation (Guo and Roberg, 1996) was introduced to blend four different angular trajectories by using interpolation and time-warping. Motion warping (Witkin and Popovic 1995) was also used to modify a reference motion in order to generate new behaviours. Nevertheless, these techniques have never been validated in comparison to real movements and, consequently, were not used in clinical applications.

2. MODEL

In our study, we used a 5-link para-sagittal lifting model (Chaffin and Anderson, 1991) currently used by ergonomists.

Similar to Witkin and Popovic (1995), we blended two sequences of joint angles to create new joint trajectories. The blend was a straightforward weighted sum (considered as a time-dependant interpolation) of the two motion curves:

$$(1) \qquad \theta_I = \alpha_i(t) * \theta_{M1} + (1-\alpha_i(t)) * \theta_{M2}$$

where θ_I, θ_{M1}, and θ_{M2} were respectively, the interpolated motion, motion one (referred to as a back lift strategy) and motion two (referred to as a squat lift strategy) and $\alpha_i(t)$ was a normalized weight function depending on time.

It was possible to compute blending coefficients $\alpha_i(t)$ at each time of the trial. In the literature, the strategy evaluated by considering the initial posture may yield to large errors (Zhang et al., 2000). Hence, the strategy could be better identified in the middle-part of the movements while the initial and final posture may be identical. To avoid this problem, only the middle part of the trial was considered in our method to identify blending coefficients.

The coefficients $\alpha_i(t)$ were computed for each angular trajectory (ankle, knee, hip, shoulder, elbow) and for each time step:

$$(2) \quad \alpha_i(t) = \frac{\theta_I(t) - \theta_{M2}(t)}{\theta_{M1}(t) - \theta_{M2}(t)}$$

The same kind of calculation $\alpha_G(t)$ was carried-out for the centre of mass movements because it reflects the global posture of the subject:

$$(3)$$

$$\overrightarrow{OG^{MI}} = \alpha_G\left(\frac{\sum m_i \overrightarrow{OG^{M1}{}_i}}{\sum m_i}\right) + (1-\alpha_G)\left(\frac{\sum m_i \overrightarrow{OG^{M2}{}_i}}{\sum m_i}\right)$$

where

$$\overrightarrow{\alpha_G} = \begin{vmatrix} \alpha_{Gx} \\ \alpha_{Gy} \\ \alpha_{Gz} \end{vmatrix} \text{ and } \alpha_{Gc} = \frac{OG_c^{MI} - OG_c^{M2}}{OG_c^{M1} - OG_c^{M2}}.$$

, with c in {x, y, z}

Where $\overline{OG}$ was the centre of mass position, $\overline{OG_i}$ was centre of mass position of the i[th] segment. m_i was the mass of the i[th] segment, α_G and α_i were obtained the same way, by computing the coefficient that linked the natural posture, the pure back-lift posture and the pure squat-lift one.

The two pure strategies and each natural lift motion engendered different centre of mass displacements that can be modelled according to equation 3. Our model was designed to be capable of simulating new lifting movements according to pre-recorded pure back lift and pure squat lift trajectories. The movements of the centre of mass depend on those of the body segments. The inverse kinetics problem that links the centre of mass position and those of the body segments engendered infinity of solutions because of the redundancy of the kinematic chain. As a first approximation we proposed to use a linear relationship between these two values, for each time step. To this end, we proposed to normalize the $\alpha_i(t)$ values by $\alpha_G(t)$:

$$(4) \quad \alpha_{iG}(t) = \frac{\alpha_i(t)}{\alpha_G(t)}$$

Using equation (3), it comes:

$$(5)$$

$$\overrightarrow{OG^{MI}} = \left(\frac{\sum m_i \frac{\alpha_i}{\alpha_{iG}} \overrightarrow{OG^{M1}{}_i}}{\sum m_i}\right) + \left(\frac{\sum m_i (1 - \frac{\alpha_i}{\alpha_{iG}}) \overrightarrow{OG^{M2}{}_i}}{\sum m_i}\right)$$

where each variable is time-dependent.

Given a α_G and a set of predefined $\{\alpha_{iG}\}$, at each time, it was then possible to design a new motion by applying equation 1. To conclude with this part, the overall system could be depicted as in figure 1

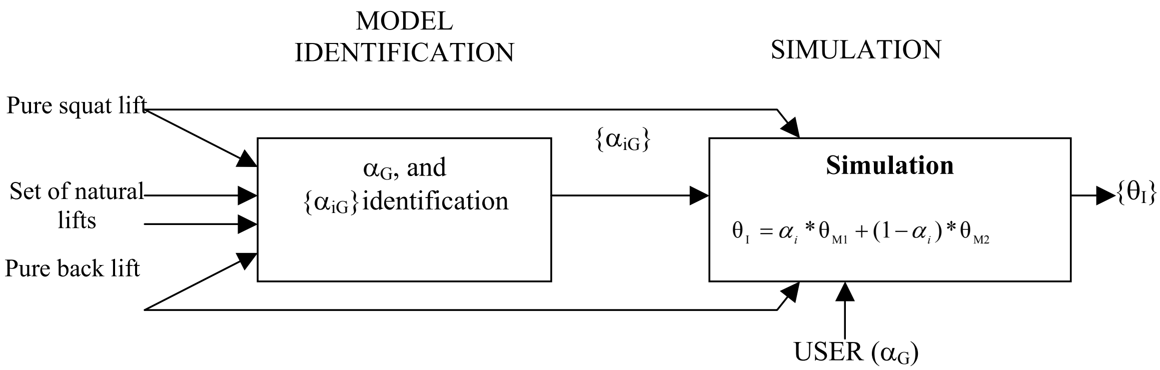


Figure 1: overview of the identification/simulation process.

