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Biomechanics analysis on *Jejag* kick of pencak silat

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ABSTRACT

The force in the pencak silat jejag kick is called the moment of force or torque. The force moment is a measure of the force that can cause an object to rotate around the axis where the axis of rotation is located at the knee joint with the length of the calf as the length of the arm (the radius of the rotation axis). This research was conducted using laboratory biomechanical analysis. The research sample consisted of three male athletes of pencak silat. Previously, anthropometric measurements were carried out in the form of measuring calf length and calf muscle mass, then taking videos of athletes doing jejag kick movements in a static state with targets, which were then analyzed by kinovea. Research results showed that the technique of the jejag kick pencak silat produces a force called the moment of force or torque. Sample 1 produces a force moment of -12.00 Nm, sample 2 produces -5.53 Nm, and sample 3 produces -8.73 (negative sign means the direction of the pencak silat jejag kick is counterclockwise). The magnitude of the force moment is influenced by the angle of knee extension and the radius of the rotation axis. The amount of force moment affects the kick speed. In the speed of a movement, there is a tendency to keep moving, which is called the moment of inertia. The fasterthe movement, the greater the moment of inertia. The result is a force moment, influenced by the rotational kinetic energy that is owned and requires effort. Every effort is made to produce a force moment; it takes power to drive the effort. This means that the greater the angle of extension and the longer the calf, the greater the force moment, the faster the kick speed, and the greater the moment of inertia. This requires a large amount of rotational kinetic energy, effort, and power.

Keywords: *Biomechanics, jejag kick, pencak silat*

INTRODUCTION

The pencak silat kick technique is a series of movements with several different elements strung together to produce an integrated movement. Pencak silat kick techniques require a variety of skills, including a series of coordination of sequential movements based on dynamic balance combined with power and performed with precision.[1] The kick is defined as an attack carried out using the legs and feet. In matches, kicks are often used as the main weapon for attack and defense to get points. Points obtained through kicking techniques are 2 or 1 + 2. The 2 points are earned when a fighter can kick and hit a certain target using power. Meanwhile, the 1 + 2 point is obtained when the fighter can dodge, or block attacks, then counterattack using kicking techniques and hit the desired target using power. In addition, kicks can also get 3 points when the fighter is able to attack, which causes the opponent to fall in the arena area. In pencak silat, the *jejag* kick is one of the front kick techniques, which is also called the foot push. The *jejag* kick is directed forward which is pushing towards the target's chest with full foot contact. Mastery of the correct kicking technique is very necessary in order to hit the target well. There are several stages of movement in the *jejag*-kick technique starting from the start, execution, and final stance. Analysis of the *jejag*-kick movement related to the laws of mechanics needs to be done to provide learning on the correct and optimal *jejag*-kick technique for the fighter. The mechanics laws related to the tackle kick include force, inertia, gravity, speed, work, and energy. Mastery of good kicking techniques will affect the efficiency level of energy use for the fighter so that the fighter is able to perform activities optimally and repeatedly for a long time. Analysis of the movement of the kick technique can be studied with sports biomechanics. The most significant differences were observed in the movement of the head, torso, hip, knee, and ankle segments, particularly during *shield* kicking. Based on the analysis carried out, it can be assumed that karate training changes the neuromuscular control strategy, encouraging an increase in an efficient mobility pattern.[2]

