THE EFFECT OF FATIGUE AND VISUAL FEEDBACK ON SUBMAXIMAL ISOMETRIC MUSCLE CONTRACTIONS

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The force production and the ability to control it is necessary to the best performance in sports. The aim of this paper is to study the effect of visual feedback and fatigue on torque accuracy. The subjects were 5 healthy young adults, who performed maximal and submaximal isometric voluntary contractions for knee extension in an isokinetics machine. The task was to maintain the isometric torque in specific values. It was measured the myoelectric activity of selected knee muscles. We found that visual feedback affected the variability and the mean activity of all muscles. Their variability and means values were higher without feedback information. We also found that fatigue affected the variability of five muscles (BF, RF, ST, VL, and VMO). Their variability was higher before fatigue. Fatigue affected the mean activity of four muscles (BF, ST, RF, and VL), and their mean activities were higher before fatigue. And finally, we found that fatigue also affected the median frequency of five muscles (BF, GL, ST, VL, and VMO). Their median frequencies were higher after fatigue exercise. We discuss those results as a consequence of joint stiffness and motor unit discharge.

KEY WORDS: Torque perception, accuracy, biomechanics, isokinetics

INTRODUCTION:

In many sports, the task accuracy decides who wins and who looses. When someone has to keep a specific level of force during a task, as she/he has to press, push or pull a object, the force production and the ability to control it is necessary to the best performance.

The ability to vary the muscular force requires its adequate control. The benefit of this ability if reflects in the performance of many motor actions, as to hold an object or in sports. Different factors can affect the ability to control the force level (Toffin, 2003), as sensory information (Körding et al, 2004; Slifkin et al, 2000) and muscle fatigue (McArdle et al, 1996; Fuglevand, 1999). Sensory information is necessary to correct the force performance (Shumway-Cook & Woolllacott, 1995). And under fatigue, muscle force generation is depressed.

As muscle torque is not directly and easily measured by biomechanical procedures, muscle torque control is an available way to study muscle force accuracy control. Thus, how muscle torque is controlled during a accuracy task? Which is the effect of sensory information and fatigue on it? To find answers for those questions, the aim of this paper is to study the effect of visual feedback and fatigue in the control of muscle torque accuracy.

METHODS:

Subjects: The subjects were two men and three women (24.4±3.3 years old, 67.7±23.1 kg weight, and 1.68±0.10 m height. The subjects had no known history of locomotor system or musculoskeletal pain disorders. They gave informed consent according to the procedures approved by the local Ethical Committee.

Apparatus: The measurement of the submaximal isometric contraction torque produced by knee extensor group was provided by the isokinetic dinamometer (Biodex, System 3, USA). We also collected the surface eletromyographic signals of selected muscles (vastus medialis obliquos, VMO; rectus femoris, RF; vastus lateralis, VL; biceps femoris, BFL; semitendinosus, ST; tibialis anterior, TA; and lateral gastrocnemius and lateral gastrocnemius, LG). Both systems were connected to an acquisition system (Noraxon, Myosystem 1400, USA), controlled by software (Myoresearch 103.04, Noraxon, USA). The sampling frequency was 1 kHz.

Protocol: As warm-up, the subjects walked on a treadmill for five minutes, and experienced the flexion-extension knee movement at the dynamometer at 120°/s. We applied the SENIAM (Surface EMG for a Non-Invasive Assessment of Muscle) (Hermes et al, 2000) recommendations for EMG technical procedures.

The first task was to produce the maximal voluntary isometric contraction (MVIC) during about 8 s. We asked to the subject to perform twice its maximal muscle effort in this task when the knee angle was 60°. After 20 minutes, the subject performed the second task (the accuracy test): to execute two submaximal voluntary isometric contractions (sMVIC) at the same angle as before (60°).

At the first, he could look at the computer monitor to see the torque level that it was applying to the system. The subject should hold the contraction for 8 s. After 10s at rest, it should perform the second sMVIC for 8 s, also, without the visual feedback information.

The torque levels were 20, 40, 60, and 80% of MVIC and they were randomly performed. Then, we asked to the subject to hold the 80% sMIVC at 60° as long as it could support. After reaching the fatigue, the subject run the accuracy test again.