3. PROTOCOL

One subject was instructed to perform back-lifts, squat-lifts and several free-lifts. Five trials of each style were performed. The subject was instructed to avoid a twist of the trunk during the lift. Every lift was started and finished from/to a stationary imposed posture. Markers were attached to the anatomical landmarks closed to joint centers and along the spine (figure 1). Joint displacements were collected with a motion capture system: VICON (370 Oxford Metrics) cadenced at 60 Hz. The joint trajectories were smoothed with cubic splines.

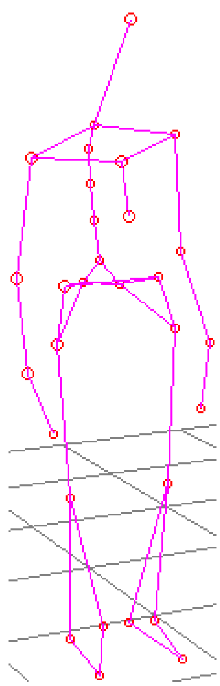


Figure 2 : position of the markers on the subject's body.

4.RESULTS

Given a lifting task with predetermined starting and ending positions, the five angular trajectories of an individual lifter are usually very consistent, with a distinctive pattern. This kind of observation was reported in the literature (Zhang et al., 2000; Hsiang et al, 1999). Standard deviation from the mean trajectory was around 3-5 degrees for all joints. This stability of the trajectory was observed for each evaluated strategy (see figure 3 for the squat-strategy). The smoothed and averaged angular trajectories for the squat-strategy and the back strategy trials are presented in figure 4. The resulting blending coefficients for all the trials are depicted in table 1.

Three kinds of behaviours were observed. Two articulations (knee and shoulder) behaved with a smooth transition between back strategy and lift strategy. Two articulations were not affected by the strategy and presented an identical shape in all cases (free, squat and back strategy). Finally an articulation (ankle) seems to be much more attracted by a strategy (squat lift) than the other (back lift).

Simulations were computed for six different values of α_G: 0, 0.25, 0.50, 0.75, and 1. Thanks to the imposed α_G, α_i for each joint were computed depending on the pre-recorded α_{iG}. The resulting movements are presented in figure 5 for α_G ranging from 0 (top of figure 5) to 1 (bottom of figure 5).

Table 1 : α_i , α_{iG} , α_G for the selected joints

Joint	α_i		α_{iG}
	mean	s.d.	Mean
Ankle	0.97	0.05	1.90
Knee	0.66	0.03	1.29
Hip	1.00	0.03	1.96
Shoulder	0.70	0.07	1.37
Elbow	0.0	0.2	0
Centre of mass (α_G)	0.51	0.1	

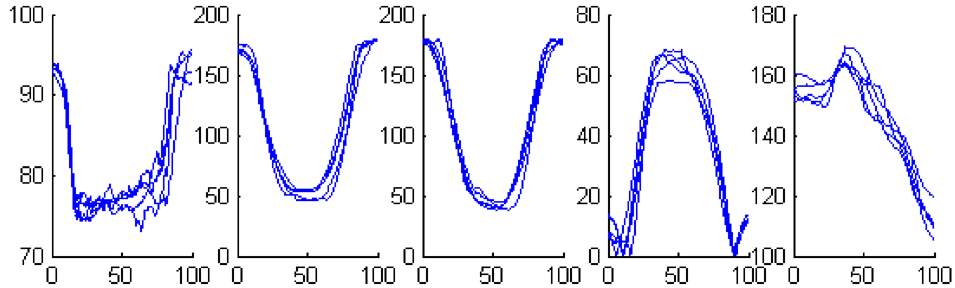


Figure 3 : angular trajectories (in degrees) of the five selected joints for the squat-strategy, ankle, knee, hip, shoulder and elbow, depending on time expressed as a percentage of the total duration of the movement.