Biomechanics is a subdiscipline of kinesiology and by definition it is the study of the application of mechanics to biological systems. Biomechanics is related to different fields including measurement and motor control of human movement and sports.[3] Based on the observations, male athletes in the sparring category are still weak in taking front kicks because the impact of the kicks is not strong enough. It is easy for the opponent to push away, and it does not make the opponent fall. In biomechanical studies, this can be due to the lack of force generated from kicks that keeps the target from moving away. For this reason, it is necessary to carry out a biomechanical study related to the analysis of motion in the pencak silat *jejag*-kick so that it can devise the correct and effective kick technique in making the opponent lose. The force on the pencak silat *jejag* kick is called the moment of force or torque. The moment of force is a measure of the force that can cause an object to rotate around an axis. The force moment on the kick has an influence on the speed of the kick motion. In the kick technique, there are three interconnected rotation axes. The first axis is on the knee, the second is on the ankle, and the third is in the coxofemoral area. This axis is moving (swinging), not stationary. In the *jejag* kick movement of *pencak silat*, the kinetic chain of muscles with 3 levers, i.e. femur, tibia and fibula, and soles at the ends of the metatarsal bones. To calculate the moment of force or torque, the axis, force, and distance from the point of action of the force on the axis of rotation are needed. On the axis of the knee joint, the calf is a segment of the forward motion, which is the length of the arm moment of force or torque. The moment of force is obtained by calculating the force and length of the arm.[4] Based on these, the researcher conducted this study to analyze the movement of the *jejag* kick in the pencak silat sport to enhance the performance of athletes.

LITERATURE REVIEW

The jejag-kick of pencak silat

The *Jejag*-kick is performed using one foot and leg with a trajectory toward the front so that the body position is facing the target. The *jejag*-kick basically involves raising the leg in an arc toward the front of the body and then the knee is rapidly extended until the instep hits the target.[5] The jejag-kick is the easiest to do so that many schools introduce the *jejag*-kick technique to their trainees first. Besides being easy to do, the *jejag*-kick can be used for long- and short-distance fights during matches. For fighters who have long legs, it is very effective for a long-distance fight because it has an advantage in terms of reach; on the other hand, for fighters who have relatively short legs, it will be more profitable for a short-distance fight.

Biomechanics in pencak silat kicks

Biomechanics is the study of structure and function of biological systems using mechanical methods (a branch of physics that involves the analysis of the actions of forces). Sports biomechanics can be defined as a science that studies the internal and external forces acting on the human body and the effects of resulted forces on the sports activities. In pencak silat kicks, there is a style called torque. Torque is a measure of the force that can cause an object to rotate around an axis. Objects can rotate because of the torque. A force acts on an object whose center of mass is at a point. The line/work force is located perpendicular to the center of the mass, so the object will rotate to the right in a clockwise direction. To a large degree, the maximum muscle torque describes the level of force that can be obtained during dynamic motion.[6] The perpendicular distance between the working line of the force and the center of mass is called the arm of force or the moment arm. In order to calculate each physical characteristic at the execution angle, such as torque, moment of inertia, speed, power, acceleration, kinetic energy, it should be from which part the kick starts as the angle of motion and which position or place the linear execution begins. There are three interconnected rotation axes. The first axis is on the knee, the second is on the ankle, and the third is in the coxofemoral area. This axis is moving (swinging), not stationary. In the front kick movement on pencak silat, the kinetic chain of muscles with three levers, namely, the femur, tibia, and fibula, as well as on the leg of the calcaneus at the end of the metatarsals, does not include the phalanges.

METHODOLOGY

This research was conducted by using laboratory biomechanical analysis. Biomechanical analysis provides a fast and reliable evaluation of the moment of force or torque. Many researchers have studied the evaluation of the value of the moment of force or torque in relation to the lower leg involved in sporting movements.[7] The research was conducted at the UNS Sports Hall and Kustati laboratory in the duration of 3 months. Three male athletes from Pencak Silat Solo were selected by using the purposive sampling technique with the criteria that they had won the provincial- and national-level Pencak Silat competitions.

