

Research Paper: Determining the Delay Time of the Muscles Around the Knee Joint in Response to Rotational Perturbation From Support Surface

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Citation: Ghasemi Dehcheshmeh F, Amiri A, Maroufi N, Jamshidi A, Jalaee Sh. Determining the Delay Time of the Muscles Around the Knee Joint in Response to Rotational Perturbation From Support Surface. Journal of Modern Rehabilitation. 2020; 14(3):169-176. <http://dx.doi.org/10.18502/jmr.v14i3.7715>

doi <http://dx.doi.org/10.18502/jmr.v14i3.7715>



Article info:

Received: 14 Feb 2020

Accepted: 02 Jun 2020

Available Online: 01 Jul 2020

Keywords:

Rotational perturbation,
Reaction time, Knee joint,
Support surface

ABSTRACT

Introduction: Knee joint injuries usually occur in a short time, so analyzing the mechanism and process of this short time can be helpful to prevent similar injuries. This study aimed to determine and compare the reaction time of knee muscles and investigate the effect of knee position and perturbation direction on the reaction time of knee muscles in response to horizontal rotational perturbation applied to lower leg from support surface area.

Materials and Methods: A total of 30 healthy women volunteers were received ± 35 degrees of horizontal rotational perturbation and speed of 120 degrees per second from the sole while standing on the right leg in four conditions (external versus internal rotation of surface while the knee was in both extension and flexion position). Electromyography of knee muscles (vastus medialis and lateralis, medial and lateral hamstring and medial and lateral gastrocnemius) was measured to study the reaction time.

Results: The reaction time of knee muscles during the perturbation was relatively long in this study (124 to 151 ms). It seems that muscles are recruited simultaneously in most conditions except in external rotation perturbation, with extension knee that the internal gastrocnemius muscle had significantly less delay time than the internal hamstring ($P < 0.05$) and external quadriceps ($P < 0.05$). The results show that most of these muscles do not react selectively and dependently on perturbation direction and knee position in response to horizontal rotational perturbation.

Conclusion: In this study, little difference was seen in the reaction time of most knee muscles in all conditions. Thus in response to this type of perturbation, the knee muscles showed co-contraction.

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1. Introduction

The knee joint is influenced by various forces and is more vulnerable to injury compared with other joints [1, 2]. The translated forces to knee joints are mostly from the lower leg and occur in short periods. Therefore, investigating the underlying mechanisms occurring in this short “time-frame”, can potentially be effective in injury prevention [3]. The forces applied to the knee joint should be controlled in a way that enough stability is established within the joint. Passive structures play significant roles in creating joint stability [1, 4]. However, considering the imposed forces on the knee joint, passive structures may not provide sufficient stability for this joint. Knee stability is controlled by the neuromuscular system through muscle activity and by passive restraint through ligaments and other passive tissues [1, 5].

Thus muscles play a significant role in this way. The relationship between muscle forces and its kinematics (changes in muscle length and forming a special position in the joint) shows that appropriate muscle function can provide mechanical stability for the joint [6-8]. This kinematics feature plays a key role in muscle stiffness and creates co-contraction for stronger stability [9]. Muscle stiffness, as well as co-contraction of muscle, are necessary for the stability of joints. One of the parameters of the neuromuscular system for the prevention of joint injury is the proper time of muscle-involvement in response to sudden perturbations [10].

Most previous studies have been done on translatory perturbations. The results of these studies show that as the translational part of perturbations increases, the amount of reaction from the lower limb muscles increases [10]. This observation suggests that two factors

play critical roles in the amount of muscle response to applied perturbations: the first factor is the displacement of the body’s Center of Gravity (COG) regarding the support surface, and the second factor is the impact of the amount of stretch applied on the muscle [11-15]. In horizontal rotational perturbations, there is less COG displacement thus just muscle stretch reflex participates in reaction time of muscle.

