Effects of Graded Exercise-Induced Fatigue on the Knee Joint Position Perception

Choi Jong-duk, M.Sc., P.T.
Dept. of Rehabilitation Therapy, The Graduate School, Yonsei University
Yi Chung-hwi, Ph.D., P.T.
Dept. of Physical Therapy, College of Health Science, Yonsei University
Institute of Health Science, Yonsei University

국문요약

운동강도에 따라 유발된 근피로가 슬관절 위치감각 인지에 미치는 영향

최종덕
연세대학교 대학원 재활학과
이충휘
연세대학교 보건과학대학 물리치료학과 및 보건과학연구소

본 연구의 목적은 운동강도(최대근수축의 10, 30, 50, 70%)에 따라 유발되는 국소적인 근피로가 슬관절의 위치감각 인지에 미치는 영향을 연구함으로써 근력강화의 운동치료적 효과와 운동학습과 관련된 효과를 동시에 만족시키는 최적의 운동강도를 제시하는 것이었다. 대상자는 건강한 성인여자 40명이었다. 청각을 통한 위치감각 정보를 제공하는 장치와 원판 각도계가 부착된 등속성 Cybex를 사용하였다. 근피로의 상태를 확인하기 위해서 근전도를 이용하여 주파수 스펙트럼 분석을 실시하였다. 청각되먹임이 주어진 각도와 대상자에 의해 재생되어진 각도의 오차값들과 근피로의 변화를 비교하기 위해 일요인 분산분석을 이용하였다. 오차값들의 평균은 50%의 군에서 가장 작았으며 근피로 또한 70%의 군에서만 크게 생성되었다. 따라서 최대 근 수축력의 50% 가 운동치료 시 가장 효과적인 운동강도임을 알 수 있었다.

핵심단어: 근전도; 근피로; 운동강도; 운동학습; 주파수 분석.

Corresponding author: Choi Jong-duk *choidew@hanmail.net*

Introduction

Exercise-induced muscle fatigue has been identified as an important factor in determining the exercise type, method, and intensity in a therapeutic exercise prescription. Muscle fatigue has an especially strong negative effect on position sense, as shown by numerous studies on the interaction between muscle fatigue and position sense (Barrack, 1989; Barrett, 1991; Barrett et al, 1991; Gooch and Randle, 1993; Laabs, 1973; Marks, 1994; Marks and Quinney, 1993; Skinner et al, 1984).

In frequency spectrum analysis, myoelectric signals in time domain are converted to frequency domain to confirm muscle fatigue (Basmajian and De Luca, 1985). Electrophysiological findings for muscle fatigue frequency shift toward lower frequency component (Broman et al, 1985). Therefore, the change of mean frequency was used to evaluate localized muscle fatigue (Hary et al, 1982; Stulen and De Luca, 1982).

Skinner et al (1986) and Mark (1994) introduced a notion that continuous high-intensity exercise may decrease perceptual threshold sensitivity of Ia afferent fibers in the muscle spindle. Consequently, this decreased perceptual sensitivity may impair one's ability to accurately perceive and process the joint position and motion sense information that are the essential sensory feedback for the execution of coordinated movement. In contrast, Marks and Quinney (Broman et al, 1985) showed no significant effect of exercise-induced muscle fatigue on the knee joint movement accuracy. The discrepancy in the previous studies may be due to the fact that exercise-induced fatigue level of the tested muscle may have varied or not been controlled. Furthermore, previous studies have failed to yield the optimal amount of exercise intensity to not compromise joint perception sensitivity and yet to maximize motor performance and accuracy.

The purposes of this study were to investigate the relationship between exercise-induced muscle fatigue at the four different isokinetic exercise level (10%, 30%, 50% and 70% of maximal force) and position sense change and then to find the optimal exercise level for motor learning and therapeutic strengthening exercise effectiveness without impairment of position sense.

Methods

Subjects

Forty healthy women, aged from 19 to 27 (mean age = 20.9 years), participated in this study voluntarily. The subjects were randomly assigned to four experimental groups of 10 subjects each. Subjects with neurological or musculoskeletal disease or cardiovascular disease were excluded. All subjects signed informed consent forms approved by the University Institutional Review Board pri-

or to their participation.