Data collection

Biomechanics has a structure with the fields of anthropometry and electromyography to describe and show mathematical models of human movement as a special fact.[3] Data collection was carried out in three ways as mentioned below:

1. Measurement of calf length (fibula)
   Data collection for calf length was done using a sliding caliper (Vernier caliper) and measurements were recorded with an accuracy of close to 0.1 mm.[8] The length of the calf in this study is the radius of the axis of rotation or distance (r).
2. Calf muscle mass measurement (calf)
   Collected calf muscle mass data were measured using MRI. Magnetic resonance imaging (MRI) is considered the gold standard imaging method for evaluating skeletal muscle because it can show the size of skin masses, skeletal muscle, adipose tissue and nonfatty accessory components.[9] In each slice, the cross-sectional area of skeletal muscle tissue was digitized, and the volume of muscle tissue (cm^3) per slice was calculated by multiplying the area of muscle tissue (cm^2) by the thickness of the slice (cm). The volume of skeletal muscle units (liters) is converted to units of mass (kg) by multiplying the volume of constant density in the skeletal muscle (1,041 kg/l). MRI images were taken using a General Electric Signa 1.5 T scanner. T1 weighted, spin echo, and axial plane series was performed with 1,500 millisecond repetition time and 17 millisecond echo time. The subject is rested calmly in a magnetic bore in a supine position with the legs and arms straightened in an anatomical position.[10]
3. Video capture
   Subjects were instructed to perform kicks at maximum controlled speed. The kick is performed in a static state with the target pecing. Movement is documented using the camera (at least 60 fps).

Data analysis

Motion analysis was performed using kinovea software to determine the knee extension angle of the kick leg (θ). Kinovea software is used to convert each video into a series of frame by frame images.[11] Then, sought are the magnitude of the moment of force or torque (τ), moment of inertia, rotational kinetic energy, effort, and power. Also, the relationship to one another on a pencak silat jejag kick is analyzed. Below is the pertinent equation:

$$\tau = r.F \qquad (1)$$

$$\tau = r.m\ .g$$

If using angles, the formula for moment of force or torque is as follows:

Note:
τ: Force moment (N m)
r: Axis of rotation to the point where the force acts (m)
m: Muscle mass (kg)
g: Gravity (m/s^2) = 9.8 m/s^2
Mejía[12]

$$I = m.r^2 \qquad (2)$$

Note:
I: Inertia moment ($kg.m^2$)
r: Axis of rotation to the point where the force acts (m)
m: Muscle mass (kg)

$$\Delta\omega = \frac{\Delta\theta}{\Delta t} \qquad (3)$$

Δω: Angular velocity d (rad/s)
Δθ: Angle change (rad)
Δt: Time change (s)

$$EK_{rot} = \frac{1}{2} I.\omega^2 \quad (4)$$

Note:
EK_{rot}: Rotational kinetic energy (J)
I: Inertia moment (kg.m^2)
ω: Angular velocity (rad/s)

$$W = \tau .\theta \quad (5)$$

Note:
W: Effort (J)
τ: Force moment (Nm)
θ: Angle (rad)

$$P = \frac{W}{t} \quad (6)$$

Note:
P: Power
W: Effort
t: Time

RESULTS

Data description

The data description explains the measurement results of the pencak silat *jejag*-kick in the form of moment of force or torque (τ), moment of inertia, rotational kinetic energy, effort, and power, which are presented in Table 1.

Table 1 shows the difference in the magnitude of the moment of force or torque (τ), moment of inertia, rotational kinetic energy, effort, and power in the pencak silat track kick. This shows the measurement data of the track-kick execution, which is a temporary picture. Then, the motion analysis is carried out with the Kinovea software.

Analysis with software kinovea

The pencak silat *jejag*-kick technique is influenced by a force called the moment of force or torque. The moment of force is the force on the rotating axis that can cause the object to move in a circle or rotate. A moving object will remain in motion; this is the object's tendency to defend itself in its motion, which is called the moment of inertia. Every movement has a speed. In a rotational motion, the speed is called angular velocity, which is influenced by the radius of the rotation axis. Apart from speed, each object also has the energy to produce movement. The energy in rotational motion is called rotational kinetic energy. In the pencak silat *jejag*-kick technique, it takes an effort to transfer the energy of the object to produce a force. For every effort that is put in, there is also an element of speed and strength called power.

