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The Effect of the Lower Leg Sensory Feedback on Force Sense of the Knee Extensor Muscles in Healthy Young Men: A Cross-Sectional Study

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Original Article

Abstract

Introduction: Sensory information is essential for controlling and modulating muscle force. The aim of this study is to examine the effect of the lower leg sensory feedback on the force sense of the knee extensor muscle.

Materials and Methods: 22 healthy young men participated in this cross-sectional study through simple random sampling. Before and immediately following manipulation of skin sensory information, the mean error of three times of reproducition of the target force [50% of Maximum voluntary isometric contraction (MVIC)] of the knee extensor muscles was measured using a special dynamometer and reported. The force sense of the knee extensor muscles was examined at an angle of 60 degrees of flexion. The test was conducted in three conditions: normal (control) state, after using a thick sponge on the distal end of the dominant leg, and after placing a bag of small ice blocks on the distal end of the dominant leg for 20 minutes. To evaluate the force sense, the force reproduction methods were used in ipsilateral and contralateral knee. Repeated measures analysis of variance (ANOVA) and paired t-test were used to compare different conditions.

Results: By manipulating the leg sensory information, no significant change was observed in the force reproduction error (absolute, constant, and variable errors) of the ipsilateral leg ($P > 0.05$). However, a significant change was observed in the force reproduction error in contralateral side ($P < 0.05$).

Conclusion: It seems that the leg sensory information plays an important role in accurate perception of the force at contralateral knee joint. Therefore, signals delivered by the sensory afferents are important in understanding and controlling force.

Keywords: Proprioception; Sensory feedback; Knee joint

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Introduction

Proprioception includes afferent information from skin, articular receptors, especially muscle mechanoreceptors that are sent to the central nervous system (CNS) and used to perceive the sense of position, kinesthesia, and sense of force (1,2). Two hypotheses have been put forward regarding the possible mechanisms for judging the sense of force; The first hypothesis is related to the conscious sense of muscle force based on the lateral discharges of the flow of motor messages to the sensory cortex of the brain, which some have called the sense of effort. The second hypothesis is that the perception of muscle voluntary force based on environmental information about the muscle receptors [especially the Golgi tendon organ (GTO)] is cutaneous and articular, called the sense of force/tension (3-6). Both of these mechanisms contribute to the sense of force of contracting muscles, which is an important component of motor function (7). Reproduction, a certain level of Maximum Voluntary Isometric Contraction (MVIC) of a muscle group on the ipsilateral or contralateral side, has been defined as two main and important methods of

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measuring the sense of force in studies (8,9).

Factors such as age, pain, fatigue, anesthesia, and joint and muscle disorders can affect the sense of force, which has been confirmed in previous studies (4,10). Limited research has been accomplished on the effect of skin feedback on force perception, which has often been in the upper limbs and in most cases in the hand muscles (11-13). In these studies, the effect of removing most of the skin receptor information by local anesthesia and in some cases by changing it with various tools such as gloves, on the perception of force has been investigated. Object surfaces are also involved in perceiving force and gravity; In such a way that soft objects feel heavier than objects with rough surfaces (12).

Anesthesia may affect perception of force or weight by reducing the facilitation of the effect of cutaneous afferent signals on descending movement orders in the involved limb (13); so that the perceived heaviness was different after anesthesia on the skin of the thumb and forefinger (more than 40% in the thumb and about 13% in the index finger). This clear difference in the thumb indicates the important role of skin receptors in controlling and producing power, as well as the variability of this sensation in different parts of the body (13). Ruffini receptors with slow adaptation and Pacinian corpuscles with fast adaptation are mainly responsible for transmitting sensory messages to the skin. Temperature changes also affect the function of the skin's sensory receptors; In this way, cold objects look heavier than objects at normal temperatures. Increased perception of the weight of cold objects up to 400% more than the original weight has been reported. The same is true of hot objects, but their effect is far less. This phenomenon has been reported as a sensory error due to weight and temperature (12-14).