Variables: From two signals, EMGs and torque time profiles, we calculated the mean and standard deviation during three time windows during the sMIVC: begging [0.75, 1.25]s, middle [3.74, 4.25]s, and end [6.75, 7,25]s. Only for EMG, we also calculated the median frequency during those windows.

Data analysis: The mean, standard deviation and median frequency were analyzed across the experimental conditions. We used 4 way analysis of variance (ANOVA) to test the effect of feedback information (two levels: with or without visual feedback), the effect of fatigue (two levels: before and after fatigue exercise); torque levels (four levels: 20, 40, 60, and 80% of MVIC); and instant of contraction (three levels: beginning, middle, and end). We only will report the effects of fatigue and visual feedback. As post hoc analysis, we use Tukey HSD test.

RESULTS

The mean, standard deviation and median frequency of torque and EMG across muscles and experimental conditions are presented in table 1,2 and 3 respectively.

Table 1: Mean RMS for different CIVM levels in the fatigue pre and pos, with and without visual feedback.

Level CIVM	Fatigue	Feedback	Mean RMS							
			TA	GL	VL	VMO	RF	BF	ST	TORQUE
20%	pos	without	1.1±0.4	1.0±0.3	1.5±0.2	1.3±0.3	1.5±0.3	1.4±0.2	1.3±0.6	0.0±0.0
		with	1.1±0.4	1.1±0.2	1.8±0.3	1.8±0.3	1.7±0.3	1.5±0.3	1.5±0.3	0.1±0.0
	pre	without	1.0±0.6	1.0±0.4	1.5±0.3	1.5±0.3	1.5±0.5	1.4±0.3	1.4±0.3	0.0±0.0
		with	1.1±0.5	1.1±0.3	1.8±0.3	1.7±0.3	1.7±0.4	1.6±0.3	1.4±0.3	0.0±0.0
40%	pos	without	1.1±0.5	1.0±0.3	1.6±0.3	1.6±0.3	1.7±0.3	1.6±0.2	1.4±0.2	0.2±0.0
		with	1.4±0.5	1.4±0.4	1.9±0.6	1.9±0.5	1.8±0.3	1.8±0.4	1.6±0.3	0.2±0.1
	pre	without	1.0±0.7	1.1±0.5	1.7±0.3	1.6±0.4	1.8±0.3	1.6±0.4	1.5±0.3	0.2±0.1
		with	1.3±0.6	1.3±0.4	1.8±0.4	1.8±0.5	1.8±0.5	1.8±0.4	1.6±0.4	0.2±0.0
60%	pos	without	1.1±0.8	1.3±0.6	1.7±0.4	1.6±0.4	1.7±0.4	1.7±0.4	1.5±0.3	0.4±0.2
		with	1.6±0.8	1.7±0.6	1.9±0.4	1.8±0.5	1.8±0.5	1.8±0.5	1.7±0.4	0.4±0.2
	pre	without	1.1±0.8	1.2±0.6	1.7±0.4	1.7±0.4	1.7±0.4	1.7±0.4	1.6±0.4	0.4±0.1
		with	1.6±0.8	1.7±0.6	2.0±0.5	1.8±0.6	1.9±0.5	1.8±0.5	1.7±0.5	0.4±0.1
80%	pos	without	1,4±0,6	1.4±0.5	1.7±0.3	1.7±0.3	1.7±0.4	1.6±0.3	1.5±0.3	0.6±0.2
		with	1.9±0.5	1.7±0.4	1.8±0.3	1.9±0.3	1.8±0.3	1.8±0.3	1.7±0.2	0.7±0.2
	pre	without	1.4±0.8	1.3±0.6	1.6±0.5	1.6±0.5	1.6±0.5	1.6±0.5	1.5±0.4	0.6±0.2
		with	1.8±0.8	1.7±0.9	2.0±0.6	2.0±0.7	1.9±0.6	1.9±0.5	1.8±0.6	0.7±0.2

Table 2: Standard deviation RMS for different CIVM levels in the fatigue pre and pos, with and without visual feedback.