TABLE 1. Measurement results for jejag kick and straight front kicks of pencak silat.

Variable	Sample 1	Sample 2	Sample 3
The radius of the axis of rotation or the distance to the point where the force acts (r)	0.49	0.45	0.45
Calf muscle mass	3.80	2.40	4.00
Angle of swing/knee extension of kick leg (θ)	124	106	116
Kick time (t)	0.13	0.21	0.18
Moment of force (torque) (τ)	–10.14	–2.95	–7.76
Moment of inertia (I)	0.90	0.50	0.82
Angular velocity (Δω)	16.65	8.81	11.25
Rotational kinetic energy (EKRot)	124.84	19.29	51.69
Effort (W)	39.24	19.80	35.87
Calf muscle mass	301.86	94.30	199.28

FIG 1. Motion analysis of sample 1: (A) knee flexion angle; (B) straight knee angle; (C) time of kick.

Figure 1 shows the motion analysis of the *jejag*-kick in sample 1, which includes the knee flexion angle, knee straight angle, and time of *jejag*-kick. Sample 1 executes the kick by forming a knee flexion angle of 54° and a straight knee angle of 178°, thus forming an extension angle of 124°. Kick time takes 0.13 seconds to achieve the maximum *jejag*-kick.

Figure 2 shows the motion analysis of the *jejag*-kick in sample 2, which includes knee flexion angle, knee straight angle, and time of *jejag*-kick. Sample 2 executes the kick by forming a knee flexion angle of 86° and a straight knee angle of 192°, thus forming an extension angle of 106°. Kick time is 0.21 seconds to achieve the maximum *jejag*-kick.

Figure 3 shows the motion analysis of the *jejag*-kick in sample 3, which includes knee flexion angle, knee straight angle, and time of *jejag*-kick. Sample 3 executes the kick by forming a knee flexion angle of 73° and a straight knee angle of 189°, thus forming an extension angle of 116°. Kick time is 0.18 seconds to achieve the maximum of *jejag*-kick.

DISCUSSION

The study of the sports biomechanics of pencak silat helps improve performance and reduce the risk of injury to athletes. Increasing performance means increasing the effectiveness of motion. Effective