The knee is the most commonly injured joint in sports injuries (15). Considering the frequent use of ice and cold sprays in rapid treatment during and after exercise and the possible effect of sensory changes on the sense of force of the knee joint, it seems necessary to examine the effect of sensory information on the amount of the force sense error. Additionally, in the instruments used to assess the sense of force, the person often presses a part of the limb to the measuring instrument in order to exert force, and it is not clear whether what is being measured is only a muscle force sense error or the sensory information due to the pressure of the limb also helps to reproduce the desired force. Therefore, the study of the effect of sensory feedback of the leg and its manipulation on the sense of force of the ipsilateral and contralateral extensor muscles of the knee with different methods of reproduction, can help to better understand the role of sensory information of the skin. The aim of this study was to investigate the effect of manipulating the sensory feedback of the leg on the sense of force in the extensor muscles of the knee joint through repeated measures.

Materials and Methods

This was a cross-sectional-analytical study. Cross-sectional studies are performed at a point or a short period of time to describe a particular population in terms of a particular feature (16).

Participants: The study was performed on 22 healthy young men with a dominant right leg. The samples were selected from 48 volunteer students by simple probabilistic sampling using RandList software (RandList 1.2 software, Released 2012, DatInf GmbH. Germany) and considering the inclusion and exclusion criteria. The inclusion criteria included a maximum difference of 5% in MVIC in the extensor muscles of both knees of the participants, no professional sports activity [score less than 7 according to the Tegner Activity Scale (TAS)] (17), no history of pain, injury, or musculoskeletal disorder (MSD) in lower extremities, and movement limitations for at least the past six months, and no history of cardiovascular and respiratory diseases, internal diseases, neurological disorders, and sensory disturbances (information on these items was collected based on the individuals' responses and demographic questionnaire items). In case of any fear or any anxiety when using the modalities, the person would be excluded from the study. The inclusion and exclusion criteria were assessed by a PhD in physiotherapy and based on the clinical history who was unaware of the study method. The required sample size was estimated to be 22 people based on the study by Galie and Jones (18) and assuming $\alpha = 0.05$ and $\beta = 0.8$.

Measuring instrument: To evaluate the force reproduction error on the contralateral limb, two accurate dynamometers were required, so that by showing the force on the reference limb, immediately and without wasting time, to ask the person to reproduce the force on the contralateral limb simultaneously or after a short time. The only device available was an isokinetic machine that has one arm and can only be used to evaluate the ipsilateral force reproduction. Therefore, a suitable tool had to be designed and built for this purpose, which in addition to high accuracy, had to have the necessary efficiency for the desired evaluations in the present study. For this purpose, a special dynamometer was designed and built by a group of physiotherapists and design, biomechanics, and electrical engineers. The dynamometer had two arms on either side of a seat with the capability to adjust height, move back and forth, and a backrest. Straps were also inserted to prevent extra movement of the trunk, pelvis, and thighs during muscle contraction (Figure 1). Other details about this device and its validity and reliability have been presented in previous studies (11,19).

Figure 1. The device used and how the test subject is positioned during force sense assessments

Method of work: First, the objectives and generalities of the implementation method were explained to the samples and the individuals entered the study after completing the written informed consent form. The room ambient temperature was maintained at about 24 °C in all stages of the tests. In order to investigate the effect of sensory afferents of the lower leg on the force perception of knee extensor muscles, the study was conducted in three stages in two days and three days apart from the first test. All subjects passed all three stages of the study and the sense of force in the participants was assessed in a random manner. One day was dedicated to assessing the sense of force under normal conditions with a sponge, and the next day was devoted only to assessing the sense of force after applying ice. The sense of force was assessed using three methods of measuring the reproduction of the ipsilateral and contralateral target force using memory and simultaneously. In order to determine the evaluation mode and the order of the evaluations, each participant was asked to choose one of the envelopes in which the name of each evaluation mode was mentioned. After determining the evaluation mode, to determine the evaluation stage, selection was made again from the other three envelopes.