Instruments

The Cybex[1] was used to induce muscle fatigue of the knee joint. To provide an auditory feedback for knee joint angle appreciation, a bell was attached to Cybex. To measure the knee joint range of motion, a disk goniometer was also attached. VCR recording devices (Camcorder) were installed at equal distance and angle from the Cybex to measure instantaneous knee joint angle. Muscle fatigue was measured by using the power spectrum method of the MP100 System[2]. For data acquisition and analysis, Acknowledge 3.7.1 software[3] was used in this study.

Procedures

Mean of Absolute Errors Comparison in Relation to Exercise Intensity

A subject was randomly assigned to four experiment groups with different exercise intensities. Maximal muscle strength was measured at 60 RPM to determine individual exercise intensity. A subject was asked to perform isokinetic pedaling at 150 RPM with the number of pedaling repetitions (30 times) that was determined

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1) Lumex Inc. FITRON Cycle-Ergometer, NY, U.S.A.
2) Biopack System Inc. Santa Barbara, CA, U.S.A.
3) Biopack System Inc. Santa Barbara, CA, U.S.A

by the pilot study. Auditory feedback was provided by a bell sound when the left pedal passed 135° so that the subject would be aware of the knee joint position. After a resting period of 5 seconds, subjects in four different groups were asked to perform isokinetic pedaling without auditory feedback at different exercise intensities. Instructions to remember the specific angle (135°) while performing isokinetic pedaling were given to the subjects. After the resting period of 5 seconds, the pedal was located passively by the experimenter to another angle that was selected by a subject. There were three angle patterns that could be selected by the subjects. The subject were then asked to relocate the left pedal actively at 135°. This procedure was repeated 5 times, and this procedure was recorded by a camcorder to measure the mean of absolute errors (between specific angle, 135° and reproduced angle)

Mean Frequency of Muscles in Relation to Exercise Intensity

Four surface EMG electrodes on the skin over the following muscles: medial rectus femoris, lateral rectus femoris, vastus lateralis, and vastus medialis (Johnson et al, 1973; Zippo, 1982). The reference electrodes were attached to the sacrum of the lowes back. Induced muscle fatigue was measured at the initial 10 seconds and at the final 10 seconds by the frequency spectrum while the subjects performed isokinetic pedaling for 50 sec-

onds at different exercise intensities. The adjusted gain was 1k. The sampling rate for data collection was 1024. A band-pass filter with a low frequency cutoff of 20 Hz and a high frequency cutoff of 450 Hz, and 60 Hz notch filter were used.

Statistical analysis

Statistical analyses were performed using SPSS 9.0 for Windows. A one-way ANOVA and a Least Significant Difference (LSD) post hoc test were used with significance level of .05.

Results

Table 1 shows the mean errors in four different exercise intensities. The highest mean error was observed at group 4. There was a significant difference in the mean error in experiment groups (p=.033). Significant differences were found between group 4 and group 1, 2 and 3, but significant differences were not found between groups 1, 2 and 3.

Table 2 shows the mean frequency change of different muscles in four different groups (Figure 1). Group 4 demonstrated the highest frequency change rate.

Table 1. Position sense change, mean errors in relation to exercise intensity　(N=40)

Groups	Exercise Intensity	Mean errors±SD	F	p
Experimental group 1	10% (n1=10)	10.39±6.69		
Experimental group 2	30% (n1=10)	10.87±4.47	3.24	.033
Experimental group 3	50% (n1=10)	8.93±3.72		
Experimental group 4	70% (n1=10)	17.71±9.07		

Table 2. Mean frequency change of different muscles in four different groups

	MRF		LRF		VM		VL	
	FC (%)	F	FC (%)	F	FC (%)	F	FC (%)	F
Group 1	3.38		3.73		1.92		4.65	
Group 2	.63*	11.05**	.99	12.40**	2.33	6.11**	4.99	13.56**
Group 3	.83*		.94*		2.97		2.38	
Group 4	.39*		-4.55*		-4.15*		-5.54*	

MRF; Med. Rectus Femoris, LRF; Lat. Rectus Femoris, VM; Vastus Medialis

VL; Vastus Lateralis, FC; Frequency change

**p<.05, *It shows the tendency of muscle fatigue.

These values were taken from during the initial 10 seconds and the final 10 seconds in four exercise groups of differing intensity.

