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Knee Muscle Reciprocal Co-Activation in Patellofemoral Pain Syndrome During Isokinetic Exercise: A Voluntary Response Index Analysis

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Introduction: The origin of the Patellofemoral Pain Syndrome (PFPS) is not still completely clear and may have a biomechanical or biochemical cause. Motor control dysfunction may have a role in this condition. Voluntary Response Index (VRI) is able to show changes in the central nervous system motor output that occur with intervention, recovery, or progression of the disorder. Therefore, the outcomes may contribute to offer another tool for PFPS motor control evaluation. The aim of the present study, therefore, was to assess the changes in the quadriceps and hamstring reciprocal coactivation patterns that may be observed in individuals with PFPS using the VRI. **Methods and Materials:** A total of 24 female participants, 12 with sound knees and 12 with PFPS participated in the present study. The study was accomplished in the Biomechanics Laboratory at Rehabilitation School of Tehran University of Medical Sciences in 2015. The participants sat on a Biodex dynamometer. They were asked to perform 10 continuous knee extension and flexion motions with maximal strength at 45˚/s and 300˚/s, distinctly. Simultaneously, electromyographic activities of the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), and biceps femoris (BF) were recorded and VRI was calculated. A two-way analysis of variance was run to assess the effect of group and velocity on the VRI (similarity index and magnitude). **Results:** There was no velocity or group main effect observed for the VRI (P>0.05). In addition, no significant velocity × group interaction was found for the VRI (P>0.05). **Conclusion:** PFPS may not be linked to altered quadriceps and hamstring reciprocal co-activation patterns during isokinetic exercise. In addition, angular velocity may not be an important parameter in voluntary motor control assessment during isokinetic exercise.

Keywords: Reciprocal Co-Activation; Voluntary Response Index; Patellofemoral Pain Syndrome; Isokinetic

Introduction

Patellofemoral pain syndrome (PFPS) is defined as an anterior or retropatellar knee pain in the absence of other pathologies (1, 2). It is a common orthopedic knee condition encountered in athletes particularly in females (2-4). Clinically, the condition can be described as a diffuse anterior or retropatellar knee pain relapsed by activities, including stair climbing, prolonged sitting, squatting, kneeling, and during sports activities (1, 5, 6). The origin of the PFPS is still not fully clear and may have a biomechanical or biochemical cause (7). The most common problem is the abnormal tracking of the patella in relation to femoral trochlea when the knee is flexed or extended (8). Abnormal transverse-plane or frontal plane (or both) motion of femur during functional movements may be observed in this condition (9). Some potential contributing factors, including vastus medialis oblique insufficiency, decreased quadriceps, hamstrings and iliotibial band flexibility, femoral anteversion, increased quadriceps angle, and patellar hypermobility may contribute to the PFPS (10-12).

A motor control deficit is a key factor for inducing PFPS and a relationship may exist between changes in the timing of activity of vasti muscles and PFPS (1, 5, 13-19). However, there is controversy regarding the role of the quadriceps with respect to the balance (in terms of timing and/or activity level) between the vastus lateralis (VL) and the vastus medialis oblique muscles. Few studies have considered this subject with respect to the effect that hamstring activity has on the patellofemoral conditions (20, 21). This may be because the hamstring muscles have direct effect on tibiofemoral rather than patellofemoral kinematics. However, secondary movements of the tibiofemoral joint also influence the patellofemoral joint (12, 22). As for the effect of hamstring activity on the patellofemoral joint, the duration of hamstring activity increases in PFPS participants (20). Indeed, rather than studying each muscle activity individually, studying activation pattern of all muscles responsible for the entire prototype of a task would be valuable. Quadriceps/hamstrings coactivation result in higher patellofemoral contact pressure than quadriceps contraction alone (21). The effect of the quadriceps and hamstrings coactivation on