The subjects were first asked to perform the MVIC of the knee extensor muscles normally in a 60-degree knee angle of flexion in the dominant and non-dominant legs with verbal encouragement and visual feedback. Each contraction was performed for 5 seconds and repeated 3 times with an interval of 60 seconds rest. The highest recorded force was considered as MVIC. The subjects then rested for 10 minutes to avoid fatigue. If the MVIC of the two sides had a difference of more than 5%, the person was excluded from the study. In the present study, the contralateral limb was used as a control and the evaluation results were likely to be affected for this reason [In the references, differences have been reported regarding the power difference between the two limbs in force reproduction (20,21)]. Therefore, in order to control the possible effect of this confounding variable, the maximum acceptable difference percentage was 5%.

In all of the following evaluations, in order to standardize the amount of target force (50% of MVIC), the MVIC of the extensor muscles of the dominant limb in the normal position, which was performed separately each day, was considered as the benchmark.

a. Assessing the sense of force in normal conditions, without sponge and ice (control group): In the method of reproducing the contralateral target force using memory, first the subject produced the target force with visual feedback in the reference limb (dominant limb) and after 5 seconds of pause, with an 8-second contraction, attempted to reproduce the target force without feedback on the opposite limb. In the contralateral force reproduction method simultaneously, the subject generated the target force in the reference limb using visual feedback and then simultaneously and without interruption, reproduced the target force with an 8-second contraction without visual feedback on the opposite side (9,22). Ensuring the completion of timing of each contraction was performed by setting an alarm in the device. At the moment of reproduction of the target force, the subjects verbally announced achieving it and maintained that force as much as possible. The average values from the moment of announcement to the end of force retention were the basis of calculation. Comparison of the target force and the reproduced force in each repetition was recorded as the amount of force reproduction error in that repetition.

The order of performing tests to assess the sense of force in the knee extensor muscles in three assessment methods was random. In order to prevent fatigue, 30 seconds of rest was given between three repetitions in each method and one minute between different methods. The above method was performed accurately in conditions of sensory disturbance with sponge and ice.

B. Evaluation of sense of force in sensory disorder conditions using 16 cm sponge: In order to reduce the effect of sensory information caused by leg pressure on the force sensors, a 16 cm thick sponge was placed in the lower third of the leg and above the inner ankle of the dominant limb. The participants were asked to reproduce 50% of normal MVIC in the extensor muscles of the knee. The subject reproduced the force generated by the dominant leg with a sponge on the ipsilateral (with sponge) and contralateral sides (without sponge).

J. Assessing the sense of force in the case of sensory disturbances using a bag of small ice blocks: The subject laid on the bed with a slightly bent knee with a small pillow under it, resting. To reduce the effect of leg sensory information, a bag of small 15 × 25 cm^2 ice blocks was first placed on the distal third of the leg above the inner ankle of the dominant limb for 20 minutes. If any discomfort was reported while placing the ice pack on the leg, the person was excluded from the evaluation. Before applying ice, skin sensitivity was assessed with the Pinprick test. To do this, using a safety pin, the person was asked to express their feelings about the stimulus. For the accurate sensation of the pin location, relative sensation of the site, lack of relative sensation of the pin location, and absolute absence of the stimulus sensation, score 0, 1, 2, and 3 was considered, respectively (23,24). After 20 minutes, the ice pack was removed and the Pinprick test was performed again (25,26). The skin surface temperature of all subjects in the lower anterior part of the leg at points 5 cm above the parallel of the inner ankle, during the previous 3 steps, after placing the ice and finishing the evaluation of the sense of force, using a non-contact infrared thermometer (MASTECH MS6520B, China) was measured and recorded. Before removing the ice pack, the subject was placed on a force sensation chair to adjust the chair to his physical condition. Then, they reproduced the force generated by the dominant leg in the ipsilateral and contralateral limbs. All tests took a maximum of 9 minutes from the time the ice pack was removed.

