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Feedback information affects accuracy and stability of continuous isometric contraction performed with different target force

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The aim of the study was to establish the effect of visual feedback (VF) on the accuracy and stability of continuous isometric contraction (CIC) performed with different target force (DTF). The subjects were young physically active men (n = 8, age 20.0 ± 1.5 years, height 182.4 ± 6.5 cm, body mass index (BMI) 22.0 ± 1.7 kg/m^2 (mean ± SD)). The subjects performed CIC with 20%, 50% and 70% of the maximum voluntary contraction (MVC) force. Three days prior to the research the subjects had been familiarized with the course of the experiment, their dominant hand and MVC had been established. The experiment was performed after three days of rest. The subjects performed two CICs with 20%, 50% and 70% of MVC force with and without VF. The sequence of carrying out the task for each subject was selected at random.

We found a significant worsening in the accuracy and stability of performing CIC at 20% and 70% of MVC force without VF, and performing the CIC at a small force target without VF the subjects overdosed it, whereas performing the CIC at a great force target the subjects did not reach the level of the force required. Also, with an increase in the percentage of force target with VF, the complexity of the force signal increased.

Key words: motor control, isometric contraction, accuracy, stability, feedback

INTRODUCTION

Accurate development of muscle contraction force is essential for motor control. Performance of a movement is a constant correction of errors allowing for the information about the movement [1–4]. A lot of information from the periphery is simultaneously received by the brain. The accuracy and stability of the movement performed depends on the amount and quality of the proprioreceptive information received. When a movement is being performed without visual feedback (VF), there occurs a decrease in feedback sources, which in turn gives rise to the so-called "noise" of sensor feedback and motor commands, affecting the accuracy of motor performance [5–8, 3, 9–11]. Besides, a person who has not yet mastered a new movement or action is not able to accurately construct a motor program [12], whereas the coordination of agonistic, synergic and antagonistic muscles depends on the accuracy of the motor program that enables a better and more accurate motor performance [13].

The objective of the study was to establish the effect of VF information on the accuracy and stability of continuous isometric contraction (CIC) performed with a different target force (DTF). The hypotheses were as

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follows: a) the absence of VF worsens the accuracy and stability of CIC, b) with an increase in force, the complexity of the force signal also increases. We strived to achieve answers to the following questions that scientists had not raised before: 1) in what way will VF affect the accuracy of CIC performed with DTF? 2) in what way will VF affect the stability of CIC performed with DTF? and 3) in what way will VF affect the complexity of CIC performed with DTF?

MATERIALS AND METHODS

Subjects

The subjects were young physically active men (n = 8, age 20.0 ± 1.5 years, height 182.4 ± 6.5 cm; body mass index (BMI) 22.0 ± 1.7 kg/m^2 (mean ± SD)).

Establishment of maximum voluntary contraction (MVC)

We tested the dominant (right) arm which had been established employing Olfield's questionnaire. The claim back of an isokinetic dynamometer (Biodex-3) was set at the angle of 90° for each of the subjects. The distance between the subject and the screen of the isokinetic dynamometer was 1 m. Contractions were performed in the isometric regimen with the elbow joint fixed at the angle of 80°. While establishing MVC, the subjects were asked to increase the force of arm flexion to the maximum and to maintain this force for 3 seconds. The procedure was repeated three times with 1 min of rest between the repetitions. The subjects were being encouraged constantly and could see on the screen of the isokinetic dynamometer the level of the force generated.

Continuous isometric contraction (CIC)

The subjects had to perform two CICs with VF and without VF. A CIC lasted 13 s, but only data of the last 10 s were analyzed, as during the first 3 s the subjects were allowed to achieve the MVC force required, and they had to maintain this force for another 10 s (Fig. 1).

On the basis of MVC, three values of the force achieved – 20%, 50% and 70% of MVC – were calculated for each subject. The percentage of the force to be achieved and maintained ("target force") was indicated by a horizontal line on the screen of the dynamometer.

The subjects performed CIC with VF, i. e. they could see the CIC on the screen of the Biodex-3 isokinetic dynamometer. When CIC was performed without VF, the screen of the dynamometer was covered.

Experimental protocol

Three days before the research the subjects had been familiarized with the course of the experiment. Their dominant arm and MVC were established. The subjects were tested during the first part of the day. They performed CIC at 20%, 50% and 70% of MVC force. The subjects performed two series of CIC, the duration of each series being 13 s. The sequence of performing the task and the contraction force for each subject were chosen randomly, e. g. CIC 50%, 70% and 20% of MVC force (Fig. 2).