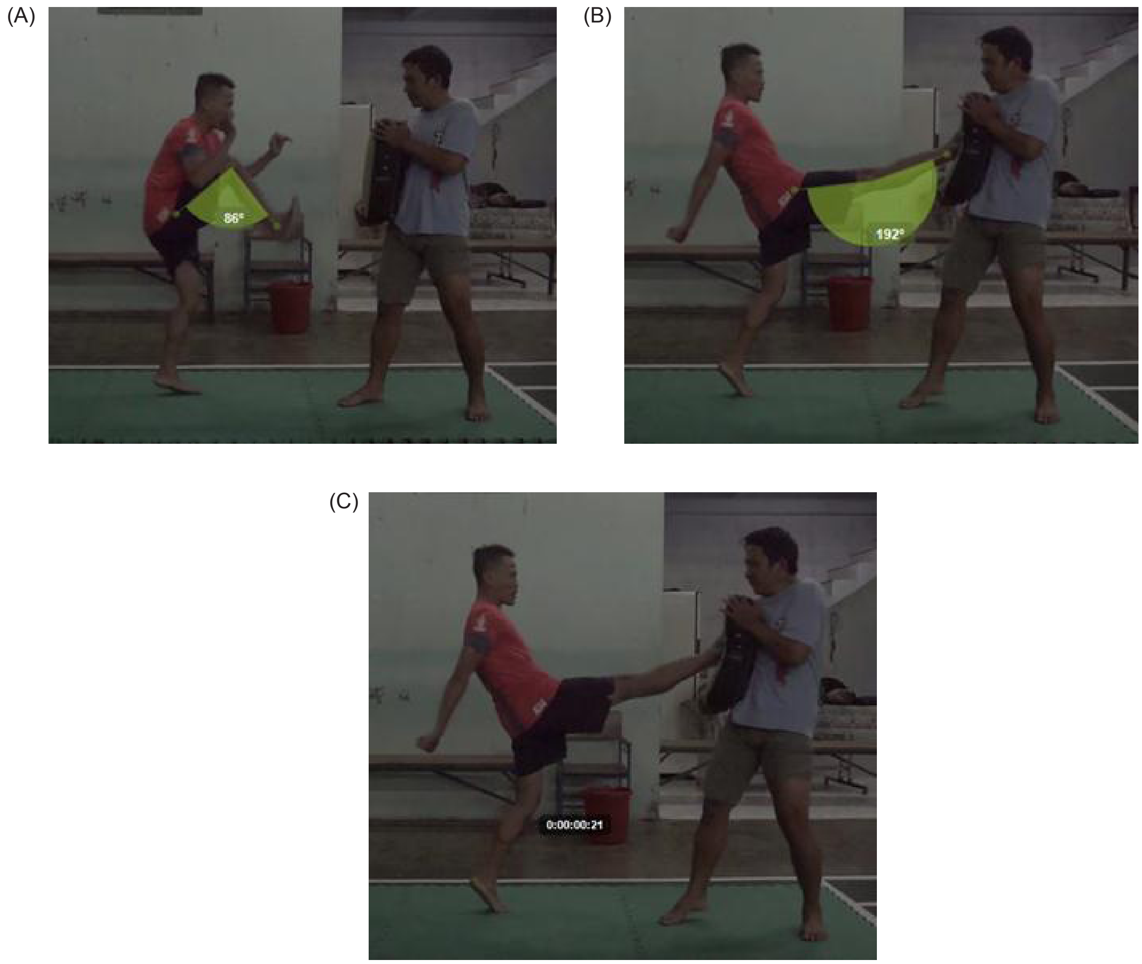

FIG 2. Motion analysis of sample 2: (A) knee flexion angle; (B) straight knee angle; (C) time of kick.

motion involves anatomical factors, physiological capacity, neuromuscular skills, and psychological/cognitive abilities. Previous research has observed that changing the height of the target results in decreased ability and the higher the height, the greater the joint coordination between the hip and knee. Also, the higher the target height, the greater the angular momentum of the thighs, calves, and feet simultaneously.[13] In other previous studies, it was shown that roundhouse kicks were analyzed at the load and kicking stages. In the weight stage, knee and hip extensions are essential to promote motion in the kicking stage. The two stages (load and kicking) analyzed are very important to carry out a perfect kick.[14]

The movement of the pencak silat *jejag*-kick is included in the rotation motion. An object moves about its axis of rotation or moves along a circular path, then the object moves in a rotational manner. When an object rotates or is on a circular path, the object can also receive forces called the moment of force or torque. From the results of the research that has been stated, it can be seen that the kick of pencak silat produces a moment of force or torque. The results of this study support previous research, which states that maximum joint torque can be used as a kicking force.[15]

There is a difference in the magnitude of the moment of force or torque in each sample. Where