In order to normalize the study data, the mean of all errors was divided by the MVIC of each individual and multiplied by 100 (mean error/MVIC*100) to evaluate the percentage of errors of each individual relative to his MVIC (8,27).

Three errors of constant error (CE), variable error (VE), and absolute error (AE) were used to calculate the force estimation error (28,29). To investigate the data distribution, the Shapiro-Wilk test was used, which with a minimum probability value of 0.089, the normal distribution of variables was accepted. Repeated measures analysis of variance (ANOVA) and paired t-test were used to compare the data in different evaluation conditions. Finally, the data were analyzed in SPSS software (version 18.0, SPSS Inc., Chicago, IL, USA). $P \leq 0.05$ was considered as the significant level.

Results

Demographic characteristics of the subjects, as well as the mean MVIC of the knee extensor are presented in table 1.

Table 1. Demographic characteristics of participants and mean Maximal Voluntary Isometric Contraction (MVIC) of the dominant leg knee extensor

Variable	Mean ± SD
Age (year)	23.90 ±3.53
Height (cm)	174.85 ±3.65
Weight (kg)	71.09 ±6.61
BMI (kg/m^2)	23.24 ±1.94
Knee extensor MVIC (N)	
(1) MVIC of the first day	302.47 ±41.63
(2) MVIC of the second day	299.57 ±40.22

SD: Standard deviation; Body mass index

The mean skin surface temperature before the test, after 20 minutes of using ice, and at the end of the force sensation assessment were reported as 34.33 ± 1.40, 10.93 ± 3.17, and 14.89 ± 3.21, respectively.

The mean MVIC of the second day was lower than that of the first day, but based on the results of the paired t-test, this difference was not significant ($P = 0.060$). The results of the repeated measures ANOVA and paired t-tests between the different evaluation modes showed that there was no significant difference in the mean of absolute, constant, and variable errors between the reproduction of the target force in the same direction in normal condition and its comparison with the error rate after using the sponge and after using ice ($P > 0.050$).

The mean of absolute, constant, and variable errors in the reproduction of the target force on the opposite side using memory in different study conditions under normal conditions and comparing it with the error after using the sponge and the error after using the ice showed a significant difference ($P \leq 0.50$).

The mean of absolute, constant, and variable errors in the reproduction of the target force on the opposite side simultaneously between different study conditions in normal mode and its comparison with the error after using the sponge and the error after using the ice was significantly different ($P \leq 0.050$).

The mean of absolute, constant, and variable errors in the target force reproduction on the same side, the target force reproduction on the opposite side using memory, and the target force reproduction on the opposite side simultaneously after using the sponge compared to the error after using ice did not show a significant difference ($P < 0.050$) (Table 2).

Table 2. Mean errors in different methods of target force reproduction

Sensation status	Target force reproduction method	Type of error	Mean ± SD	Normal test or control conditions (Mean ± SD)	P
Conditions for applying sponge	Force reproduction on ipsilateral side	Absolute error	2.81 ±1.34	2.22 ±1.17	0.291
		Fixed error	1.96 ±0.90	1.33 ±0.72	0.073
		Variable error	2.02 ±1.17	1.78 ±0.92	0.997
	Force reproduction on contralateral side at the same time	Absolute error	5.74 ±2.27	2.38 ±0.97	≤ 0.001*
		Fixed error	-5.29 ±1.85	1.20 ±1.41	≤ 0.001*
		Variable error	2.61 ±1.04	1.84 ±1.01	0.039*
	Force reproduction on contralateral side using memory	Absolute error	4.44 ±1.36	2.73 ±1.05	≤ 0.001
		Fixed error	2.07 ±4.24	1.33 ±1.22	≤ 0.001*
		Variable error	3.29 ±1.55	1.96 ±0.98	0.007*
Conditions for applying ice	Force reproduction on ipsilateral side	Absolute error	2.71 ±1.18	2.22 ±1.17	0.705
		Fixed error	1.82 ±1.09	1.33 ±0.72	0.309
		Variable error	1.96 ±0.88	0.92 ±1.78	0.999
	Force reproduction on contralateral side at the same time	Absolute error	5.72 ±2.02	2.38 ±0.97	≤ 0.001*
		Fixed error	5.25 ±2.14	1.20 ±1.41	≤ 0.001*
		Variable error	2.37 ±0.83	1.84 ±1.01	0.038*
	Force reproduction on contralateral side using memory	Absolute error	5.11 ±1.45	2.73 ±1.05	≤ 0.001*
		Fixed error	-5.87 ±1.69	1.33 ±1.22	≤ 0.001*
		Variable error	3.01 ±1.31	1.96 ±0.98	0.015*