The accuracy of CICs was calculated as the constant error (CE) and absolute error (AE), whereas for estimating the

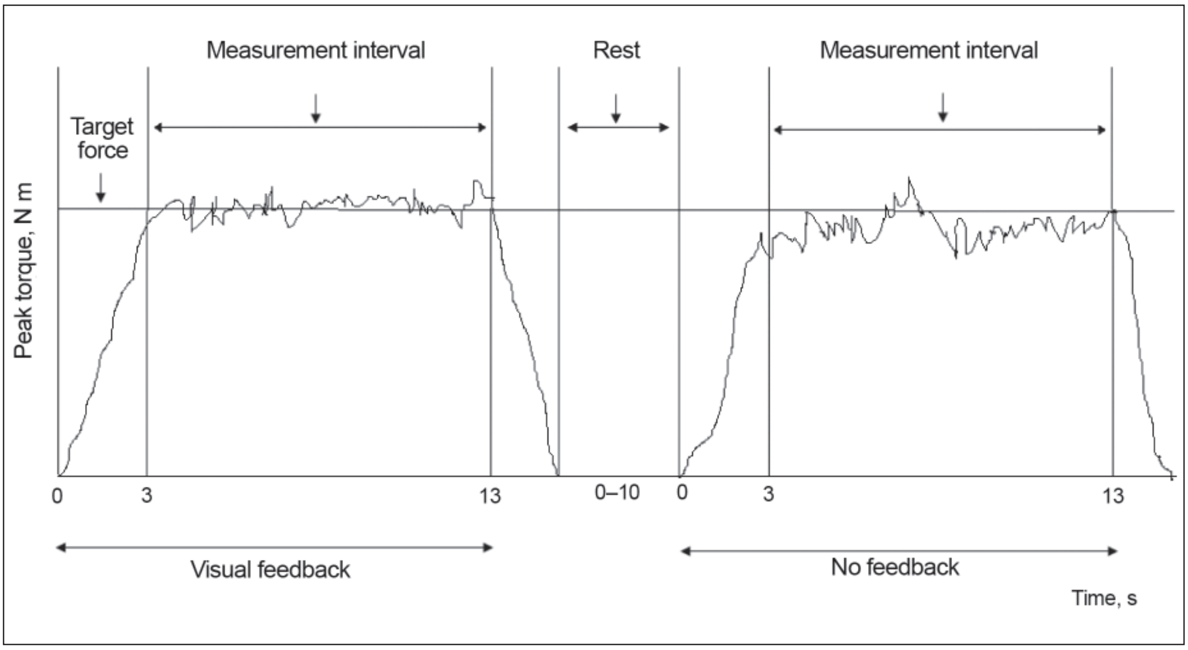

Fig. 1. Continuous isometric contractions performed with and without visual feedback

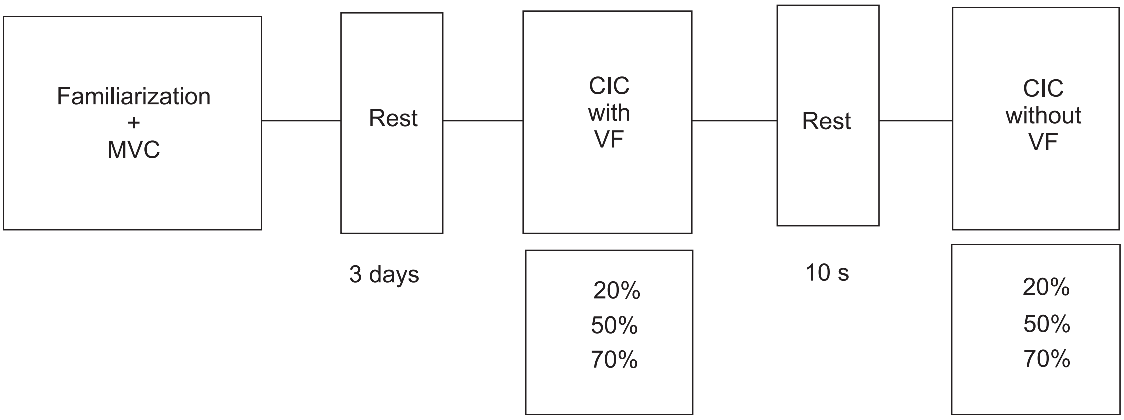

Fig. 2. Study protocol. MVC – maximum voluntary contraction, VF – visual feedback, CIC – continuous isometric contraction