the knee joint kinematics and stability has been investigated both in vitro (23, 24) and in vivo (25-30) studies. Accordingly, an insufficiency in the hamstrings coactivation can result in a decrease in knee joint stability. Quadriceps muscle contractions can then impose unwanted stresses on internal joint structures, joint instability, and atrophy of the surrounding muscles. Therefore, with respect to significant neurophysiologic role of the knee muscular coactivation in maintaining joint stability and high prevalence of PFPS in young adults, it is necessary to assess the neuromuscular coactivation pattern of knee muscle groups during voluntary movements in patellofemoral pain group compared with that in normal participants. VRI has been used as a sensitive measure of motor control to determine abnormal voluntary movements (31-36). The VRI consists of two numeric values, one obtained from the total electrical activity of all muscles during a task (magnitude; Mag), and the other calculated from the electromyographic (EMG) distribution across the recorded muscles (similarity index; SI). This method analyzes, quantitatively, the surface EMG activity of the related muscles during a given voluntary movement for assessment of voluntary motor control.

In assessing voluntary motor control assessment, the surface EMG activities of related muscles are analyzed during a given voluntary movement.

Although the velocity is suggested to significantly affect the muscle activity in extremities (38-42), there is a lack of experiments to examine the effects of different velocities of knee movements on the activation pattern of knee muscles. Another purpose of the present study was to determine the effect of movement velocity on muscle control strategy using the VRI. In the present cross-sectional study, the surface EMG patterns of the vastus medialis (VM), VL, rectus femoris (RF), and biceps femoris (BF) were compared between a group of participants with PFPS and a healthy control group during isokinetic motor tasks.

Methods and Materials

Participants

Twelve healthy females (age: 25.4±2.5 yr and BMI: 21.5±2.2 kg/m^{-2}) with no musculoskeletal or neurological impairment, and 12 females (age: 24.8±2.3 yr and BMI: 21±2.7 kg/m^{-2}) with PFPS participated in the present study after signing an informed consent approved by the Ethics Committee of Tehran University of Medical Sciences. The study was carried out in the Biomechanics Laboratory of Rehabilitation School at Tehran University of Medical Sciences in 2015. The PFPS patients were diagnosed and referred by an orthopedic specialist. The inclusion criteria was reporting a retropatellar pain during squatting, ascending, or descending stairs. The average score of the visual analogue scale of the PFPS patients was 3.65±1.5. The patients had no other pathology or injury in their lower extremities. The reason for selecting females only was the high prevalence of the syndromes in the females rather than in males.

Instrumentation

Isometric and isokinetic concentric contractions of the knee flexors and extensors were performed using a Biodex system 3 dynamometer (Biodex Medical, Shirley, New York, USA). Simultaneously, EMG activities of the RF, VM, VL, and BF muscles were measured with a sampling rate of 1 kHz using a Biometrics DataLog EMG set up (Biometrics Ltd, Gwent, UK). According to the protocol recommended by the SENIAM (Surface EMG for Non-Invasive Assessment of Muscles), silver/silver chloride electrodes (1 cm diameter, 2 cm spacing) were attached to the RF, VL, VM, and BF muscles.

Experimental Procedure

Bipolar surface EMG was used to record the electrical activity of the VM, VL, RF, and BF muscles during isokinetic contractions. Following skin preparation, pairs of sEMG electrodes were attached to the skin, oriented on a line parallel to the muscle fibers. The ground reference electrode was fastened over the right wrist. With the electrodes firmly in contact with the skin, the thigh was wrapped by a rubber band to prevent direct contact of the thigh-stabilizing strap with the electrodes and cables. All the EMG signals were band-passed filtered from 25 Hz to 450 Hz, and sampled at 1 kHz with a CMRR of 110dB before any analysis.