SD: Standard deviation; Body mass index
*P ≤ 0.050

Discussion

The aim of this study was to investigate the effect of the lower leg sensory feedback on perception of the knee extensor muscle force in healthy young men. Based on the findings, manipulation of the sensory feedback of the lower leg on the error of reproduction of the force of the knee joint extensor muscles is effective in the methods of reproduction of the target force on the opposite side, but in the method of reproduction of the target force in the ipsilateral limb, despite increasing the error, there was not a significant difference.

Tremblay et al. examined the ability to accurately detect weight on the same side after 20 minutes of cold application using an ice pack on the bulk quadriceps muscle of the right knee in 20 healthy individuals and concluded that the quadriceps muscle sense was not impaired with cold (30). The results of their study were consistent with the findings of the present study in the reproduction of the target force in the same side. They found that the quadriceps muscle cryotherapy has relative immunity in the ability to accurately detect weight on the same side (30). The results of the study by Furmanek et al. also showed that topical application of cold has no effect on the accuracy of proprioception in the knee of healthy individuals (31).

Galie and Jones examined the effect of temperature changes of 24 to 32 °C on the skin of the index finger on the perception of the force of this finger and did not observe a significant difference. Although the decrease in the skin temperature was not significant in their study, the results of the repeated measures ANOVA test revealed that with decreasing skin temperature, the target force reproduction error increases (18).

The effect of ice on sensory feedback, the cold penetration depth, and time of changes in the tissue has been somewhat determined. For example, Rupp et al. found that placing an ice pack for 20 minutes reduced the intramuscular temperature by 8 degrees (32). Moreover, the effects of cold inside the muscle by immersion in ice water were lasting for 90 minutes (32,33). The results showed that a 7 °C decrease in skin temperature (34), with a decrease in nerve conduction velocity (NCV) to half before placing the ice, was associated a decrease in skin and muscle afferent information transmission (35) and a decrease in pain sensation (36).

Manipulation of sensory information at the distal end of the leg by ice and sponge in both methods of target force reproduction on the contralateral side caused a significant change in force reproduction error. The subject reproduced the perceived force in a sensory condition (with sensory disturbance with ice and a 16 cm thick sponge at the distal end of the dominant leg) and in the contralateral limb under a different sensory condition (without sensory disturbance). Therefore, the disturbance of the sensory feedback of the leg in this method, due to the different sensory conditions, disturbed the perception of the target force. In these methods, the reproduced force was less than the target force and the constant error rate was negative (underestimation). Furthermore, the stability or variety of individual responses to a stimulus or variable error was significantly different compared to normal conditions.

For two reasons, the existence of a significant difference in the reproduction error of the target force on the contralateral side can be justified. First, force production occurs in a different sensory condition than force reproduction, which may be due to the decreased facilitation of the effect of cutaneous afferent signals on the descending motor commands of the involved limb (13). Second, the sensory pathways are different from the reproduction method in the same organ due to force reproduction in the contralateral limb and changes in the sensory hemisphere of the brain (8,37,38).

