

## A SIMPLE MATHEMATICAL MODEL OF KARATE FRONT KICK

Jiro Doke and Arthur D. Kuo

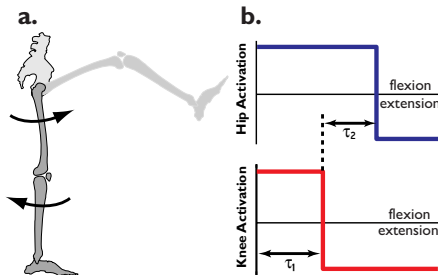
Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI, U.S.A.  
 email: [jdokeh@umich.edu](mailto:jdokeh@umich.edu)

### INTRODUCTION

A front kick is one of the most common forms of kick in karate. From observation, the hip and knee joint of the kicking leg go through a sequence of flexion and extension. Experimental studies have shown that, kinematically, the kick starts with hip and knee flexion, then the knee starts to extend, and the hip extends slightly at impact [1]. The front kick is often taught as a maximal effort technique, and we might superficially expect the hip and the knee muscles to be activated with a bang-bang control. However, torque and EMG data has shown the muscles to be not maximally active. We created a simple mathematical model to test whether bang-bang control is the optimal technique and to examine the effects of activation and coordination on kicking performance.

### METHODS

We derived a simple, two-segment model with anthropomorphic inertial properties to simulate a closed stance front kick (Figure 1a). The hip and knee joints were actuated by a simple Hill-type muscle model with force-velocity dynamics. We activated the muscle model with an adjustable, constant activation level during flexion and extension phase, with no activation dynamics. Coordination was controlled by two timing parameters (Figure 1b). The first timing was the time from the beginning of the kick to when the knee torque switched from flexion to extension. The second timing was the time from the knee switch timing to when the hip torque switched from flexion to extension. We performed a forward-dynamic simulation, with a terminating condition of 60-degree knee flexion angle. We noted whether the kick terminated with the foot in the target area, which was an area of about 4 mm<sup>2</sup> around the hip height level. As a performance measure, we used horizontal foot velocity at kick completion. For each combination of joint activation levels, we optimized about the switch timings to find the maximum final horizontal foot velocity.



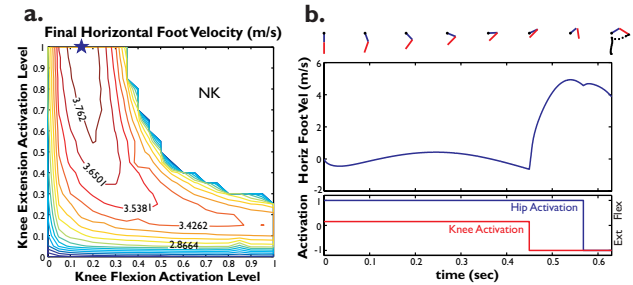
**Figure 1:** a. Simple two-segment karate front kick model. b. The torques at the hip and the knee are activated with specified activation levels and switch timings.

### RESULTS AND DISCUSSION

We found that the hip needed to be fully activated in both flexion and extension, and the knee had to be maximally extending to achieve maximum performance. However, the knee had an optimal flexion activation level that was not maximal (Figure 2a). Maximum final horizontal foot velocity of 3.874 m/s was achieved at only 15% knee flexion activation and 100% knee extension activation. High activations at the

knee caused the knee joint to rotate too fast and kick below the target. At lower knee flexion activations, maximum horizontal foot velocity was achieved at an intermediate activation level (i.e. in the range of 0% ~ 35%, Figure 2a “star”). This optimality arises from the kinematic coupling between the thigh and the shank. At 15% knee flexion activation, the knee is optimally flexed for increasing the horizontal foot velocity during the latter half of the kick. For knee extension, greater activation resulted in increased the foot velocity. These results agree with observations of human kicks, which show relatively low knee joint activity in the flexion phase, but greater activity in the extension phase [2]. Furthermore, a parametric study showed that hip parameters, such as maximum hip torque and velocity, played a greater role in improving kick performance than did knee parameters.

A qualitative analysis of the optimal kick revealed that hip extension torque just prior to kick termination increased the horizontal velocity of the foot (Figure 2b), which can be observed in human data [2]. As the knee straightened, the foot velocity decreased, and this suggested that foot impact should occur before the knee is fully extended, ideally, when the velocity is at its local maximum.



**Figure 2:** a. The optimal kick is indicated by a star, with final horizontal foot velocity of 3.874 m/s. The “NK (no-kick)” region is where no successful switch timing combination was found. b. Horizontal velocity profile of the foot during an optimal kick.

### CONCLUSIONS

We simulated a karate front kick using a model with simple muscle activation mechanics. We reduced the degree of freedom of the complex kicking motion in order to study the essence of the movement. We found the hip to have a more significant role in kicking performance, and the knee had to be moderately activated during flexion in order to ensure target placement and high horizontal foot velocity. Hip extension just before impact also increased foot velocity. These results resemble what has been observed in experiments, and moreover, give insights to coordination of joints in performing an effective kick.

### REFERENCES

1. Robertson DGE. et al. *World Congr. of Biomech.*, 2002.
2. Sorensen H. et al. *J. of Sports Science*, **14**, 483-495, 1996.