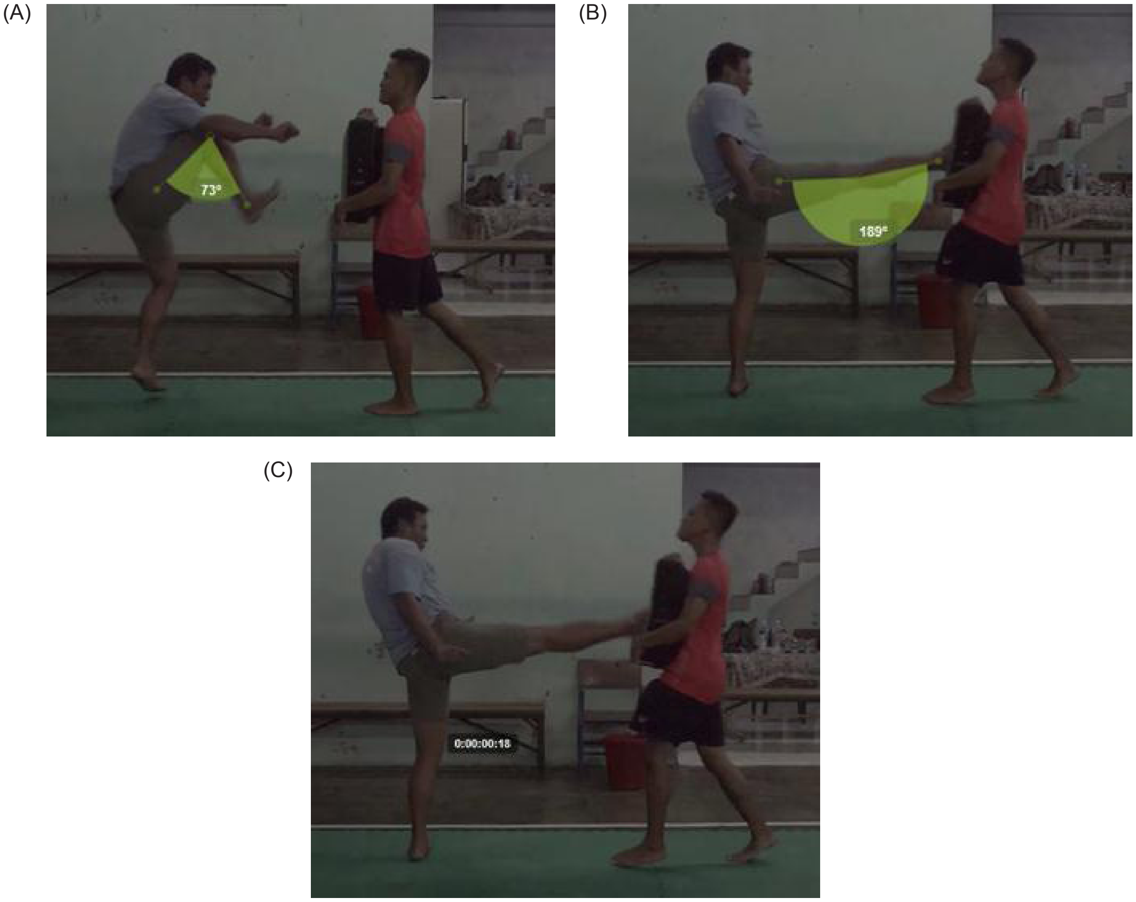

FIG 3. Motion analysis of sample 3: (A) knee flexion Angle; (B) straight knee angle; (C) time of kick.

sample 1 generates a value, the moment of force or torque is the greatest when compared with another sample. Motion analysis shows that the moment of force of sample 1 is -10.14 Nm greater than sample 2 of -2.95 Nm and sample 3 is -7.76 Nm (the negative sign in the moment of force means the direction of the moment of force is counterclockwise, which means that the direction of the straight kick is counterclockwise). The magnitude of the force moment is influenced by the magnitude of the leg swing angle or the knee extension angle. The leg swing angle on sample 1 is 124° greater than that of sample 2 of 106° and sample 3 of 116°. Physical activity in the *jejag*-kick technique involves leg swing, which is an important factor in producing optimal kicks. The greater the swing angle, the greater the force that is generated. To a large degree, the moment of maximum muscle force describes the level of force that can be obtained during dynamic motion.[6]

