KINETICS AND ELECTROMYOGRAPHY OF THE MARTIAL ARTS HIGH FRONT KICK

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INTRODUCTION

It is generally accepted that fast unloaded movements (i.e. striking, throwing and kicking), in which the aim is maximal linear speed of the involved segmental chain's most distal end (i.e. hand or foot), are performed in a proximo-distal sequential order (e.g. 1985; Herring, 1992; Putnam, 1993). In kicking, for instance, it is observed that the total movement starts with forward angular acceleration of the thigh while the shank lags behind. Then the thigh decelerates while simultaneously the shank accelerates (Putnam, 1983, 1993). The simultaneous thigh deceleration and shank acceleration often lead to a situation in which the thigh is completely decelerated when the shank reaches its maximal angular velocity. This seems disadvantageous from a kinematic point of view, considering that the resulting linear velocity of the foot relative to the ground equals the vector sum of the resulting linear velocities of the knee relative to the ground and the foot relative to the knee. Two conflicting kinetically based theories concerning this thigh deceleration have been proposed. One states that the thigh is actively decelerated by the hip extensor muscles and that thigh deceleration enhances shank acceleration in a whiplash like manner (Herring, 1992). The other theory states that the thigh is decelerated because of the shank's motion, i.e. when the shank rotates it exerts a decelerating force on the thigh (Putnam, 1983, 1993).

In an attempt to clarify the contrasting theories mentioned above we decided to examine the high front kick used in most oriental martial arts. To the best of our knowledge this type of kick has not yet been analysed. Previous work has dealt with soccer or punt style kicking (e.g. Putnam, 1983; Robertson, 1985; Dunn, 1988). In these types of kicks the target is typically situated at ground level or slightly above, whereas the high front kick is aimed at chin level. Similar to previous studies of kicking the present study used kinematic measurements to derive the kinetics through inverse dynamics. Furthermore, in addition to methods used in previous kicking studies, we recorded the electrical activity of selected muscles in order to asses their temporal activation during the kick.

In summary, the purpose of this study was to establish the kinetics of a typically proximo-distal sequential movement with special emphasis on the possible use of active deceleration of proximal segments to enhance acceleration of distal segments.

METHODS

Subjects. Seventeen skilled taekwon-do practitioners ranging from club level to top European level gave informed consent to serve as subjects for this study.

The kick. The basic high front kick is executed from normal standing position by flexing the hip and extending the knee (see the stick figure sequence in Fig. 2). The ankle joint of the kicking leg is kept fully plantarflexed and the toes fully dorsiflexed in order to hit the target with the ball of the foot. During the kick the supporting leg remains on the floor. Contradictory to most other taekwon-do kicking techniques the front kick is confined to the sagittal plane which makes it suited for two-dimensional analysis. After warming up each subject performed three kicks aiming at a tennis ball suspended from the ceiling and adjusted to chin level. The fastest kick from each subject was selected for further analysis.

Cinematography. The subjects were filmed from their right side with a 16 mm high speed camera (Teledyne DBM 45) operating at a picture rate of 200 frames per second. Markers were placed on selected anatomical landmarks in order to identify body segments and joints. Position coordinates of the optical centres of the markers were automatically digitised (Peak Performance Technologies). Displacement data were lowpass filtered with a digital fourth order Butterworth lowpass filter with zero degrees phase lag (Winter, 1990). Optimal cut-off frequencies (6-10 Hz) were determined from residual analysis (Winter, 1990) and the Jackson Knee method (Jackson, 1979). From the filtered displacement data angular velocities and accelerations of the thigh and lower leg as well as linear velocities and accelerations of the hip, knee and ankle joint were derived by finite difference computation.

Electromyography. EMG recordings were obtained with Ag/AgCl surface electrodes from 5 lower extremity muscles. The electrode wiring permitted the subjects to kick unrestricted. Signals were sampled by a DT-2801-A A/D-converter (Data Translation, Inc., Marlboro, MA) operating at 1000 Hz and fed to an IBM PC DX2 clone. Data treatment included digital detrending to remove eventual DC-components, highpass filtering at 20 Hz to remove eventual movement artefacts and lastly a digital full-wave rectification. The EMG data were not normalised in any way, as they were merely intended to provide information about temporal aspects of muscle activation. Synchronisation between film and EMG data was provided by simultaneously triggering the A/D-converter and flashing a light diode in the field of view.