stability of CICs we calculated the standard deviation (SD) (variable error VE and the coefficient of variation CV) [13, 14]. When calculating the size of CE, attention was paid to algebraic signs (±). The AE shows the absolute deviation from the level of the target force required (in this case, 20%, 50% and 70% of the isometric force were required):

constant error = $\Sigma (x_i - T) / n$,

where x_i is the CIC performed (N · m), T is the target quantity, i. e. the CIC quantity required, n is the number of trials the subject performed; round brackets (Σ) indicate that the mean was calculated considering the algebraic signs (±);

absolute error = $\Sigma |x_i - T| / n$,

where x_i is the CIC performed (N · m), T is the target quantity, i. e. the CIC quantity required, n is the number of trials the subject performed; vertical brackets $|x_i - T|$ indicate that the mean was calculated without considering the algebraic signs (±);

standard deviation (variable error) =

$$\sqrt{\sum_i (x_i - \bar{x})^2 / n},$$

where x_i is the CIC performed (N · m), CE_{mean} is the mean constant error, n is the number of trials the subject performed;

coefficient of variation (normalized variable error) = $(SD \div \bar{x}) \times 100$,

where SD is the mean standart deviation of CIC performed, and $\bar{x}$ is the CIC mean (N · m).

The structure of force variability was examined by using permutation entropy (PE). We calculated PE from a time series of 1000 data points with parameters $n = 3$ and the time lag $\tau = 1$ as recommended by Bandt and Pompe [15]. The PE can take values from zero (for an increasing or decreasing sequence of values) to log $n! / (n - 1)$ (for a completely random system where all $n!$ possible permutations appear with the same probability), where n is the order of permutation. A high value of PE reflects a low degree of regularity.

Data analysis

The values were expressed as the mean ± standard deviation (Sx). The effect of error type and target force level was calculated by two-way ANOVA. The p values of the post-hoc analysis were adjusted for multiple comparisons and presented at three different levels: <0.05, <0.01 and <0.001.

RESULTS

The effect of visual feedback and different "target force" on the size of constant and absolute errors

When the subjects had been asked to perform CIC with VF with different force, they performed CIC with 20% MVC force with 19.8 ± 0.4% force, 50% with 49.3 ± 0.4% force and 70% with 69.2 ± 0.7% force, respectively. When the subjects did not see the CIC performed on the screen of the dynamometer and could not adjust it, they performed CIC with 20% MVC force with 21.3 ± 2.7% force, 50% with 49.9 ± 5.3% force and 70% with 66.1 ± 4.2% force, respectively. The difference between the "target force" and the force achieved by the subjects was greatest while performing CIC with 70% MVC force without VF (see Table 1).

Table 1. **Difference between the "target force" and the force achieved (%)**

With visual feedback			Without visual feedback		
20%	**50%**	**70%**	**20%**	**50%**	**70%**
–1.2 ± 2.1	–1.4 ± 0.8	–1.2 ± 1.0	4.8* ± 13.2	–1.6 ± 11.2	–6.2* ± 6.8

* – $p < 0.01$, comparing data on the "target force" and the force achieved ($\bar{x} \pm Sx$).

Data in Fig. 3 demonstrate the influence of visual feedback information on the CV of absolute error. The CV was significantly lower when CIC was performed without visual feedback information with small (20%) and high (70%) strength.

Effects of visual feedback and different "target force" on isometric force variability

The CV of CIC performed with a different target force is shown in Fig. 4. It is of interest that there was the greatest CV at the 50% of force target when the CIC was performed without VF, while the CV was smallest when the CIC was performed at the same level of target force with VF. There was a significantly greater SD as well as CV of CIC performed at all levels of MVC without VF than with VF ($p < 0.05$).

The effect of visual feedback and different "target forces" on the results of permutation entropy

The permutation entropy significantly increased from 20 to 50% force target (Fig. 5). There was a significant ($p < 0.01$) increase in permutation entropy when CIC was performed with 20% force without VF than with VF.

