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EFFECTS OF SUPERIMPOSED SUBMAXIMAL ELECTRICAL STIMULATION ON EXPLOSIVE MOVEMENTS DURING FATIGUE

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VPLIV DODATNE PODPRAŽNE ELEKTRIČNE STIMULACIJE NA EKSPLOZIVNA GIBANJA PRI UTRUJENOSTI

Abstract

The aim of the study was to evaluate the influence of superimposed electrical stimulation (ES) of muscles on movements during fatigue. Ten male students of physical education performed a series of maximal explosive pushes with the right arm against weight in a vertical direction. A specially constructed apparatus was used to control both the loads and direction of the movements. The pushes against 66 % of maximal voluntary isometric force (MVC) load were executed every two seconds. When fatigue was observed (after 8 to 12 pushes) a superimposed ES of m. triceps brachii (MTB) was performed for the next two pushes. The vertical forces acting on the weight were recorded for the first push, the last push before ES, the push in the middle between these two and for both pushes with ES. Results showed that dynamic force peaks, as well as force impulses in the first 200 msec after the force onset, were strongly influenced by fatigue. On the other hand, the maximal vertical velocity of the weight at the first push with ES was significantly greater ($p < 0.01$) than for those before. The greatest effect was observed during the second half of the movement at high elbow extension. In the first pushes (with no fatigue) the first part of the workout seemed to be more important, while with fatigue and especially during ES, the force impulses were distributed more equally throughout the whole path which caused the greater maximal velocity at the end. It was concluded that superimposed ES of MTB effected maximal explosive movements.

Key-words: arm extension, electrical stimulation, intermuscular coordination, movement velocity, fatigue

Izvleček

Namen naloge je bil ugotoviti vpliv dodatne električne stimulacije (ES) mišic na gibanje v utrujenosti. Deset študentov športne vzgoje je izvedlo serijo najbolj eksplozivnih iztegovanj desne roke z obremenitvijo v navpični smeri. Uporabljena je bila posebej izdelana upornica za kontrolo bremena in smeri gibanja. Breme je znašalo 66% največjega izometričnega bremena, iztegovanja pa so bila izvedena vsaki 2 sekundi. Ko je nastopila utrujenost (po 8 do 12 ponovitvah), so bili merjenci pri naslednjih dveh iztegnitvah stimulirani (m. biceps brachii - TB). Vertikalne sile, delujoče na breme, so bile izmerjene pri prvi in zadnji iztegnitivi, iztegnitvi na sredi med njima in pri obeh z ES. Rezultati so pokazali, da sta bili največja dinamična sila ter impulz sile v prvih 200 ms močno pod vplivom utrujenosti, medtem ko se je največja vertikalna hitrost bremena pri uporabi ES povečala ($p<0.001$). Največji vpliv ES je bil opazen v drugi polovici giba, pri iztegnjeni roki. Pri prvih iztegnitvah (brez utrujenosti) se zdi prvi del giba pomembnejši, medtem ko je bila pri utrujenosti in še posebej pri ES porazdelitev impulza sile enakomernejša, kar je prispevalo k večji končni hitrosti giba. Mogoče je zaključiti, da dodatna ES mišic vpliva na najbolj eksplozivne gibe v utrujenosti.

Ključne besede: iztegovanje roke, električna stimulacija, medmišična koordinacija, hitrost gibanja, utrujenost

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Introduction

The inability to sustain the same force level during continuous muscular contraction, or decreasing maximal force level during repeated contractions are the most typical signs of fatigue. There are numerous mechanisms underlying fatigue which can be considered as a command chain for muscular contraction (5). According to their positions in that chain, they have been classified into central and peripheral mechanisms (2). It is not only the force level that is subject to fatigue but also the slope of the force-time curve in explosive movements is affected (17).

In brief, explosive muscular contractions, motor units are activated for a short period of time with a burst of neural impulses with a firing frequency which may exceed 100 Hz (6). It is not important just to reach as high a firing frequency as possible, but also to spend the minimum possible time to reach it (13). Another important feature is the synchronization of motor units, to contract in parallel and not in their normal sequence (8, 9). In movements where the goal is to achieve the highest speed at the end of the path, great attention should be given to intermuscular coordination, especially when more muscle groups are involved (13, 11).