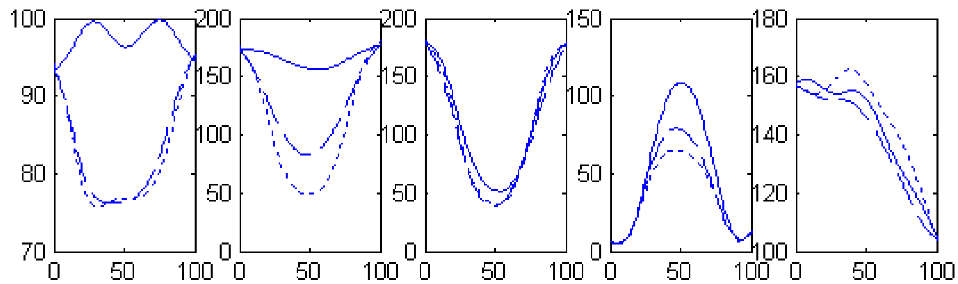


Figure 4 : angular trajectories (in degrees) of the five selected joints (ankle, knee, hip, shoulder and elbow) depending on time (% of the movement duration), for the three lifting condition; back lift in solid line, squat lift in dotted line and a free lift in dashed line.

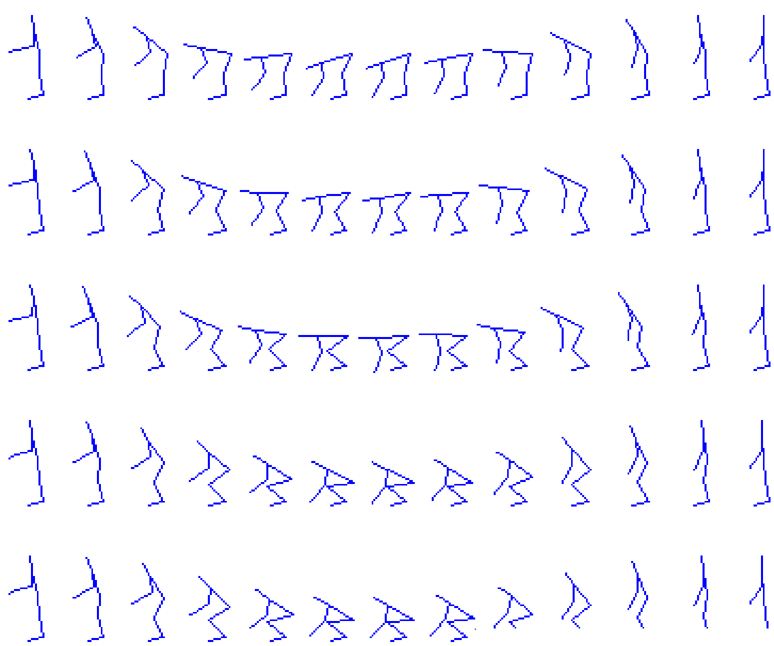
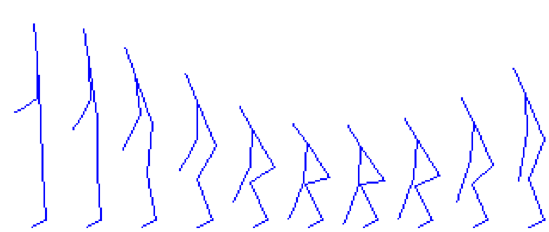


Figure 5 : simulated movements for α_G ranging from 0, t



5. DISCUSSION

This paper described a new approach to simulate a kinematical model of lifting movements thanks to a biomechanical analysis of lifting. As a result to this analysis, a new lift index was introduced. This input parameter of our model was the centre of mass blending coefficient between a squat and a back strategy. Such a blending coefficient is interesting as it relies to a physical meaning: the movements of the centre of mass. In addition to the index, a set of parameters were identified. These parameters deal with the link between the centre of mass position and the joints configuration. A table contained all these data to parameterize the simulation model. This method and its results can be applied in computer animation or in clinical biomechanics. For this last application field, using a costly motion capture system is not always possible. The alternative is generally to use force-plates that provides with other kinds of information (ground reaction forces, momentum and position of the centre of pressure). Consequently, it is necessary to define methods to use force-plates in order to indirectly access kinematic parameters. Force plate enables to evaluate the centre of mass displacements. Hence, our system enables to evaluate lifting strategy by only focusing on the centre of mass movements and using identified parameters.

To conclude, this approach could be applied to all kinds of movements involving a compromise between two extreme strategies, such as lifting.

REFERENCES

Burgess-Limerick, R., Abernethy, B., 1997. Toward a quantitative definition of manual lifting postures. Human Factors 39, 141:148.

Chaffin, D.B., Andersson, G.B.J., 1991. Occupational Biomechanical Models. In: Occupational Biomechanics. Wiley, New York

Guo S. and Roberg J., 1996. A high-level mechanism for human locomotion based on parametric frame space interpolation. Computer Animation and Simulation'96, 95-107

Hsiang S.M., Chang C., McGorry R.W. 1999 Development of a set of equations describing joint trajectories during para-sagittal lifting, Journal of Biomechanics 32, 871:876

Witkin, A., Popovic, Z. 1995. Motion Warping SIGGRAPH 95, Los Angeles, August 6–11 Computer Graphics Proceedings, Annual Conference Series.

Zhang, X., Nussbaum, M.A., Chaffin D.B. 2000. Back lift versus squat lift: an index and visualization of dynamic lifting strategies. Journal of Biomechanics 33, 777:782