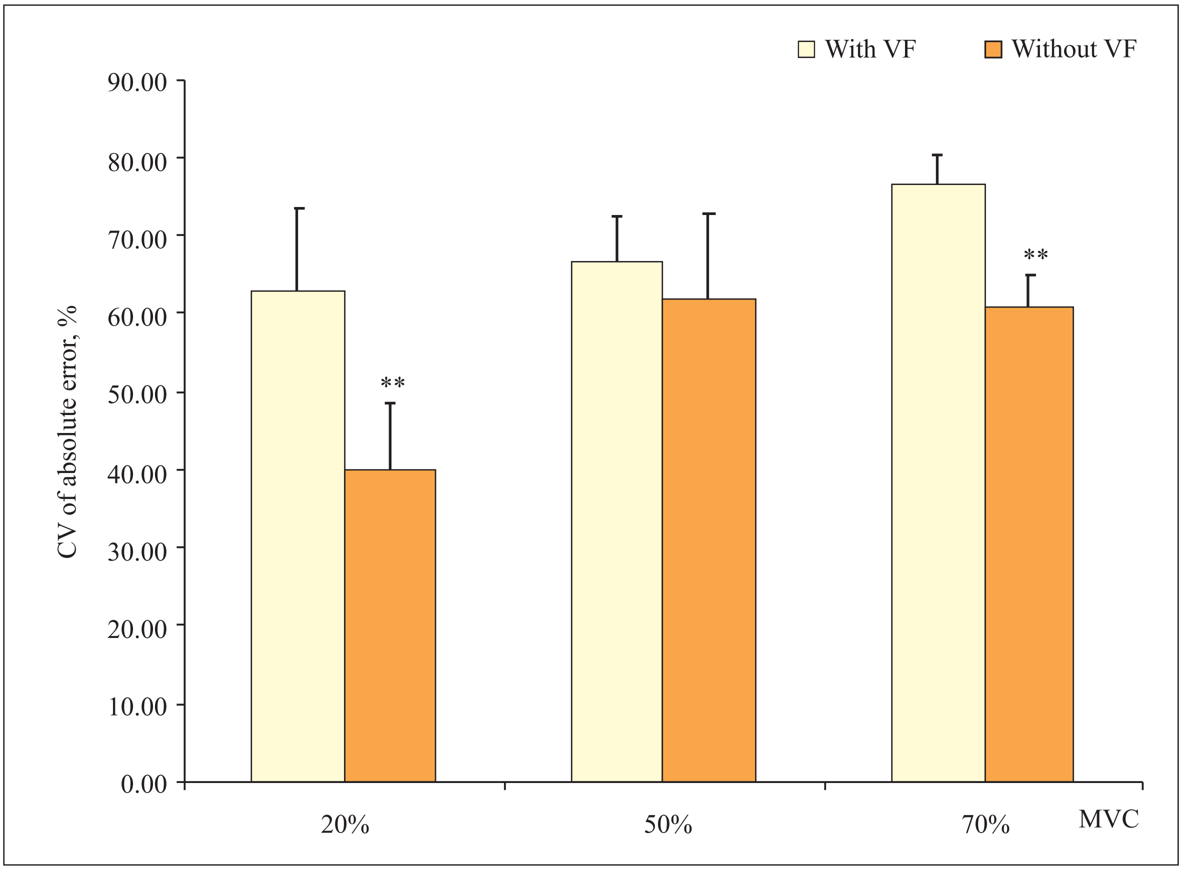

Fig. 3. The effect of visual feedback on the coefficient of variation of absolute error in the case of CIC performed with different force. ** – $p < 0.001$, comparing the results of the CIC performed with and without visual feedback (VF) information ($\bar{x} \pm Sx$)

