【国際セッション３】

Basic Mechanism of Throwlike Movement

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In throwlike movement such as pitching, batting and kicking, it is important to generate high velocity of an end point of a body or a hitting tool. Although many biomechanical experiments on throwlike movement have been carried out, its scientific mechanism has been poorly understood: it is usually explained by ambiguous words such as "whip-like action" or "kinetic link". We also find some misconceptions about mechanics in literature: in one of the standard textbooks [1], for example, the law of angular momentum conservation is erroneously applied.

As an extension of our physical consideration [2], we study the fundamental mechanism of end-point acceleration on the basis of Newtonian mechanics. With simple models of sticks and their equations of motion, we find that inertial force and gravity, which usually acts unintentionally, play important roles in the kinetic link process.

In the rest of this abstract we illustrate how inertial force acts on an extended body by a stick model. Consider a thin uniform stick with mass m and length l, which is put in the y-direction. We call one end **A** and the other end **B**. Suppose that one moves **A** linearly in the $-x$ direction with acceleration a. In that sprit second, how **B** moves? If we introduce the noninertial frame which moves with **A** (**A**-frame), this question becomes much easier. In **A**-frame, "inertial force" ma appears in the $+x$ direction. Then we obtain the equation of motion of rotation,

$$I_{(A)}\frac{d^2\theta}{dt^2} = ma\frac{l}{2}\cos\theta, \quad I_{(A)} = \frac{1}{3}ml^2,$$

where $I_{(A)}$ is the inertia moment of the stick around **A**, and θ is the rotation angle. Then the acceleration of B in A-frame becomes

$$\alpha_{B(A)} = l\frac{d^2\theta}{dt^2} = \frac{3}{2}\cos\theta,$$

and accordingly, the net acceleration in the inertial frame is

$$\alpha_B = \alpha_{B(A)} - a = \left(\frac{3}{2}\cos\theta - 1\right)a$$

This means that **B** is accelerated in the opposite direction to the external force acting on **A** when $\cos\theta > 2/3$. At the moment θ=0, the net acceleration is $a/2$.

This simple model gives the basics of the inertial force effect. One of the most important consequences is "braking effect" as follows. Suppose that the same stick is in translational motion with velocity v_0 , and that at some instant one stops **A** momentarily. Simple calculation leads to the conclusion that the velocity of **B** becomes 1.5 v_0 instantaneously. This is one of the main mechanisms of whip-like action. Actually this is not like a whip.

A real body is, of course, much more complex than this simple model. This simple model explains only a basic part of mechanism of throwlike movement. We should emphasize, however, that one cannot understand a complex system of a human body without understanding a simple model properly. In this sense the present work is a starting point to understand the whole mechanism of sports movement based on physics.

We anticipate that our physical-model approach based on equations of motion is complementary to biomechanical experiments and will help players to improve their skills. Such a physical model of sports movement can also be utilized as an attractive subject in high-school physics or elementary physics in university.

References

[1] E. Kreighbaum and K.M. Barthels, "*Biomechanics: A Qualitative Approach for Studying Human Movement*" (4th ed.), Benjamin Cummings, (1995)

[2] Nobuyuki Sakai, "*Physics of Sports Motion: Models in Rigid Bodies with Rubber*", Journal of the Physical Society of Japan, 64, 849 (2009)