To run the test, the participant was asked to sit on the dynamometer seat with her back reclined at 55 ° (43). The leg was positioned so that the lateral knee joint line was aligned with the dynamometer center of rotation. In that position, trunk, waist, and upper portion of the thigh of the leg were stabilized with self-stick straps to prevent any other movement that could affect the measurements. Participants were tested at angular velocities of 45°/s and 300°/s, separately. They performed 6-10 submaximal warm-up repetitions at each angular velocity to become familiar with procedure. Next, they performed a maximal effort concentric contraction of the quadriceps (extension) followed by a maximal effort concentric contraction of the hamstrings (flexion) for ten continuous repetitions at both tested velocities. The sequence of velocity testing was randomized. The motion ranged from 10° to 90° of knee flexion. A 10-min rest period was given between two tests to prevent any fatigue effect (42). Participants were instructed to work as hard as possible in both directions using strong verbal encouragement and visual feedback during the test procedures.

Data analysis

Data was analyzed using DataLog software. Surface EMG data was enveloped using a root mean square (RMS) algorithm that produced measures in the unit of microvolt. The enveloped data was considered as the basis for subsequent processing. Background

Table1: Means and standard deviations of the voluntary response index parameters for each phase of each movement for both groups. SI: similarity index, Mag: magnitude

Group	Variable	Extension45°/s		Flexion 45°/s		Extension300°/s		Flexion300°/s	
		SI	Mag (μs)	SI	Mag (μs)	SI	Mag (μs)	SI	Mag (μs)
Control	Mean	0.56	6.39	0.28	7.92	0.57	6.60	0.27	10.05
	SD	0.08	3.47	0.06	4.49	0.06	3.40	0.05	6.77
Patient	Mean	0.54	8.88	0.29	13.91	0.58	6.25	0.31	13.21
	SD	0.06	5.80	0.05	8.67	0.09	1.48	0.06	11.00

Table 2: Descriptive indices of the percent of changes of multifidus muscle endurance in two groups

Variable	Phase	velocity	group	Velocity*group
SI	KF	0.45	0.18	0.36
	KE	0.25	0.89	0.53
Mag	KF	0.68	0.12	0.41
	KE	0.15	0.44	0.09

P values calculated from the effect of the "group", the "velocity", and the "velocity*group interaction" on SI and Mag in each phase of each movement. KF: knee flexion; KF: knee extension; Mag: magnitude.

activity was similarly measured using a 500 ms window immediately preceding the movement. For each phase of each test, the background activity was subtracted from the overall activity. The three middle trials for the 4 recorded muscles were averaged. These sets of values, one for each muscle, were considered as the Response Vector (RV) for each phase of each movement. The RV for each phase of each task was then normalized by the magnitude of the vector. The magnitude was the square root of the sum of the squares of the vector components, *i.e.* activity of the selected muscles. The SI was computed as the cosine of the normalized RV and the Prototype Response Vector (PRV) obtained from the healthy participants for the same motor task. An average of RVs across the 12 control participants was used to generate a PRV for each phase of each movement.

Statistical analysis

All the statistical analyses were performed using the SPSS (v. 17, SPSS Inc., Chicago, IL, USA). Reliability of the EMG measurements between repetitions for each muscle was estimated using intraclass correlation coefficient (ICC). Since data was normally distributed, as determined by Kolmogorov-Smirnov tests, a 2-way repeated measurement ANOVA was run to assess the effect of group (participants with PFPS vs. participants without PFPS) and angular velocity (45˚/s vs. 300˚/s) on the magnitude of the RV and the SI values for each phase of each test. This statistical procedure allowed the testing of the interaction effects and the main effects for group and velocity. A significant level of 0.05 was set for all analyses.

Results

The ICC between EMG measurements for each muscle ranged between 0.85 and 0.99 (P<0.05). The means and standard deviations of the voluntary response index parameters for patients with PFPS and control group at different velocities and phases are given in Table 1.

The results of two-way analysis of variance revealed no significant main effect for "group" or "velocity" with regard to the magnitude of RV or SI measurements for each phase of each test (P>0.05). None of the interactions between these factors were found to be significant (P>0.05) (Table 2).

Voluntary response index values obtained from patients with patellofemoral pain syndrome and the control group are presented in Figure 1. The patients demonstrated similar values of the SI and magnitudes of RV compared with those of the control group at different velocities and at all phases of movements.