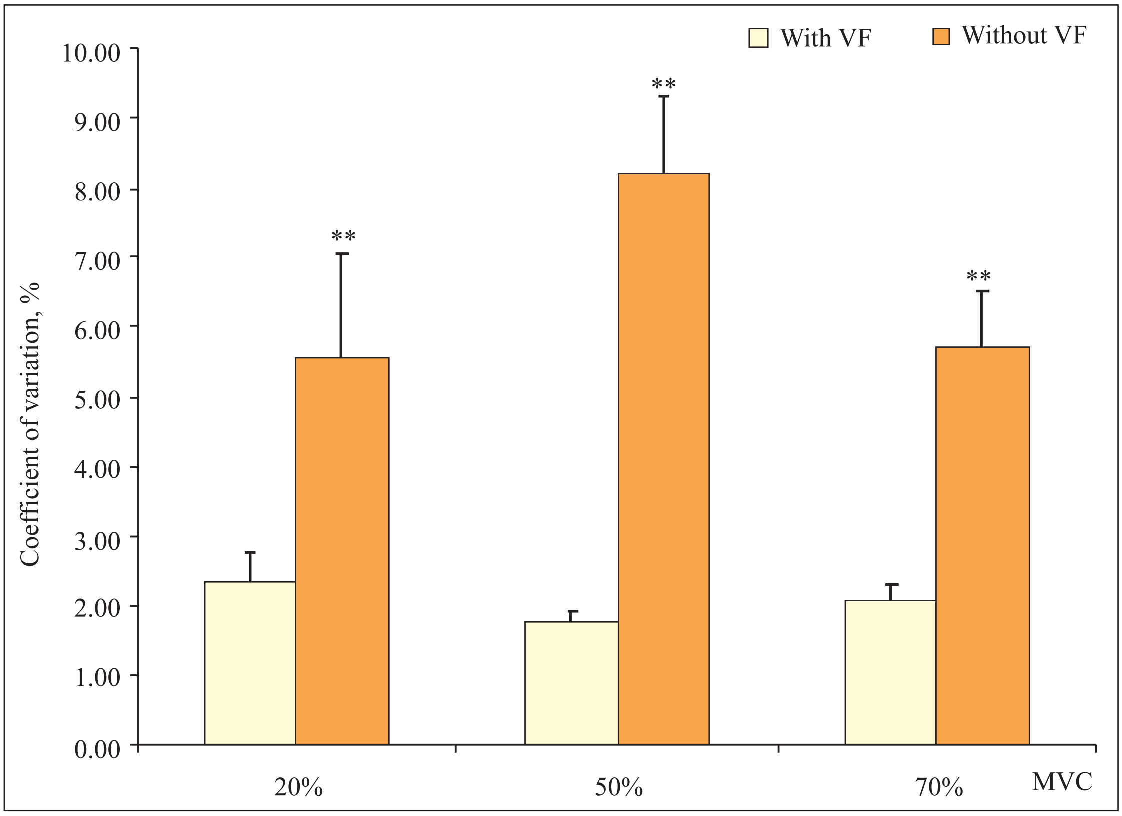

Fig. 4. The effect of visual feedback on the size of coefficient of variation in the case of CIC performed with different force. ** – $p < 0.001$, comparing the results of the CIC performed with and without visual feedback (VF) information ($\bar{x} \pm Sx$)