Significant differences were found between group 4 and groups 1, 2 and 3, and significant differences were not found among groups 1, 2 and 3. The decreases of the four muscles mean frequency represent the tendency of muscle fatigue. This result can be explained by the fact that muscle fatigue in group 1, 2, and 3 was not prominent compared with that in group 4.

Discussion

Position sense is reduced because the sensitivity of Ia afferent fiber of muscle spindle is decreased and the ability to carry information to the central nervous system is decreased (Marks, 1994). In experiment 1, we expected a progressively increasing mean of absolute errors with increasing exercise intensity based on findings of Marks (Marks, 1994). However, muscle fatigue in groups 1, 2, and 3 was not prominent compared with that in group 4. Therefore, position sense errors in groups 1, 2, and 3 were not evident. Improved position sense in group 3 can be explained by two possible mechanism. First, warm-up effect could have favorably influenced position sense. Second, recognition and integration of position sense by auditory feedback in an identical environment could surpass the localized muscle fatigue (Marks and
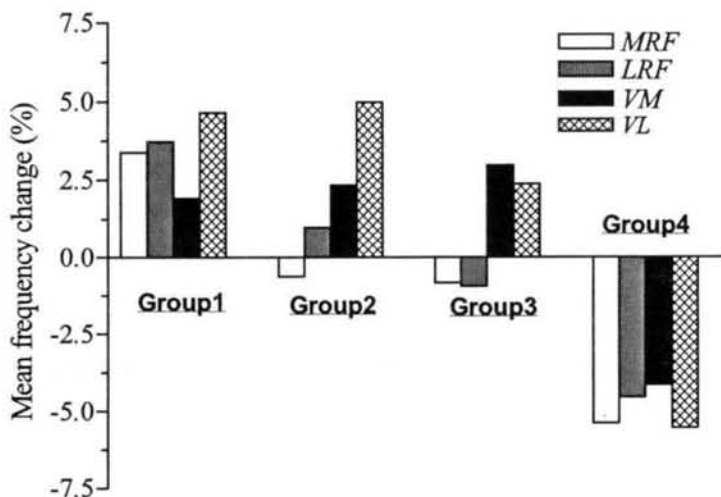

Figure 1. Mean frequency change in four different groups. These values were taken from during the initial 10 seconds and the final 10 seconds in four exercise groups of differing intensity. Decreases of group 4 show the tendency of muscle fatigue significantly.

Quinney, 1993). Clark et al (1979) suggested that the recognized level of joint position provided initially during the experiment improves as the subjects adapt to their environment during the experiment. This supports the findings of Whitley and Elliott (1968) that improved learning was achieved by minimizing the effect of fatigue and maximizing the performance of repetitive muscle contraction for position sense recognition. In experiment 2, the prominent quadriceps muscle fatigue in group 4 is closely related to increased position sense error (Table 1, 2). The mean frequency was shifted toward low frequency domain as localized muscle fatigue occurred (Arendt-Nielsen et al, 1989; Basmajian, 1979; Basmajian and De Luca, 1985; Hary et al, 1982; Mills, 1982; Sadoyama et al, 1988). Muscle is composed of slow twitch fiber and fast twitch fiber. Slow twitch fiber in low frequency domain has characteristics such as resistance to fatigue. Therefore, with a sustained muscle contraction, fatigue resistant slow twitch muscle fiber continues to activate, and fatiguing fast twitch muscle fiber stops activating resulting in the mean frequency shifting to a lower frequency domain (Mills, 1982).

Conclusion

This study investigated the effect of muscle fatigue induced by different exercise intensities on position sense in healthy subjects. In experiment 1, position sense error in group 4 increased remarkably compared with groups 1, 2, and 3. In experiment 2, prominent muscle fatigue was observed in group 4 compared with groups 1, 2, and 3.

We suggest that 50% of the maximal muscle contraction is the most effective exercise intensity without interfering therapeutic exercise effectiveness based on strength or motor learning effect which is completed by perceiving joint position. Further studies involving patients with impaired knee position sense are needed to precisely investigate the relationship between muscle fatigue and position sense and to apply this finding in clinical settings.

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