Apart from being influenced by the angle, the length of the arm also affects the magnitude of the force moment. The moment of force is obtained by calculating the force and length of the arm.[4] The arm moment of force in this study is the calf length. The length of the calf is the radius of the axis of rotation or distance. Sample 1 has a calf length of 0.49 m longer than sample 2 of 0.45 m and sample 3 of 0.45 m. The amount of force moment affects the angular velocity. Sample 1 produces a greater angular velocity of 16.65 rad/s when compared to sample

2 of 8.81 rad/s and sample 3 of 11.25 rad/s. This means that if the calf as the radius of the rotation axis is longer, it will produce a large force moment, which affects the swing speed. The faster swing will benefit the athlete in making long kicks that are not easily deflected by the opponent because they are done quickly. The time required for sample 1 is 0.13 seconds is faster when compared to sample 2 of 0.21 seconds and sample 3 of 0.18 seconds.

The faster a movement, there is inertia or a tendency to maintain the speed of the movement; this is called the moment of inertia. The moment of inertia is the object's tendency to defend itself (still remains stationary or remains in motion). This concept explains Newton's I law where a stationary object will remain at rest and an object in motion will remain in motion. Sample 1 produces a moment of inertia of 0.90 kgm^2, which is larger than sample 2, which produces a moment of inertia of 0.50 kgm^2, and sample 3, which produces a moment of inertia of 0.82 kgm^2.

An object can move because of the force generated by the energy. Also, in the pencak silat kick, it has the energy that causes the foot to kick. The energy in the pencak silat *jejag*-kick is rotational kinetic energy. Every object that has velocity also has kinetic energy. Rotation in this case is due to the rounded kick doing rotational motion. The amount of energy in the *jejag*-kick is influenced by the magnitude of the angular velocity and the moment of inertia. The energy expended in doing kicks depends on the amount of speed given. The greater the angular velocity and moment of inertia, the greater the rotational kinetic energy. This means that the greater the kick speed and the tendency to maintain the kick speed, the greater the rotational kinetic energy required tocarry out a long kick. The kinetic energy of impact is determined by velocity.[16] Rotational kinetic energy on sample 1 is 124.84 J larger than the sample 2 of 19.80 J and greater than the sample 3 of 51.69 J.

In rotational motion, an effort is needed, which is the transfer of energy through a moment of force or torque so that the object rotates with a certain angular displacement. Effort is required to perform a *jejag*-kick. The amount of effort is influenced by the rotational kinetic energy of the kick. The greater the energy, the greater the effort required to transfer this energy to produce a moment of force or torque. Sample 1 requires more effort than sample 2 and sample 3. Sample 1 has a rotational kinetic energy of 124.84 J, so it requires 39.24 J of effort to produce a moment of force or torque of -10.14 Nm. Sample 2 has a rotational kinetic energy of 19.29 J, and it requires an effort of 19.80 J to produce a moment of force or torque of -2.95 Nm. Sample 3 has a rotational kinetic energy of 51.69 J, and it requires an effort of 35.87 J to produce a moment of force or torque of -7.76 Nm. The magnitude of the force moment requires power to move the effort. For every effort put forth, there is an element of speed and strength called power. Power will arise if there is an effort. In this study, the power in sample 1 is 301.86 watts, which is greater than the power in sample 2 of 94.30 watts and power in sample 3 of 199.28 watts.

CONCLUSIONS

The motion analysis showed that the pencak silat *jejag*-kick technique produces a force called the moment of force or torque. The magnitude of the moment of force is influenced by the knee extension angle and the radius of the rotation axis. The amount of force moment affects the fastness and kick speed. In the speed of a movement, there is a tendency to keep moving, which is called the moment of inertia. The faster the movement, the greater the moment of inertia. The result is a moment of force, influenced by the rotational kinetic energy that is owned and requires effort. Every effort is made to produce a moment of force, and it takes power to drive the effort. This means that the greater the angle of extension and the longer the calf, the greater the force moment, faster the kick speed, the greater the moment of inertia, and a large amount of rotational kinetic energy, effort, and power is required to perform efficiently.

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