MOVEMENT QUALITY OF MARTIAL ART OUTSIDE KICKS

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INTRODUCTION: The Concise Oxford Dictionary defines martial arts broadly as "fighting sports such as judo and karate". Other definitions of martial arts are used as "the study of any kind of combat and/or self-defence techniques", which includes techniques not embraced within the notion of sports. A biomechanical analysis of martial arts techniques is extremely difficult in the light of the huge number of different arts and styles practiced. However, analysis seems tangible in the light of a guiding principle. Jigoro Kano (Kano, 1994, published posthumously) introduced the all-pervasive principle "to make the most efficient use of mental and physical energy". While this principle is concerned with the mental and physical aspects of martial arts, the following study concentrates on the physical/biomechanical characteristics that follow from this principle. What is an efficient use of physical energy? Surely something like applying a technique whereby the energy cost is minimized. The technique we analyze is the "Pak Kat Tari Cha Gi" also called outside kick. This kicking technique is simple enough to be executed by beginners hence complex enough to display various degrees of proficiency. The goal is to deliver a kick perpendicular to the line connecting the attacker and the target (Figure 1).

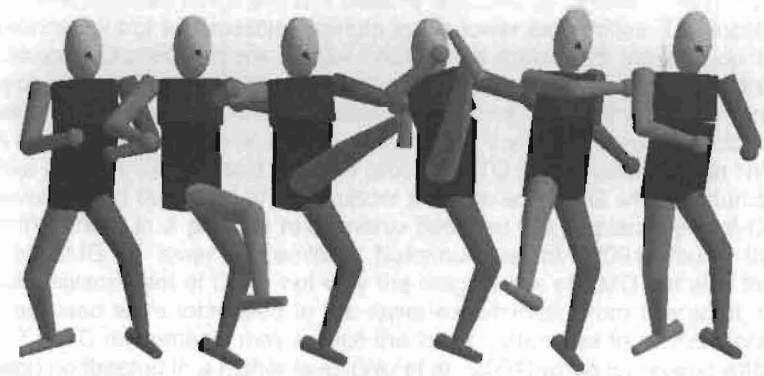

Figure 1 Outside kick (Pak Kat Tari Cha Gi) - temporal ordered from left to right.

The efficiency we define as delivering the kick with a high velocity vector lying in a level surface perpendicularly to the frontal plane of the athlete, while the overall energy needed to perform the entire movement is as low as possible.

METHODS: Nine subjects with 17 markers were videotaped by five digital cameras of 50 Hz (PAL standard). Each participant did three consecutive kicks with the right and three consecutive kicks with the left leg. Using the APAS system we digitized all views. The software system Human-Builder converts all the tracks of the markers and creates together with a given subject anthropometry the input for the simulation system (SDS 6.2 of Solid Dynamics). To compare the results of the different subjects we prepared the movement information in such a way to be able to create a simulation using a fixed subject anthropometry. The Human-Builder software system converts the marker coordinates into a data set containing the coordinate and the orientation of the hip segment and all Cardan angles describing the relative orientation of all segments and herewith the body posture (Figure 2).