Discussion

The present study has two main findings. First, the summed absolute magnitude (Mag) and the EMS pattern (SI) of quadriceps/hamstrings coactivity in participants with PFPS are similar to the prototype of the reference group. Second, there is no effect of velocity on the VRI of the knee muscles during isokinetic contractions.

The purpose of the present study was to investigate how similar the PFPS patients' knee reciprocal coactivation pattern was to an expected healthy pattern. This approach can assist motor control evaluation of the central nerve system of the patients with patellofemoral pain more comprehensively. In addition, this method helps to justify the necessary treatment for this heterogeneous syndrome. Our results showed that the magnitude of RV and SI variables for knee flexion and extension movements were nearly close to those for the control group. This finding suggests that both the absolute level of activity and relative distribution of motor-unit activation across antagonistic muscles

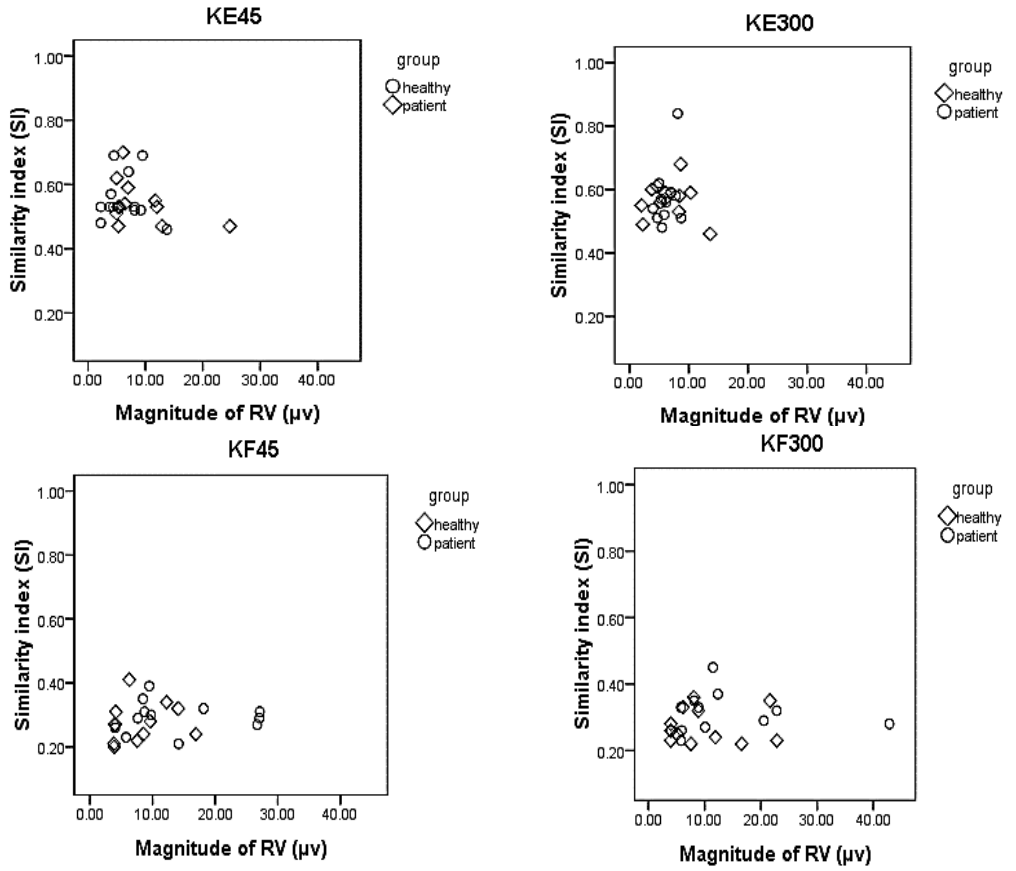

Figure 1. SI-Magnitude plot of the PFPS and healthy groups during (a) KE45, knee extension at velocity of 45˚/s; (b) KE300, knee extension at velocity of 300˚/s, (c)KF45, knee flexion at velocity of 45˚/s; (d) KF300, knee flexion at velocity of 300˚/s. Voluntary response index values obtained from healthy and patients with patellofemoral pain syndrome