In Shultz experiments with a lower extremity perturbation device, the rotational perturbation was applied near COG, via the trunk. In this type of perturbation, COG displacement also occurs and muscle response appearing in short-latency show spinal reflexes that may be independent of the stretch receptors of ankle muscles [3]. Therefore, this study aimed to determine knee muscle reaction time in a less stable base of support. For this purpose, the subjects were standing on a single-leg stance. To compare the effect of knee position and perturbation direction on muscle response time, the subjects were perturbed in both knee extension and 30-degree knee flexion conditions and two directions of perturbation external and internal rotation.

2. Materials and Methods

Subjects

A total of 30 healthy females (Mean±SD=height: 164±6.4 cm, weight: 58.4±4.1 kg, age: 23.6±3.4 years) volunteered to participate in the present study. The subjects would be excluded from the study if they had any history of trauma or surgery or deformity in the lower extremity or any neurological disease. They had a normal range of motion and good muscle strength in the knee joint and they did not do any professional sports. The study was approved by the Iran University of Medical Sciences (IUMS).



Figure 1. Electromyography recording device (ME6000model, Mega electronic Ltd)

Instruments

Electromyography device

The electrical impulses from muscles were recorded using an electromyography device, (ME6000 model, Mega Electronic Ltd, Finland) (Figure 1), with a gain of 305, a common mode rejection ratio of 100 dB, the input impedance of 10 Ω , and a sampling rate of 1000 Hz. In this study, electrical impulses were recorded from seven channels. Six channels were used for recording the electrical activities of six muscles (vastus medialis and lateralis, medial and lateral hamstring, and medial and lateral head of gastrocnemius) and 1 channel for synchronization with perturbation device.

The perturbation device from the support surface

The perturbation device is used for sudden rotational perturbation on the transverse plane. This device is made of a circular section with a diameter of 40 cm and is placed on a rectangular plate with dimensions of 60×80 cm. The height of the device from the ground is 15 cm. This device creates sudden rotational perturbation, in both clockwise (the external rotational perturbation) and anti-clockwise (internal rotational perturbation) directions in the transverse plane and its mechanical design allows for a fixed amplitude of the imposed horizontal rotation at ± 35 degrees and speed of 120 degrees per second [16].

Procedure

We explained the test procedure for the subjects and asked them to fill out the data collection forms with their permission. The subject's skin was prepared and surface electrodes were placed in a parallel arrangement. According to the official sources of SENIAM were as follows [17]. The surface electrodes were placed in a parallel arrangement. In the biceps femoris over the middle of the line that connects the ischial tuberosity to the external epicondyle of the tibia, due to semitendinosus over the middle of the line that connects the ischial tuberosity to the internal epicondyle of the tibia, in The lateral head of gastrocnemius, was placed at the upper third of the line that connects the head of the fibula bone to the heel. In the medial head of gastrocnemius over the most bulky part of the muscle.

In the Vastus lateralis muscle with an angle of 15 degrees to the vertical line and 10 cm higher and 8 cm outside the upper edge of patella. And for vastus medialis with an angle of 55 degrees relative to the vertical line,

4 cm upper and 3 cm medial, relative to the medio-superior edge (measured from the center of the electrode) (SENIAM). The inter-electrode distance was 2 cm.

The subject stands on the center of the circular perturbation device and for the prevention of falling during perturbation; the subject wears a supportive device that contains a belt that connects to the ceiling (Figure 2). We asked the subject to stand on the dominant leg (right leg) while the other leg is in the flexion and fixed position and hold her hands on the side of her body and look straight. The subjects were asked not to lean on the supportive device. Before starting the main tests, the subject received rotational perturbation in a position similar to the main test. Therefore, they could become familiar with the procedure of the main test.

First, the subject was perturbed with her knee in a straight position, and then in a bending position (Figure 2). Each subject was tested for four conditions and the order of conditions was randomized. The central nervous system prepares postural responses differently in anticipated compared to non-anticipated perturbations [18]. In this study, the subject did not know the exact time of perturbation. The rotational perturbation platform is made of a circular platform that has an engine embedded underneath.