Level CIVM	Fatique	Feedback	Standard Deviation RMS							
			TA	GL	VL	VMO	RF	BF	ST	TORQUE
20%	pos	Without	1.0±0.4	0.8±0.4	1.2±0.2	1.1±0.3	1.2±0.2	1.2±0.2	1.0±0.7	0.0±0.0
		with	1.0±0.4	1.0±0.2	1.5±0.2	1.4±0.3	1.4±0.2	1.3±0.2	1.2±0.2	0.0±0.0
	pre	without	0.8±0.6	0.8±0.5	1.3±0.3	1.2±0.3	1.2±0.4	1.2±0.3	1.0±0.3	0.0±0.0
		with	0.8±0.4	1.0±0.3	1.4±0.3	1.5±0.3	1.3±0.3	1.4±0.2	1.1±0.2	0.0±0.0
40%	pos	without	0.9±0.5	1.0±0.3	1.3±0.2	1.3±0.2	1.4±0.2	1.3±0.2	1.1±0.2	0.0±0.0
		with	1.2±0.5	1.3±0.4	1.5±0.5	1.5±0.4	1.4±0.3	1.4±0.4	1.2±0.2	0.0±0.0
	pre	without	0.9±0.6	1.2±0.5	1.3±0.3	1.3±0.3	1.5±0.3	1.3±0.3	1.2±0.2	0.0±0.0
		with	0.1±0.6	1.4±0.4	1.5±0.4	1.5±0.4	1.4±0.4	1.5±0.3	1.2±0.3	0.0±0.0
60%	pos	without	0.9±0.7	1.2±0.5	1.3±0.3	1.3±0.3	1.3±0.4	1.3±0.5	1.1±0.2	0.0±0.0
		with	1.3±0.6	1.4±0.5	1.5±0.3	1.4±0.5	1.4±0.5	1.4±0.5	1.3±0.3	0.0±0.0
	pre	without	1.0±0.8	1.2±0.5	1.4±0.4	1.4±0.4	1.4±0.4	1.4±0.3	1.2±0.3	0.0±0.0
		with	1.5±0.7	1.6±0.6	1.6±0.5	1.5±0.5	1.5±0.4	1.5±0.4	1.3±0.4	0.0±0.0
80%	pos	without	1.2±0.5	1.2±0.4	1.3±0.3	1.3±0.3	1.3±0.3	1.3±0.2	1.1±0.2	0.0±0.0
		with	1.6±0.5	1.5±0.3	1.5±0.8	1.5±0.3	1.5±0.3	1.4±0.2	1.3±0.2	0.0±0.0
	pre	without	1.1±0.7	1.2±0.5	1.3±0.4	1.3±0.4	1.4±0.4	1.3±0.4	1.1±0.3	0.0±0.0
		with	1.5±0.7	1.4±0.9	1.5±0.6	1.6±0.5	1.5±0.5	1.5±0.4	1.4±0.5	0.0±0.0

Table 3: Median frequency RMS for different CIVM levels in the fatigue pre and pos, with and without visual feedback.