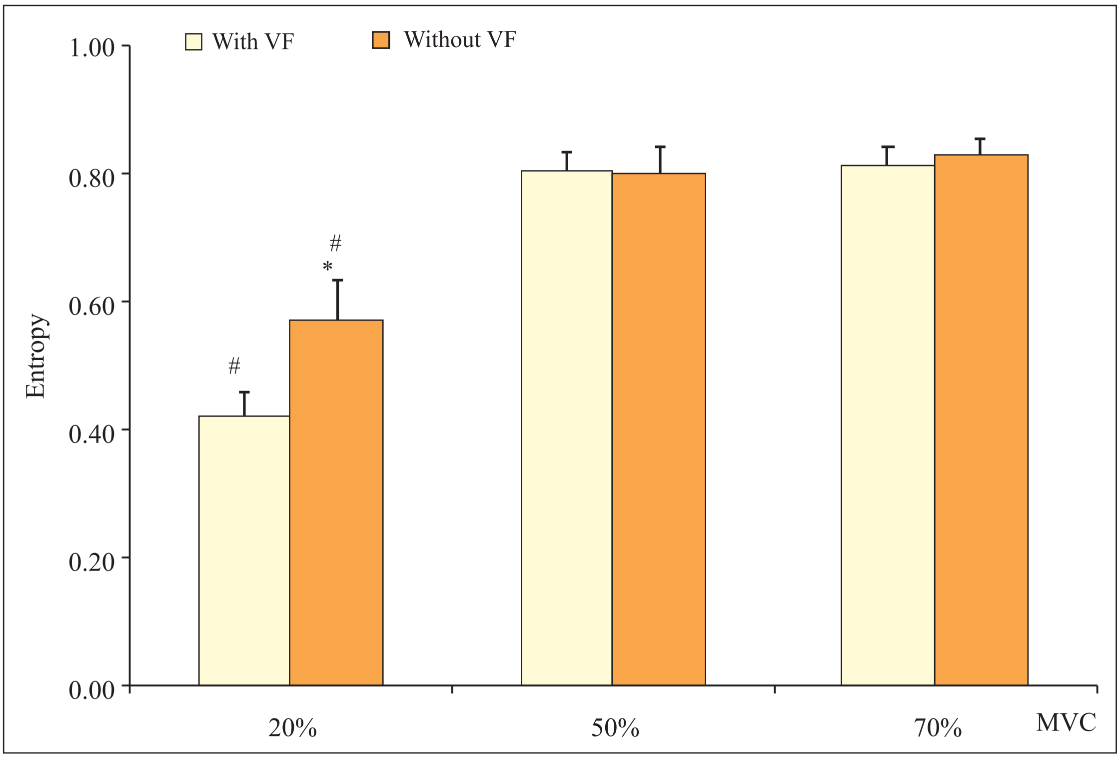

Fig. 5. The effect of visual feedback information (VF) on the size of entropy in the case of CIC performed with different force. * – $p < 0.01$, comparing the results of the CIC performed with and without visual feedback (VF) information; # – $p < 0.001$, comparing the results of the CIC performed at 20% with those performed at 50% and 70% of maximum voluntary contraction (MVC) with and without VF ($\bar{x} \pm Sx$)

Subjects performing CIC with a different target force without visual feedback information maintained a similar style of performance (Fig. 6). A strong correlation was found between CICs performed with different force (Table 2).

DISCUSSION

There are three main findings of this study: a) there is a significant worsening in the accuracy and stability of performing CIC at 20% and 70% MVC force of without VF; b) while performing CIC at a small force target (20% MVC) without VF, the subjects overdose it, whereas while performing CIC at a great force target (70% of MVC) the subjects did not reach the level of the force required; c) with an increase in percentage of force target with and without VF, the complexity of the force signal increased.

The accuracy and stability of CIC is worse without visual feedback

We have found that there was a greater accuracy and stability in maintaining the force required when CIC was per-

Table 2. **Correlation of different force isometric contraction**

	Constant error		Absolute error	
	with VF	without VF	with VF	without VF
20–50%	0.63	**0.85**	–0.60	0.46
20–70%	0.16	**0.84**	0.26	**–0.90**
50–70%	–0.35	**0.92**	–0.49	–0.52