may not be affected due to patellofemoral pain syndrome. In other words, PFPS patient's ability to select, sequence, and modulate knee antagonist muscle coactivation is normal. Therefore, it does not have implications for choosing rehabilitation strategies in terms of the variables related to muscle coactivation. The relationship of muscular interaction and the PFPS has been studied. However, direct comparisons with previous studies are difficult to make because no other researchers analyzed knee EMG activity of antagonist muscle groups by the VRI approach in the PFPS. In most cases, the analysis of EMG data has been limited to the assessment of signal amplitude and muscle timing (43, 44). Talebian *et al.* were the first who noticed changes in the EMG pattern of synergistic knee muscles in participants with PFPS during voluntary movements (45). They showed that the SI values in PFPS group were statistically different from those in the control group. The paradoxical results of our study, compared with that of Talebian *et al.*, can be attributed to two major methodological differences. First, there were differences in testing protocol. For example, our study involved 10 continuous isokinetic knee extension and flexion movements at 45˚/s and 300˚/s, whereas Talebian *et al.* used open kinetic chain (OKC) and closed kinetic chain (CKC) tasks. In addition, in the present study, the VM, VL, RF, and BF were selected to assess the pattern of agonist/antagonist muscle activities during knee flexion/extension, whereas they evaluated coactivation patterns of the VM, VL, and RF during a functional fatigue test.

The other finding of the present study was that velocity alteration had no significant main effect on VRI values in both groups. Changes in the velocity affect the VRI of the cervical muscles during functional voluntary neck movement (36). It appears, therefore, that angular velocity is not an effective parameter in the motor control assessment of isokinetic movements. However, that the functional voluntary movements at different velocities at various stages of the syndrome are considered as the diagnostic criteria is not clear.

Conclusion

The number of participants of the current study was relatively small. Caution should be emphasized in generalizing the

findings. Further research may be needed with larger number of patients with PFPS without any previous treatment to better understand the abnormal pattern of reciprocal coactivation around the knee in the brain motor control assessment protocol. To clinically validate this index, several parallel studies during different dynamic conditions should be designed using patients with neuromuscular impairments.

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The authors declare that there is no conflict of interests.