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Figure 2. The rotational perturbation device and subject's position

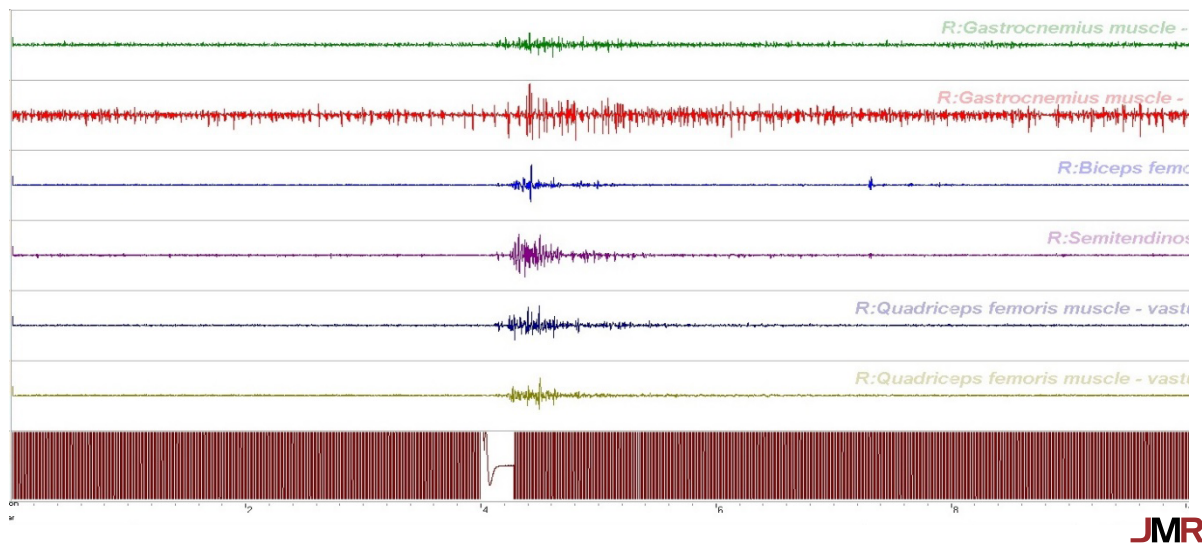


Figure 3. A sample of the recorded raw signals from six muscles, with their names and the electrical signal related to the rotational perturbation device in the study

The subject stands on the platform with her knee in a straight position, and then the rotational perturbation was applied unexpectedly. In the next stage, the perturbation was applied in the same way; however, the subject's knee was bent at a 30-degree angle.

To set the state of the semi-flexion knee position during perturbation, the subject was asked to bend the knee of her right leg until our goniometer showed 30 degrees of knee flexion. While the subject maintained her knee at a 30-degree angle, the subject was asked to look ahead and keep her head perfectly straight. When the knee flexion was about 30 degrees, the perturbation was applied suddenly.

Signal processing and analysis

We recorded the raw EMG signals, in appropriate environmental and technical conditions. Then a series of data processing was conducted for a more accurate study. The total recorded EMG signals were used within 3 to 4 seconds. The recorded signals were visually assessed, and after approval, the following criteria would be chosen, if the signal did not have noise and the signals were recorded for all six muscles.

In this study, to determine the onset time, we used the Root Mean Square (RMS) algorithm with a 10 ms overlapping windows time, and a time frame of 4 seconds of the RMS signal [3]. The initial onset time relative to the moment of perturbation applied was calculated. Thus, to calculate the average baseline activity of background muscle, we took a timeframe of 500 ms (700 -200 ms before the rotational perturbation) period. To calculate the underlying activity, we distracted 200-ms time before the

moment the rotational perturbation device to minimize the possibility of any feed-forward activity of the underlying activity. Synchronization of the perturbation and electromyography devices was performed by connecting the perturbation device to one of the channels. The moment of perturbation as an electrical signal is observed by a change in the process of creating an electric wave in the seventh signal (Figure 3).

Visual observations showed that muscular responses were in the range of 200 ms after perturbation. The moment of muscle response was considered as the point on the electromyogram in the range of 30 to 200 ms after the rotation of the perturbation screen. This point is defined as the time point when the myoelectric activity first exceeded two Standard Deviations (SD) of the Mean baseline activity in the muscles (muscle relaxation time) that was measured for 500 ms [4].