Modelling. To facilitate inverse dynamics computations the kicking leg was modelled as a two segment link-segment model with the lower leg and foot treated as one segment and hip and knee treated as hinge joints. As the high front kick movement is determined by hip and knee joint kinematics, and since these have been reported not to be influenced by the ankle moment (Marshall, 1985), we consider our two-segment model adequate for our purpose. To explain the kinetics of the kicking motion we used the equations developed by Putnam (1983). In these equations the generalised coordinates used to describe the two-segment system are x,y position of the hip and absolute angular positions of the thigh and

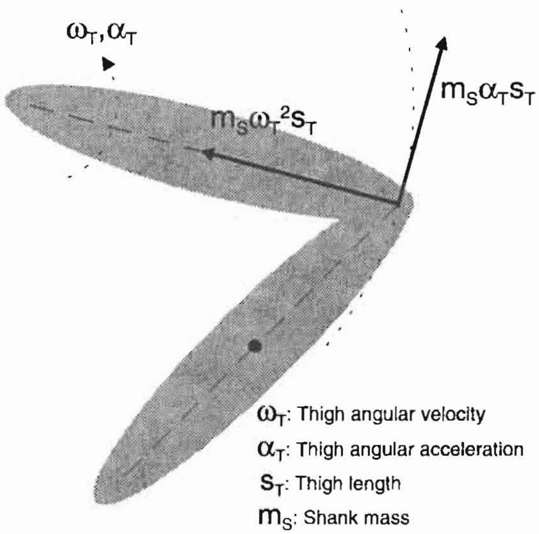

Figure 1. When the thigh rotates the knee follows the dashed trajectory. A centripetal force and a tangential force is hereby exerted on the shank's proximal end causing forward angular acceleration of the shank.

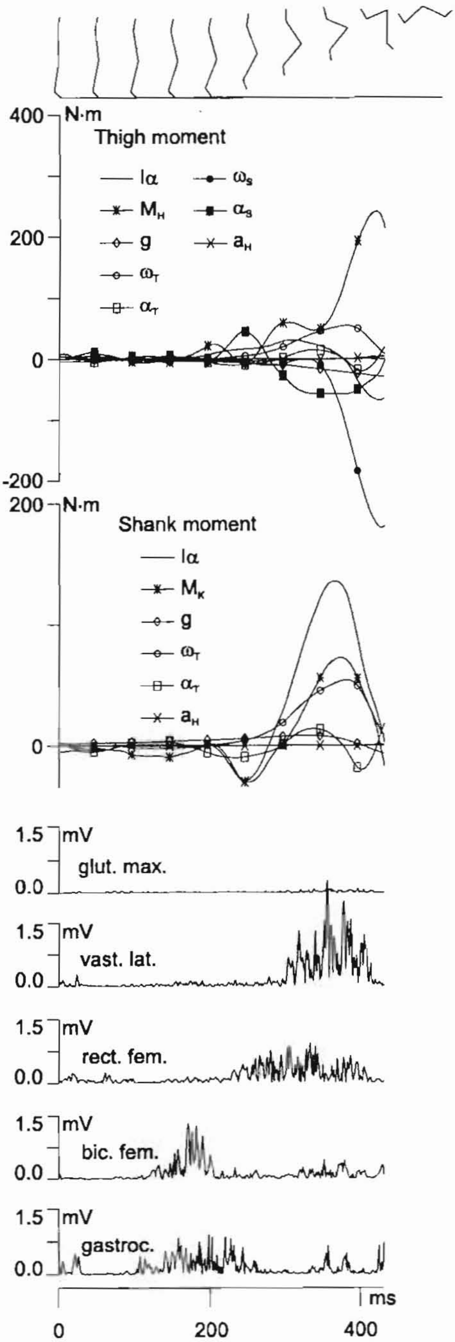

Figure 2. Moments acting on the thigh and shank with simultaneous EMG recordings. Uppermost end of the hip segment determines the temporal alignment of the stick figure. See text for explanation to legends.

shank. This enables expressions of the equations of motion for the thigh and shank in which the influence from the segments angular acceleration and velocity on intersegmental forces is readily obtainable. See for instance Fig. 1 where the influence from thigh angular acceleration and velocity on shank angular acceleration is illustrated.

RESULTS

Fig. 2 shows the time dependant moments together with the rectified EMG recordings from one representative subject. Positive moments accelerate the segments in counter-clockwise (kicking) direction, while negative moments accelerate the segments in clockwise direction (i.e. decelerate the segments).