References

1. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Archives of physical medicine and rehabilitation. 2001;82(2):183-9.
2. Brukner P, Brukner KK. Khan's clinical sports medicine. North Ryde, NSW, Australia: McGraw-Hill. 2012.
3. Taunton JE, Ryan MB, Clement D, McKenzie DC, Lloyd-Smith D, Zumbo B. A retrospective case-control analysis of 2002 running injuries. British journal of sports medicine. 2002;36(2):95-101.
4. Tumia N, Maffulli N. Patellofemoral pain in female athletes. Sports Medicine and Arthroscopy Review. 2002;10(1):69-75.
5. Piva SR, Fitzgerald GK, Irrgang JJ, Fritz JM, Wisniewski S, McGinty GT, Childs JD, Domenech MA, Jones S, Delitto A. Associates of physical function and pain in patients with patellofemoral pain syndrome. Archives of physical medicine and rehabilitation. 2009;90(2):285-95.
6. Fulkerson JP. Diagnosis and treatment of patients with patellofemoral pain. The American journal of sports medicine. 2002;30(3):447-56.
7. Cesarelli M, Bifulco P, Bracale M. Quadriceps muscles activation in anterior knee pain during isokinetic exercise. Medical engineering & physics. 1999;21(6):469-78.
8. de Marche Baldon R, Nakagawa TH, Muniz TB. Eccentric hip muscle function in females with and without patellofemoral pain syndrome. Journal of athletic training. 2009;44(5):490.
9. Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. Journal of Orthopaedic & Sports Physical Therapy. 2003;33(11):639-46.
10. Tyler TF, Nicholas SJ, Mullaney MJ, McHugh MP. The role of hip muscle function in the treatment of patellofemoral pain syndrome. The American journal of sports medicine. 2006;34(4):630-6.
11. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. Journal of orthopaedic & sports physical therapy. 2005;35(12):793-801.
12. Mizuno Y, Kumagai M, Mattessich SM, Elias JJ, Ramrattan N, Cosgarea AJ, Chao E. Q - angle influences tibiofemoral and patellofemoral kinematics. Journal of Orthopaedic Research. 2001;19(5):834-40.
13. Cowan SM, Bennell KL, Crossley KM, Hodges PW, McConnell J. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. Medicine and science in sports and exercise. 2002;34(12):1879-85.
14. Hodges PW, Ervilha UF, Graven-Nielsen T. Changes in motor unit firing rate in synergist muscles cannot explain the maintenance of force during constant force painful contractions. The journal of pain. 2008;9(12):1169-74.
15. Mellor R, Hodges PW. Motor unit syncronization is reduced in anterior knee pain. The Journal of pain. 2005;6(8):550-8.
16. Cowan SM, Hodges PW, Bennell KL, Crossley KM. Altered vastii recruitment when people with patellofemoral pain syndrome complete a postural task. Archives of physical medicine and rehabilitation. 2002;83(7):989-95.
17. Tucker K, Butler J, Graven-Nielsen T, Riek S, Hodges P. Motor unit recruitment strategies are altered during deep-tissue pain. The Journal of Neuroscience. 2009;29(35):10820-6.
18. Ng EC, Chui MP, Siu AY, Yam VW, Ng GY. Ankle positioning and knee perturbation affect temporal recruitment of the vasti muscles in people with patellofemoral pain. Physiotherapy. 2011;97(1):65-70.
19. Nakagawa TH, de Marche Baldon R, Muniz TB, Serrão FV. Relationship among eccentric hip and knee torques, symptom severity and functional capacity in females with patellofemoral pain syndrome. Physical Therapy in Sport. 2011;12(3):133-9.
20. Hess T, Gleitz M, Egert S, Hopf T. Chondropathia patellae and knee muscle control. Archives of orthopaedic and trauma surgery. 1996;115(2):85-9.
21. Li G, DeFrate L, Zayontz S, Park S, Gill T. The effect of tibiofemoral joint kinematics on patellofemoral contact pressures under simulated muscle loads. Journal of orthopaedic research. 2004;22(4):801-6.
22. Lee TQ, Morris G, Csintalan RP. The influence of tibial and femoral rotation on patellofemoral contact area and pressure. Journal of Orthopaedic & Sports Physical Therapy. 2003;33(11):686-93.
23. Draganich L, Vahey J. An in vitro study of anterior cruciate ligament strain induced by quadriceps and hamstrings forces. Journal of Orthopaedic Research. 1990;8(1):57-63.
24. da Fonseca ST, Vaz DV, de Aquino CF, Brício RS. Muscular co-contraction during walking and landing from a jump: comparison between genders and influence of activity level. Journal of Electromyography and Kinesiology. 2006;16(3):273-80.
25. Fallah-Yakhdani HR, Abbasi-Bafghi H, Meijer OG, Bruijn SM, van den Dikkenberg N, Benedetti M-G, van Dieën JH. Determinants of co-contraction during walking before and after arthroplasty for knee osteoarthritis. Clinical Biomechanics. 2012;27(5):485-94.
26. da Fonseca ST, Silva PL, Ocarino JM, Guimaràes RB, Oliveira MT, Lage CA. Analyses of dynamic co-contraction level in individuals with anterior cruciate ligament injury. Journal of Electromyography and Kinesiology. 2004;14(2):239-47.
27. Cheney PD, Kasser R, Holsapple J. Reciprocal effect of single corticomotoneuronal cells on wrist extensor and flexor muscle activity in the primate. Brain research. 1982;247(1):164-8.
28. Williams GN, Chmielewski T, Rudolph KS, Buchanan TS, Snyder-Mackler L. Dynamic knee stability: current theory and implications