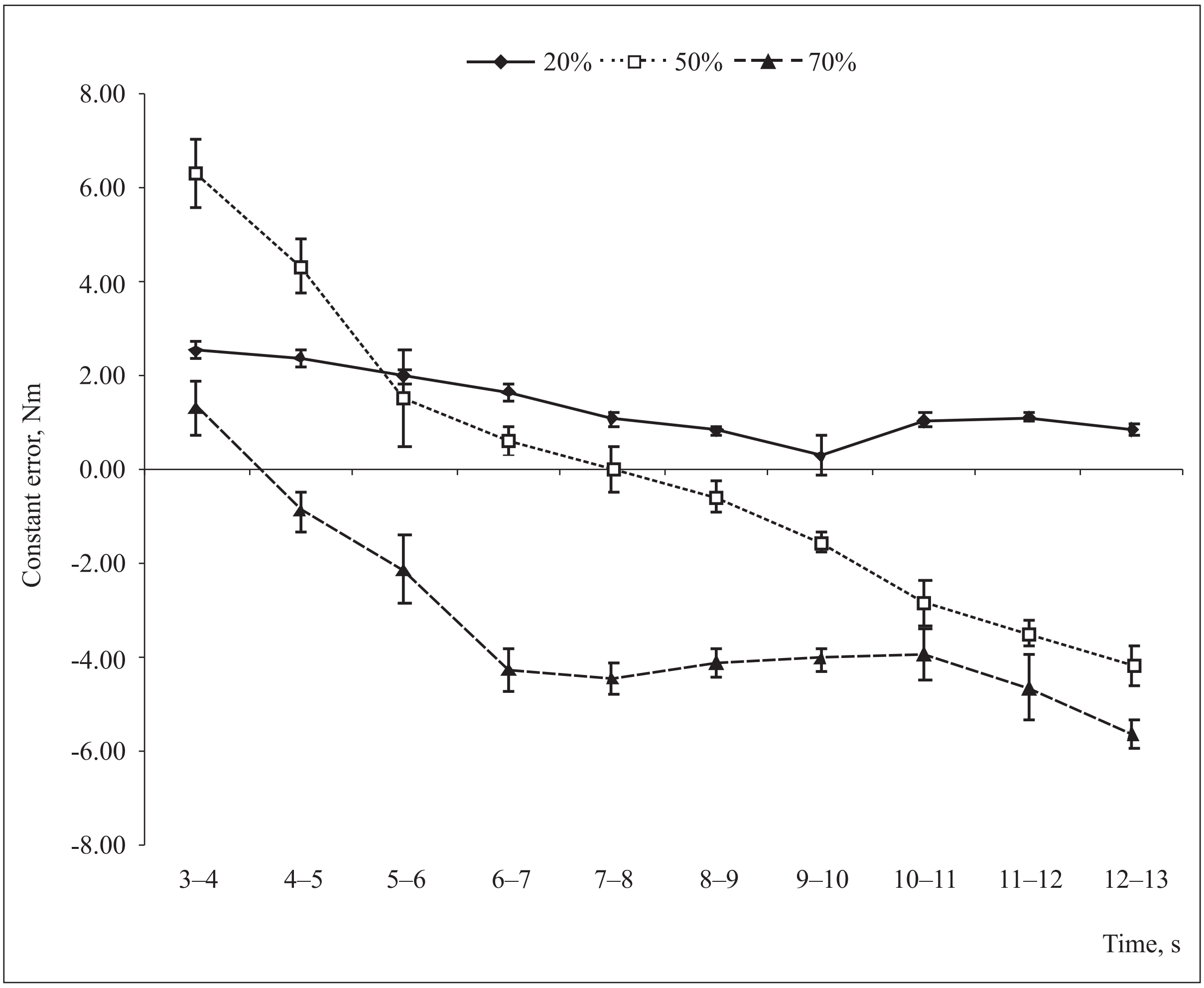

Fig. 6. Changes of CIC constant error without visual feedback information, performed with different force

formed with VF. These results are opposite to the results reported by Tracy [16] who showed that the reduction in fluctuations without VF was significant across a large range of target forces. VF is of special importance in a continuous maintenance of muscle force [17, 18]. The absence of VF increased the number of absolute (constant and variable) errors (AE) because CIC performance without VF decreased the possibility of the neuro-muscular system to make use of the feedback received from vision receptors, i. e. the information that would enable one to perform corrections during CIC itself [19, 20]. Variability is frequently defined as an index of stability of the sensory-motor system [10, 21]. Consequently, the smaller variability of the movement, the greater is stability. Analysis of our data show that doing exercise without VF the subjects performed CIC with a considerably lower stability. The standard deviation of torque increased non-linearly with the force level and decreased with visual gain, and the CV decreased with the force level and visual gain [17].

The standard deviation of the task-related force output increased exponentially with the force level [22, 23]. The variability of a CIC has been best defined as a "sigmoidal logistic function" [24–26]. The variability of muscle force depends on two basic mechanisms which are the number of recruited motor units and their discharge frequency [26, 27]. Thus, Jones et al. [28] have made a conclusion that the variability of an isometric force signal is dependent rather on the variability of motor units than on the "noise" variability of motor command. The findings from these separate studies on different subjects indicate that force fluctuation depends on the muscle force level, the type of contraction and on the muscle group [16, 27, 29].

It is known that the movement is performed with a feedback, and when it lasts over 150 ms the proprioceptive information allows corrections to be performed during the movement [14, 30]. Information about the movement performed is received from a number of feedback sources: a) the brain (efferent copy); b) the muscles; c) the tendons; d) the joints; e) the skin, and f) the eyes [31–34]. When the movement is performed without VF, there occurs a decrease in the number of feedback sources and there arises the so-called sensory "noise" of feedback and motor commands, which affects the accuracy of motor performance [5–11, 35]. When a person performs new, not yet fully mastered movements, he / she is more dependent on feedback [36–40]. Besides, a person who has not yet mastered a new movement or action is incapable of accurately building up a motor program [12].