The curves labelled Iα (moment of inertia times angular acceleration) show the resulting moments acting on the respective segments. A segment's resulting moment is the sum of all moment components acting on the segment. For the thigh these moment components are the hip muscle moment (M_H), a component due to gravity (g) and 5 motion dependant components due to thigh angular velocity and acceleration (ω_T and α_T), shank angular velocity and acceleration (ω_S and α_S), and hip linear acceleration (a_H). Identical nomenclature is used for the shank, M_K is knee muscle moment, though.

The curves stop when the shank resulting moment (Iα) becomes negative, i.e. the shank has reached maximum angular velocity and starts decelerating.

The thigh moment curves show that the resulting moment (Iα) is positive (the thigh is accelerating) except for the last 75 ms, where the curve is negative (the thigh is decelerating). The component primarily responsible for the positive resulting moment is the hip muscle moment (M_H) which especially during the last 100 ms reaches a very high magnitude. EMG recordings suggest that this hip flexor moment is generated by rectus femoris. Iliopsoas, which we did not record, is presumably also active. Note that no support for active hip extensor muscles can be observed, neither in the moment computations nor in the EMG recordings from gluteus maximus and hamstrings. During the last 200 ms the positive (flexing) hip muscle moment is counteracted by the moment component from shank angular acceleration (α_L) and during the last 100 ms also by the moment component from shank angular velocity (ω_L). These negative moments, and especially the latter, are of such magnitude that they force the resulting moment negative despite the large positive hip muscle moment.

The shank moment curves show that the resulting moment ($I\alpha$) has a negative phase of app. 75 ms where the shank is accelerating backwards into knee flexion. This is followed by a 175 ms positive phase of considerable magnitude where the backward swing is stopped and the shank is forcefully accelerated forwards. The components primarily responsible for the positive resulting moment are the knee muscle moment (M_K), the presence of which is consistent with the EMG recordings from vastus lateralis and rectus femoris, and the component from thigh angular velocity (ω_T). The decline of both of these components causes the decline of the resulting moment and eventually its shift from positive to negative. We suggest that the knee muscle moment component (M_K) declines as a consequence of the knee extensor muscles high shortening velocity and that the component from thigh angular velocity declines as a consequence of the thigh's deceleration.

CONCLUSION

These data suggest that thigh deceleration is caused by motion dependant moments due to shank motion, primarily shank angular velocity. No support for active deceleration by hip extensor muscles was found. Shank acceleration is caused by a knee muscle extensor moment and a motion dependant moment due to thigh angular velocity. Thigh deceleration is therefore considered unwanted but unavoidable due to the intersegmental forces arising when the shank is accelerated.

REFERENCES

Dunn, E.G. and Putnam, C.A. (1988). The influence of lower leg motion on the thigh. In Biomechanics XI-B (edited by G. de Groot, A.P. Hollander, P.A. Huijing and G.J. van Ingen Schenau), pp. 787-790. Amsterdam: Free University Press.

Herring, R.M. and Chapman, A.E. (1992). Effects of changes in segmental values and timing of both torque and torque reversal in simulated throws. Journal of Biomechanics, 25, 1173-1184.

Jackson, K.M. (1979). Fitting of mathematical functions to biomechanical data. IEEE Transactions on Biomedical Engineering BME-26, 2, 122-124.

Marshall, R.N., Jensen, R.K. and Wood, G.A. (1985). A general Newtonian simulation of an n-segment open chain model. Journal of Biomechanics, 18, 359-367.

Putnam, C.A. (1983). Interaction between segments during a kicking motion. In Biomechanics VIII-B (edited by H. Matsui and K. Kobayashi), pp. 688-694. Champaign: Human Kinetics Publishers, Inc.

Putnam, C.A. (1993). Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. Journal of Biomechanics, 26, suppl. 1, 125-135.

Robertson, D.G. and Mosher, R.E. (1985). Work and power of the leg muscles in soccer kicking. In Biomechanics IX-B (edited by D.A. Winter, R.V. Norman, R.P. Wells, K.C. Hayes and A.E. Patla), pp. 533-538. Champaign: Human Kinetics Publishers, Inc.

Winter, D.A. (1990). Biomechanics and Motor Control of Human Movement. New York: John Wiley & Sons, Inc.