Level CIVM	Fatique	Feedback	Median Frequency							
			TA	GL	VL	VMO	RF	BF	ST	TORQUE
20%	pos	Without	103.5±30.8	109.4±25.1	80.1±13.1	76.2±15.0	93.8±15.1	85.9±22.9	89.8±19.1	11.7±5.4
		with	103.5±25.5	113.3±28.4	76.2±13.4	76.2±16.2	93.8±16.0	87.9±18.8	89.8±19.8	11.7±5.5
	pre	without	99.6±28.9	107.4 ±28.5	72.3±16.3	78.1±17.9	89.8±20.2	78.1±19.7	80.1±25.1	11.7±5.9
		with	103.5±27.4	95.7±27.3	76.2±15.6	72.3±15.3	91.8±17.5	84.0±17.7	87.9±20.4	11.7±5.1
40%	pos	without	91.8±24.6	95.7±25.8	84.0±20.9	80.1±18.3	95.7±18.2	93.8±17.1	91.8±21.8	9.8±3.0
		with	93.8±24.6	103.5±29.2	82.0±15.7	80.1±16.6	93.8±19.1	97.7±20.6	95.7±18.9	9.8±3.1
	pre	without	97.7±27.8	89.8±28.6	82.0±18.0	78.1±21.0	91.8±19.1	91.8±17.2	89.8±22.5	9.8±3.5
		with	91.8±26.8	105.5±29.4	76.2±16.9	72.3±18.7	91.8±19.9	87.9±19.2	85.9±23.0	9.8±2.8
60%	pos	without	106.4±30.9	115.2±36.9	85.9±19.6	84.0±17.9	97.7±20.8	100.6±25.6	99.6±23.1	9.8±2.8
		with	107.4±32.1	117.2±31.6	85.0±19.3	81.1±20.1	96.7±19.7	103.5±22.6	101.6±22.9	9.8±2.9
	pre	without	85.9±32.8	107.4±29.3	82.0±21.0	80.1±19.3	95.7±23.3	89.8±23.8	91.8±23.8	9.8±2.3
		with	91.8±28.9	111.3±33.7	84.0±18.1	78.1±17.8	93.8±23.8	91.8±21.7	93.8±27.4	9.8±1.9
80%	pos	without	97.7±36.7	117.2±27.1	84.0±18.1	84.0±18.5	93.8±18.3	103.5±21.7	93.8±18.8	9.8±2.9
		with	93.8±39.1	119.1±27.0	85.9±17.3	82.0±17.3	87.9±20.0	103.5±20.2	91.8±20.3	9.8±2.0
	pre	without	99.6±34.5	117.2±26.6	84.0±16.3	80.1±19.6	93.8±20.9	89.8±21.9	89.8±22.8	9.8±2.0
		with	97.7±29.2	117.2±25.5	80.1±17.4	82.0±17.0	85.9±19.8	97.7±15.0	93.8±23.2	11.7±2.1

We ran ANOVA and found that visual feedback affected the variability ($F(1,282)>16.7$, $p<0.00001$) and the mean activity of all muscles ($F(1, 282)>28.8$, $p<0.00001$). Their variability and means values were higher without feedback information ($p<0.00001$).
After ANOVA, we found that fatigue affected the variability of five muscles (BF, RF, ST, VL, and VMO: $F(1, 282)>4.2$, $p<0.03$). Their variability was higher before fatigue (BF, RF, ST, VL, and VMO: $p<0.04$). Fatigue affected the mean activity of four muscles (BF, ST, RF, VL: $F(1,282)>4.3$, $p<0.03$). Their mean activities were higher before fatigue (BF, ST, RF, VL: $p<0.03$). Fatigue also affected the median frequency of five muscles (BF, GL, ST, VL, VMO: $F(1,282)> 4.5$, $p<0.03$). Their median frequencies were higher after fatigue exercise (BF, GL, ST, VL, VMO: $p<0.03$).
At last, means and variability torque was not affected by fatigue or visual feedback.

DISCUSSION

Our first result is related to feedback information effect. Visual feedback affected means and variability, but median frequency. Those results suggest that when the subjects could not look at the computer monitor to check how much muscle torque they were applying to the machine, they experienced the increase of muscle activation. However, we did not find a

very specific effect of visual information on force control, as Slifkin et al (Slifkin et al, 2000) did. As muscle torque was not affected by feedback, the uncertainty of how accurate they were during the task pushed them to increase the muscle activation and variability to achieve successfully the task. The torque level has remained the same because agonist and antagonist increased their activity. So, the result was not a torque increase, but an increase in knee joint stiffness, to assure the torque accuracy. It means that in accuracy force task, it is required to control the motor activity and not the perceived torque (Toffin, 2003).
As median frequency has remained the same, the numbers of motor units discharging, not the changing the type of motor units, during the task may have increased to support the increase in muscle activation.
For fatigue, we found a selective effect across muscles. Some of them were affected, others not. Three muscles were always affected by fatigue (BF, ST and VL). Meanwhile their means and variability decreased after fatigue, their median frequencies increased after fatigue. As torque levels were not affected by fatigue, the response to achieve accuracy during the task under fatigue effect could be explained as a tentative to decrease the joint stiffness (lower activation) and change the modulation of muscle units discharges (changing median frequency).

CONCLUSION

It was evidenced in the present study that the fatigue and the visual feedback did not affect muscle torque. However, both factors provoke different effects on muscle activity. To be accurate without feedback information leads to a increase in joint stiffness, while to be fatigue leads to decrease the joint stiffness and to change the motor unit discharge.

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