While performing CIC with a small force the subjects overdosed it, i. e. generated a greater force than required, whereas when performing CIC with a greater force the subjects did not achieve the level of the force required. This circumstance could be explained by the fact that an increase in force is accompanied by an increase in the number of motor units recruited and in the frequency of their discharge rate, i. e. by increasing voluntary efforts ever bigger and stronger motor units are being involved. We might only speculate that the disturbance of feeling the effort depends on the target force level when VF is absent. The neurophysiological basis of these results remains to be elucidated. The activity of motor units (discharge frequency and recruitment) may by influenced by various signals coming from the periphery, i. e. from the receptors located in the muscle spindles, tendons (Golgi tendon organs), joints and skin [41]. Some signals (e. g. signals coming from muscle spindles) stimulate, while others (e. g. arising from Golgi tendon organs) inhibit the function of motor units, and this may influence the accuracy and alteration of the movement performed.

Effect of VF and force target on permutation entropy

With an increase in the level of force, a model of the approximate entropy of force response shaped as an inverted "U" was established [22, 24]. The approximate entropy of the force output did not change as a function of the force level [17]. However, in our case, there were no changes in permutation entropy while performing CIC with 50% and 70% of MVC force. The results of our research have shown that there occurs an increase in permutation entropy while performing CIC with up to 50% of MVC force, and later no changes have been registered. While performing movements with visual feedback, the variability of the force signal is of a more complex nature [17, 18, 42]. An increase in entropy while performing an isometric muscle contraction with VF contradicts the data of our research which indicate entropy to be greater in the case of performing CIC with 20% of MVC force without VF than with VF. These discrepancies might be explained by the specific character of permutation and approximate entropy.

CONCLUSIONS

We have found a significant worsening in the accuracy and stability of performing CIC at 20% and 70% of MVC force without VF, and while performing CIC at a small force target without VF the subjects overdosed it, whereas when performing CIC at a great force target the subjects did not reach the level of the force required. Also, with increasing the percentage of the force target with VF, the complexity of the force signal increased.

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VAIZDINĖS GRĮŽTAMOSIOS INFORMACIJOS IR SKIRTINGOS PROCENTINĖS JĖGOS ĮTAKA NENUTRŪKSTAMŲ IZOMETRINIŲ SUSITRAUKIMŲ TIKSLUMUI IR STABILUMUI

Santrauka

Tyrimo tikslas – nustatyti vaizdinės grįžtamosios informacijos (VGI) ir skirtingos procentinės jėgos (SPJ) įtaką nenutrūkstamų izometrinių susitraukimų (NIS) tikslumui ir stabilumui. Buvo tiriami aštuoni jauni fiziškai aktyvūs vyrai (n = 8; amžius 20,0 ± 1,5 m; ūgis 182,4 ± 6,5 cm; kūno masė 73,0 ± 5,7 kg; KMI kūno masės indeksas 22,0 ± 1,7 kg/m^2 (vid. ± SD)). Tiriamieji atliko nenutrūkstamus izometrinius susitraukimus 20 %, 50 % ir 70 % jėga nuo maksimalios valingosios jėgos (MVJ). Prieš tris dienas iki tyrimo tiriamieji buvo supažindinti su tyrimo eiga, buvo nustatyta jų dominuojanti ranka ir MVJ. Po trijų dienų poilsio tiriamieji atliko pagrindinį eksperimentą – du nenutrūkstamus NIS su ir be VGI, kuris truko 13 sek., tačiau buvo analizuojami tik paskutinių 10 sek.

duomenys, nes per pirmąsias 3 sek. tiriamiesiems buvo leidžiama pasiekti reikiamą jėgą nuo MVJ ir ją išlaikyti likusias 10 sek. Užduoties atlikimo eiliškumas kiekvienam tiriamajam buvo parenkamas atsitiktiniu būdu.

Nustatėme, kad be vaizdinės grįžtamosios informacijos atliekamų nenutrūkstamų izometrinių susitraukimų tikslumas ir stabilumas reikšmingai pablogėjo: tiriamieji šiuos susitraukimus maža (20 %) jėga perviršija, o didele jėga (70 %) nepasiekia reikiamos jėgos dydžio. Taip pat nustatėme, kad didėjant atliekamos jėgos dydžiui, didėja ir jėgos signalo kompleksiškumas atliekant nenutrūkstamus izometrinius susitraukimus su vaizdine grįžtamąja informacija.

Raktažodžiai: judesių valdymas, izometriniai susitraukimai, tikslumas, stabilumas, grįžtamoji informacija