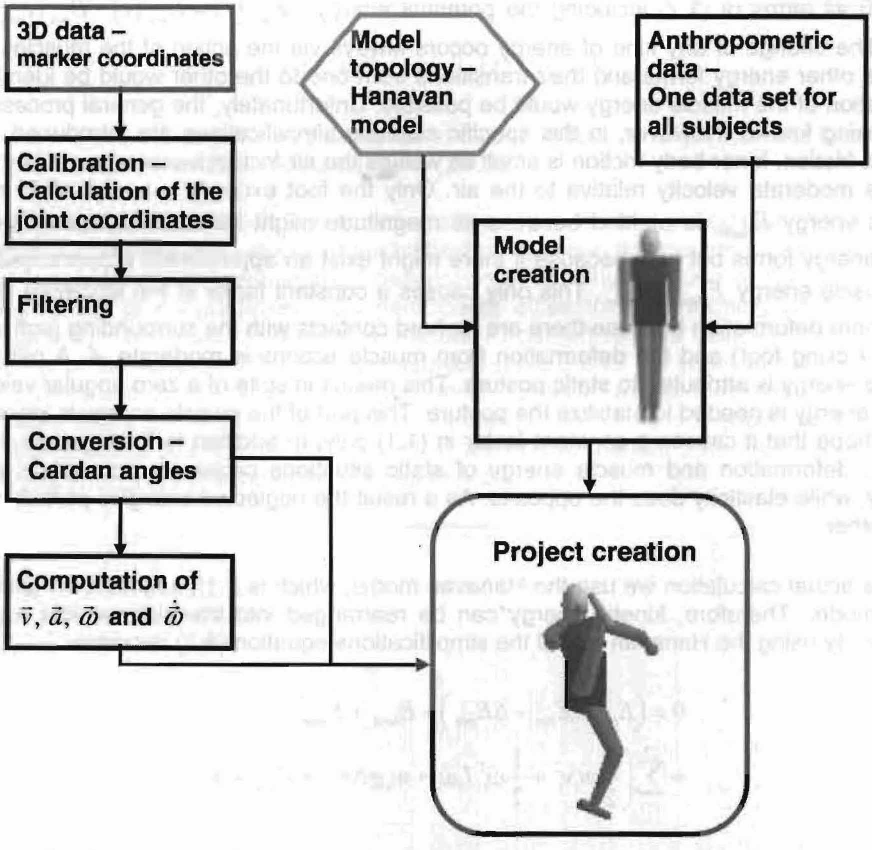

Figure 2 Preparation of the project using Human-Builder.

With this preparation, namely the introduction of Cardan angles, our results are largely independent of the actual body structure of the participants. We define the efficiency as velocity of the kicking leg at the time of contact with the target divided by the muscle energy needed for the complete movement. The movement itself consists of three consecutive kicks. We take the average of the velocity at the three incidents.

$$\eta = A \cdot \sum_{i=1}^{3} \frac{v_i}{3E_{mus}\left(t_{final}\right)} \tag{1.1}$$

The constant $A = 10^3 \frac{s}{kg \cdot m}$ is chosen for the efficiency to be dimensionless and a number between 0 and 10. The calculation of the energy expenditure E_{mus} is one of the problems in biomechanics, which's solution is still in the infancy. However, the defining equation can be established. For the outside kick the initial as well as the final situation is a human body at rest. During the whole movement muscle energy is the driving resource since no external energy is supplied. As always in classical physics the energy is conserved. So the following energy balance equation describes the process.

$$0 = E_{kin}(t) + \Delta E_{pot}(t) + E_{friction}(t) + E_{elastic}(t) + E_{deformation}(t) + E_{heat}(t) + E_{mus}(t) \tag{1.2}$$

At $t=0$ all terms of (1.2) including the potential energy $\Delta E_{pot}(t)=E_{pot}(t)-E_{pot}(t_{initial})$ are zero. The change of any kind of energy occurs always via the action of the muscles. If the various other energy forms and their transitions from one to the other would be identified, a calculation of the muscle energy would be possible. Unfortunately, the general process is far from being known. However, in this specific situation simplifications are introduced. 1. We neglect friction. Inner body friction is small as well as the air friction because most body parts have a moderate velocity relative to the air. Only the foot exceeds a speed of 10 m/s. 2. Elastic energy $E_{elastic}$ is omitted because its magnitude might be small compared with the other energy forms but also because if there might exist an approximate proportionality with the muscle energy $E_{elastic}:E_{mus}$. This only causes a constant factor in the efficiency (1.1). 3. We ignore deformation because there are no hard contacts with the surrounding (soft landing of the kicking foot) and the deformation from muscle actions is moderate. 4. A part of the muscle energy is attributed to static posture. This means in spite of a zero angular velocity in a joint energy is needed to stabilize the posture. This part of the muscle energy is ignored too in the hope that it causes a constant factor in (1.1) only. In addition to these points of view, friction, deformation and muscle energy of static situations cause an increase in muscle energy, while elasticity does the opposite. As a result the neglected energies partially cancel each other.

For the actual calculation we use the Hanavan model, which is a 15 segment, 14 joints rigid body model. Therefore, kinetic energy can be rearranged into translational and rotational energy. By using the Hanavan model the simplifications equation (1.2) becomes

$$\begin{aligned} 0 &= \left(E_{tra}+E_{rot}+\Delta E_{pot}\right)+E_{heat}+E_{mus} \\ &= \sum_{i=1}^{15}\left(\frac{1}{2}m_i v_i^2+\frac{1}{2}\vec{\omega}_i^T I_i \vec{\omega}_i + m_i g \Delta h_i\right)+E_{heat}+E_{mus} \end{aligned} \tag{1.3}$$

Equation (1.3) describes a situation wherein the muscles transfer energy into the body in the form of translational, rotational, and potential energy. These three energy forms transform freely into each other as long as either the angular velocities in the various joints are null or the respective joint torques are zero. If these two criteria are not met two situations can occur: either the joint power can be positive or negative. Positive power means work is transferred from the muscles into the body. Negative power means work is transferred from the body into the muscles and ends up as heat. However, positive and negative power of neighbouring joints might cannel, if they are connected by two-joint muscles. All four extremities of the human body meet this criterion. As an approximation for the muscle energy we select the *source approach* where all joint power serves either as source for the mechanical energy or to increase heat (equation (1.4), see Vieten 1995).