The data were collected from the muscular response times for the six muscles in two different conditions of perturbation direction and knee position. For this purpose, perturbation applied towards an internal rotation relative to the lower limb in a weight-bearing state (counter-clockwise) and external rotation (clockwise), and in both positions of the knee joint, straight, and bent.

The data were analyzed in SPSS. To compare six muscles with each other in terms of time to act and in each of the four situations (external rotation with the knee in the flexion position, external rotation with the knee in extension, internal rotation with the knee in the flexion position and internal rotation with the knee in the extension position) separately, we used repeated measure test.

To compare muscle latency between the two muscles, we used the Bonferroni test.

Also to investigate the effect of knee position (straight knee and bent knee) and rotation direction (external and internal rotation) on the time of muscle reaction, the delay time of each muscle was compared to itself in four conditions by the one-way ANOVA repeated measured test. And to determine which of the two states were significantly different, we used the Bonferroni test.

3. Results

Muscle reaction time

This study aimed to compare the delay time of muscle reaction with each other in four conditions separately. For this purpose, a repeated measure test was used, and to compare muscle latency between two muscles, the Bonferroni test was used. The reaction time of knee muscles during the perturbation was relatively long in this study (124 to 151 ms).

Based on the results, muscles are recruited simultaneously in most conditions, except for external rotation perturbation with extended knee condition that The internal gastrocnemius muscle showed a significant difference compared to the internal hamstring and lateral quadriceps ($P < 0.05$).

Regarding the effect of knee position (straight knee and bent knee) and rotational direction (external and internal rotation) on the time of muscle reaction in the face of sudden horizontal perturbation, the result of the one-way ANOVA repeated measure test and Bonferroni test showed that the "delay-time" for the involvement of the two muscles, medial gastrocnemius, and medial hamstring

muscles, during some of the rotational perturbation in the four positions had a statistically significant difference.

In examining the effect of rotational direction, in a straight knee, the medial hamstring muscle becomes involved much faster during internal rotational perturbation than the external rotation ($P < 0.05$) and the medial gastrocnemius muscle was activated during external rotational perturbation faster than internal rotational perturbation ($P < 0.05$). In examining the effect of knee position, the medial gastrocnemius muscle was activated during external rotational perturbation in the straight position of the knee faster than knee bent ($P < 0.05$). Delay time in other muscles did not differ significantly under different conditions ($P > 0.05$). Regarding the reliability of delayed time in six muscles, most of them showed moderate- to high-reliability values (Monroe classification) [19].

4. Discussion

Measurement of long-latency responses

Knee joint injuries usually occur in a short period, so analyzing the mechanism and process of this short time can be helpful to prevent similar injuries. This study aimed to determine the reaction time of knee muscles in response to horizontal rotational perturbation applied to lower leg from support surface area and compare the effect of knee position and perturbation direction on response times of the muscles.

The reaction time of knee muscles during the perturbation was relatively long in this study (124 to 151 ms) and based on these findings they are within the long-loop response answer range that indicates that central programming controls the stability of the limb in rotational perturbation [20]. While there is little difference in reaction

Table 1. The Mean±SD "delay-time" for the involvement of the muscles in the face of rotational perturbation (specified in millisecond)

Muscle	Knee Extension						Knee Flexion External Rotation						
	External Rotation			Internal Rotation			External Rotation			Internal Rotation			
	Mean	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	SD
M Gastr	124.7	94.5	177	148.5±17.1	96	193	146.8±24	110.7	193	151.4±22.9	128	191	16
L Gastr	141.12	109.5	185.25	142.3±21.21	108.75	176	143.8±15.4	100	201	145.6±23.67	115	187.5	15.6
M Quadr	137.4	108.25	191.75	147±20.3	110.25	182	137.1±21.9	113.5	166.3	144.3±14.8	113	190.2	20.09
L Quadr	143.94	106.25	189	142.1±21.27	101	183.25	138±18.7	107	171.67	147±16.49	110.25	182	15.3
M Hams	147.17	118	177	138.46±15	119.25	185	139.4±18.7	114.5	183.6	133.5±18.4	109.25	167.25	17.4
L Hams	139	110.5	186	141.4±18.6	97.5	174.5	139.7±19.3	110.2	164.75	139.6±15.5	105	176.5	17.3

time of most knee muscles in all conditions, approximately co-contraction which in turn causes stiffness in the knee joint and therefore stiffening strategy does not permit any changes in COG position (no displacement).