Other studies have emphasized the importance and impact of sensory feedback on power generation and perception. For example, Jones and Piateski reported that by sensory disturbance in the fingers of the reference limb using a plastic splint, in estimating the reproduction of the target force on the contralateral side and the error of estimating the force of the index finger flexor muscles, the hand and elbow flexors were less than the real limit (Undershoot) compared to the normal state (12). Scotland et al. examined the effect of visual and vibration feedback on the perception of hand muscle strength in the reproduction of the target force in the ipsilateral and contralateral limbs and concluded that visual and vibration feedback or sensory impairment is effective in perceiving force (27).

In their study, Monzee et al. investigated the effect of contact surface (rough surface and abrasives with a smooth metal surface) on the thumb and forefinger before and after anesthesia on the control of 0.5, 1, 1.5, and 2 N forces. They concluded that at the rough level, the force reproduction error was lower and numbness also disrupts the force control coordination. In other words, sensory information played an important role in perceiving force, and the sense of effort alone was not sufficient to coordinate and control force (39). As the abovementioned studies confirmed the effect of sensory feedback on force generation and reproduction, cutaneous mechanoreceptors also produce information for recognizing and differentiating objects and functional information necessary for hand function, and due to the effect of numbness on the fingers on force perception and heaviness, the MVIC value decreases due to the weak presence of sensory feedback (40).

Each method of the target force reproduction has advantages and disadvantages that the examiner chooses based on the study needs. In the research on the sense of force, such as the study of the effect of environmental and central fatigue on it, it is recommended to use the method of reproduction of the target force on the opposite side (12,40-42).

Given the results of the present study, the sensory disturbance of the leg, although it had little effect on the method of reproduction of the target force on the ipsilateral side, was effective on the reproduction of the target force on the contralateral side. Therefore, in exercises and sports activities such as football, where the precise movements of the two limbs are very important and ice and other anesthetics are used extensively, the possibility of injury, especially in the contralateral limb, should be considered. Perception of force seems to require a sense of effort and environmental receptors to calibrate it, and these two are correlative. Therefore, in the sense of force studies, different evaluation methods should be used in order to accurately observe the changes.

Limitations

The subjects of the present study were only healthy men. Therefore, the findings are not generalizable to people with various disorders or other genders. On the other hand, due to instrumental limitations, it was not possible to perform a kinematic study.

Recommendations

It is necessary to perform studies on sick people and women. Furthermore, to evaluate the function of the extensor muscles of the knee, it is better to use surface electromyography to more accurately assess muscle activity during production and reproduction of the target force.

Conclusion

Based on the findings, it seems that sensory information has an effect on the perception of the sense of force or the reproduction of the target force; this means that numbness or sensory disturbance on one side may affect the sense of muscle strength.

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The present was extracted from the research design with number 65178 and ethics code IR.TBZMED.REC.1399.573. The authors would like to appreciate all the participants who contributed to the present study.

Authors' Contribution

Minoo Khalkhali-Zavieh: study design and ideation, specialized statistical services, manuscript

preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to referees' comments; Bahram Amirshakeri: study design and ideation, attracting financial resources for the study, support, executive, and scientific study services, providing study equipment and samples, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to referees' comments; Abbas Soltani-Someh: providing study equipment and samples, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to referees' comments; Mina Ahmadi-Kahjoogh: data collection, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to referees' comments.

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Conflict of Interest

The authors declare no conflict of interest. Dr. Amirshakeri did not receive any funding for this study and has been working as an assistant professor of physiotherapy at Tabriz University of Medical Sciences, Tabriz, Iran, since 2017. Dr. Khalkhali-Zavieh is an associate professor of Physiotherapy at Shahid Beheshti University of Medical Sciences, Tehran, Iran, Dr. Soltani-Someh is an assistant professor of physiotherapy and Dr. Ahmadi-Kahjoogh is an assistant professor of occupational therapy at Tabriz University of Medical Sciences.

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