for clinicians and scientists. Journal of orthopaedic & sports physical therapy. 2001;31(10):546-66.
29. McGinnis K, Snyder-Mackler L, Flowers P, Zeni J. Dynamic joint stiffness and co-contraction in subjects after total knee arthroplasty. Clinical Biomechanics. 2013;28(2):205-10.
30. Aagaard P, Simonsen E, Andersen J, Magnusson S, Bojsen - Møller F, Dyhre - Poulsen P. Antagonist muscle coactivation during isokinetic knee extension. Scandinavian journal of medicine & science in sports. 2000;10(2):58-67.
31. Lim H, Lee D, McKay W, Priebe M, Holmes S, Sherwood A. Neurophysiological assessment of lower-limb voluntary control in incomplete spinal cord injury. Spinal Cord. 2005;43(5):283-90.
32. Lee D, Lim H, McKay W, Priebe M, Holmes S, Sherwood A. Toward an objective interpretation of surface EMG patterns: a voluntary response index (VRI). Journal of Electromyography and Kinesiology. 2004;14(3):379-88.
33. Lin J-j, Lim HK, Soto-quijano DA, Hanten WP, Olson SL, Roddey TS, Sherwood AM. Altered patterns of muscle activation during performance of four functional tasks in patients with shoulder disorders: interpretation from voluntary response index. Journal of Electromyography and Kinesiology. 2006;16(5):458-68.
34. McKay W, Ovechkin A, Vitaz T, de Paleville DT, Harkema S. Neurophysiological characterization of motor recovery in acute spinal cord injury. Spinal Cord. 2011;49(3):421-9.
35. Zoghi M, Galea M, Morgan D. A brain motor control assessment (BMCA) protocol for upper limb function. PloS one. 2013;8(11):e79483.
36. Cheng C-H, Wang J-L, Lin J-J, Wang S-F, Lin K-H. Position accuracy and electromyographic responses during head reposition in young adults with chronic neck pain. Journal of Electromyography and Kinesiology. 2010;20(5):1014-20.
37. Kellis E, Baltzopoulos V. The effects of the antagonist muscle force on intersegmental loading during isokinetic efforts of the knee extensors. Journal of biomechanics. 1999;32(1):19-25.
38. Miller JP, Croce RV, Hutchins R. Reciprocal coactivation patterns of the medial and lateral quadriceps and hamstrings during slow, medium and high speed isokinetic movements. Journal of Electromyography and Kinesiology. 2000;10(4):233-9.
39. Remaud A, Cornu C, Guével A. Agonist muscle activity and antagonist muscle co-activity levels during standardized isotonic and isokinetic knee extensions. Journal of Electromyography and Kinesiology. 2009;19(3):449-58.
40. Snow CJ, Cooper J, Quanbury AO, Anderson JE. Antagonist cocontraction of knee flexors during constant velocity muscle shortening and lengthening. Journal of Electromyography and Kinesiology. 1993;3(2):78-86.
41. Goharpey S, Shaterzadeh M, Emrani A, Khalesi V. Relationship between functional tests and knee muscular isokinetic parameters in patients with patellofemoral pain syndrome. Journal of Medical Sciences. 2007;7(8):1315-9.
42. Dehkordi SN, Talebian S, Olyaei G, Montazeri A. Reliability of isokinetic normalized peak torque assessments for knee muscles in post-stroke hemiparesis. Gait & posture. 2008;27(4):715-8.
43. Aminaka N, Pietrosimone BG, Armstrong CW, Meszaros A, Gribble PA. Patellofemoral pain syndrome alters neuromuscular control and kinetics during stair ambulation. Journal of Electromyography and Kinesiology. 2011;21(4):645-51.
44. Kim H, Song CH. Comparison of the VMO/VL EMG ratio and onset timing of VMO relative to VL in subjects with and without patellofemoral pain syndrome. Journal of Physical Therapy Science. 2012;24(12):1315-7.
45. Talebian S, Moosavi M, S K. Muscle fiber behaviors during dynamic fatigue in anterior knee pain and healthy subjects. J Tavanbakhsh Novin. 2012;6:62-8.

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