$$E_{mus}(\tau)=\sum_{k=1}^{14}\int_0^{\tau}\left|P_i(t)\right|dt=\sum_{k=1}^{14}\int_0^{\tau}\left|\left(\vec{\omega}_{k,d}-\vec{\omega}_{k,p}\right)\cdot\vec{T}_k\right|dt \tag{1.4}$$

In addition we allow for energy transfer between segments within each extremity, which changes the equation to the form (1.5).

$$E_{mus}(\tau)=\sum_{i=neck,\,trunk,\,4\ extremities}\int_0^{\tau}\left|P_i(t)\right|dt \tag{1.5}$$

Here each extremity's power is of the form

$$P_i(t) = P_{i,1}(t) + P_{i,2}(t) + P_{i,3}(t) \tag{1.6}$$

where the indices 1,2 and 3 stand either for shoulder, elbow, wrist joint or hip, knee, ankle joint. For a detailed discussion see Zatsiorsky (2002).

RESULTS AND DISCUSSION: The resultant efficiency as defined in equation (1.1) depends on the two parameters foot velocity at the highest point during the movement and the muscle energy. It represents the mathematical description of the physical side of Kano's principle. With this we can give a gradation of the participants' efficiency in performing the outside kick (see Figure 3). This order of increasing efficiency from left to right coincides well with the experience of the subjects. The first four subjects have 0.5 to 1.5 years of experience, the others 5 years and more with the one exception of subject v0 who participates in martial arts since about 2 years. His advantage as well as that of subject v4 is a good bodily flexibility that exceeds those of the other participants. If we look at the two parameters foot velocity and muscle energy we find the results of Figure 4 and Figure 5.

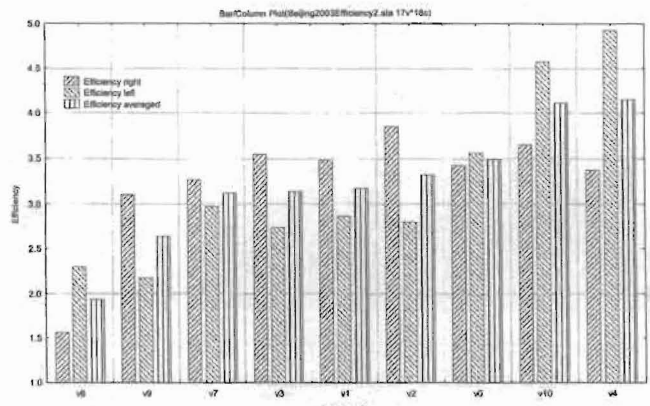

Figure 3 Average efficiency for the participants increasing from left to right.

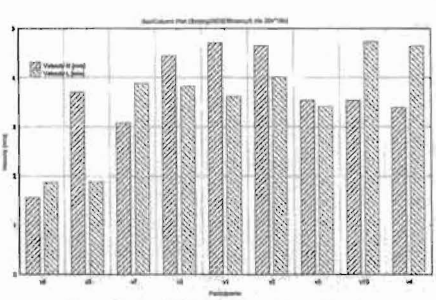

Figure 4 Kicking velocity.

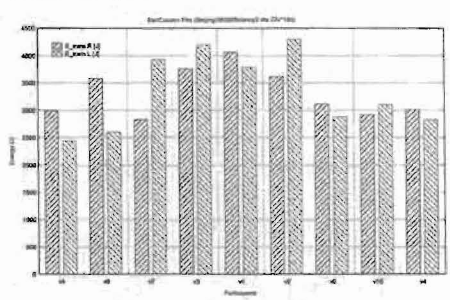

Figure 5 Muscle energy.

We state that the kicking velocities of the subjects are not that dissimilar. The main advantage of the subjects v0 and v4 (they are most flexible) as well as the subject v10 (the most advanced one) is the ability to generate the kicking velocity with a moderate amount of muscle energy.

CONCLUSION: Kano's principle can be established in the mathematical equation of the efficiency of equation (1.1). It allows for judging the technical skill of an outside kick not just according to the obvious parameter kicking speed. Good efficiency allows a fighting style during a prolonged duration without running out of energy and in consequence no loss of accuracy of the performance. Our method can also serve as a mean to select effective techniques, which can be applied without wasting energy so to sustain an individual's performance for the necessary period of time in a tournament.

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