The results of this study contradict the studies that have been done in the past on translational perturbation concluding that the muscles had a short delay time. In translatory perturbation, there is more displacement in the position of COG and this state potentially is a more serious threat to the stability of the body [14]. Also in our study, perturbation is applied from the lower leg region which is far from COG. It means that the changes may not reach COG and forces may be attenuated in the lower limb and less change reaches to it.

Among knee muscles, the medial gastrocnemius muscle showed the lowest latency time despite its long latency period. This result may be due to the interaction biomechanics of the ankle and lower limb. External rotation of ankle in close kinetic chain can induce internal rotation in the knee which in turn may put some strain on knee ligament like ACL. Perhaps this is the possible reason for the slower delay time of the gastrocnemius.

According to previous studies in angles closer to extension, due to proprioceptive activities, the majority of muscles have a lower latency period [21]. Moreover, as changes in muscle length and capsular ligament length increase proprioception activation in angles close to extension, there would be statistically significant changes in muscle activation time in these muscles in extension position [22]. But the issue that is constant here is a lack of significant changes in the body's center of gravity. Therefore, in the application of this type of perturbation from the soles, changes in the position of the COG is a more important factor in determining muscle response, in comparison to the knee position.

In the majority of the studies, the reaction time of the muscle in response to perturbation was lower compared to the current study, in a way that they fall into a lower level range of motor control [3, 13, 21, 23, 24]. Perhaps this is the difference between these two types of studies. During translational perturbations, in contrast to rotational perturbation in the transverse plane, there is a displacement in the position of the COG, and this condition can potentially be a more serious threat to the stability of the body [10].

Some studies have also examined the rotational perturbations applied from the upper-body, e.g. a study carried out by Shultz in which horizontal rotational perturbation was applied from the trunk and muscles. In the Shultz

study (horizontal rotational perturbation), all muscle encountering perturbation shows shorter reaction times which conflicts with this study results [3]. It seems that rotational perturbation applied in the trunk region and near COG induce further displacement of COG relative to the rotational perturbation from supporting surface platform [25]. Perhaps the cause is the further displacement of the body's center of gravity in relation to the support surface, compared to the present study.

In the study carried out by Chen and colleagues, the experimental design was similar to the current study, but the same muscles had a longer delay time compared to the present study [16]. The speed and degree of perturbation applied were similar in both studies. The only difference was the position of the study subjects who were under perturbation. In this study, the subjects were standing on one leg, and in the study by Chen, they stood on both legs. Thus, the more unstable the perturbation condition, the shorter would be the delay time of the muscles. However, because the mechanism of joint damage is created in a short time, muscle response cannot prevent damage from a perturbation with the same intensity and range of perturbation in his study due to the long delay time.

5. Conclusion

Rotational perturbation from support surface induce knee muscle reaction time in the range of long-loop response and more muscles are independent of knee position and direction of applied perturbation. Moreover, the co-contraction of knee muscle rather than preferential recruitment induces body parts stiffness and the stability of COG. In perturbation time, the more stable subject, the longer the reaction time of muscle would be.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed about the purpose of the research and its implementation stages; they were also assured about the confidentiality of their information; moreover, they were free to leave the study whenever they wished, and if desired, the research results would be available to them.

Funding

The present paper was extracted from the MSc. thesis of the first author, at the Department of Physiotherapy, School of Rehabilitation, Iran University of Medical Sciences.

Authors contributions

All authors contributed in preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgements

We sincerely thank all members of the Physical Therapy Department (Rehabilitation Sciences Faculty of Iran University of Medical Sciences) who provided the research team with the necessary facilities to complete the study.

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