Duchateau and Hainaut (3) stated that intracellular processes play the major role in contractile failure during sustained and intermittent contractions. They found also that the nerve conduction velocity is not reduced in intermittent contractions. However, in voluntary contractions there are not only physiological factors that influence the activation of motor units, but also psychological ones, which act on motor centres in the cortex.

The purpose of this study was to examine the influence of superimposed electrical stimulation of muscles on the explosive movements during fatigue to observe the effect of improved central neural drive to muscle. In order to explore this effect, a submaximal cutaneous ES of m. triceps brachii (MTB) was employed during a vertical push against a weight.

Methods

Ten male students of physical education (age: 25 ± 3.8 years, height: 179 ± 4.2 cm, weight: 74 ± 5.5 kg) volunteered for the study. All subjects were fully informed of the procedures and possible risks involved in the study. They gave a conscious consent to their engagement.

Each subject performed a series of maximal explosive vertical pushes against a weight in a specially constructed apparatus (16). They laid on their backs with a 90 degree angle between the trunk and the upper arm and the lower arm perpendicular to the upper arm. Loads were adjusted to 66 % of the subjects' maximal voluntary isometric force. They executed a single push every two seconds. After fatigue was observed as an inability to start moving the weight with the same starting acceleration as in the beginning (after 8 to 12 pushes) a superimposed submaximal electrical stimulation of MTB was introduced for the next two pushes.

The subjects were instructed to give their maximum for every single push and were encouraged during the whole workout to do so. The return of the weight into the starting position was done with the same arm, slowly and without any external help. The start of the workout was controlled by an electronic counter, set to send a beep sound every two seconds. An experimenter encouraged each subject during the whole series. Every subject was informed about the start of ES. Before testing, a warm-up procedure was performed.

A FES electrical impulse generator (Gorenje, Velenje, Slovenia) was employed for direct electrical stimulation of MTB. The anode (15 X 5 cm) was placed proximally and the cathode (8 X 5 cm) distally over the muscle. Unimodal, square wave, constant current impulses, at a frequency of 50 Hz were given. The train of impulses lasted for 1 sec. The amplitude (in mA) was set individually to be a little over the motor threshold. The impulse generator was manually triggered at the beep sound.

The vertical force acting against the weight was recorded with a piezo sensor placed into the load's handle. The force signal was amplified, digitized and processed with a PC (sampling frequency 500 Hz). From force-time curves (F(t)) the maximal dynamic force during each single push (MDF) was evaluated. With a numerical integration of force-time curves over the first 200 msec, after the force onset, the start impulses (SI) were calculated. The maximal vertical velocity during each single push (MVV) was calculated, according to the following equation:

$$MVV = 0.002 * m^{-1} * \Sigma (Fi - m) \qquad i = s,..,e$$

s,e = start and end of time interval,
m = mass of the weight, Fi = vertical force

Data was collected for the first push (P1), the last push before ES (P3), the push between these two pushes (P2), the first push with ES (P4) and the second push with ES (P5). The mean F(t) curves for the target pushes were also calculated.

For every single push and every single variable, the mean and the standard deviation of all ten subjects were calculated, as well as a T-test for paired samples between pushes for every variable. Statistical significance was set to the 5 % level of alpha error.

Results

Figure 1 shows the mean F(t) curves for the single pushes. Two clusters of curves could be seen, one representing P1 and P2 and the other P3 to P5. The starting impulses (Fig. 2) of the first two observed pushes differed significantly from the others. P1 had a lower, although nonsignificant, value than P2. There was a scarcely visible, nonsignificant difference (46.75 and 46.27 Ns) between P3 and P4, which represented the voluntary activation and the voluntary activation with superimposed ES. Maximal dynamic forces during pushes (Fig. 3) showed slightly different relations than those in figure 2, since P2 was lower than P1. An absolute decline of 7 % between P1 and P5 was observable. All differences, except P1-P2 and P3-P4 were statistically significant. Completely different behaviour was seen in the maximal vertical velocities (Fig. 4). At P4 (first push with ES) subjects reached the highest velocity. The only statistically significant difference was that between P3 and P4, where also an extremely high correlation was observable (r= 0.999). The statistical significance between pairs of pushes for all variables are shown in Table 1.

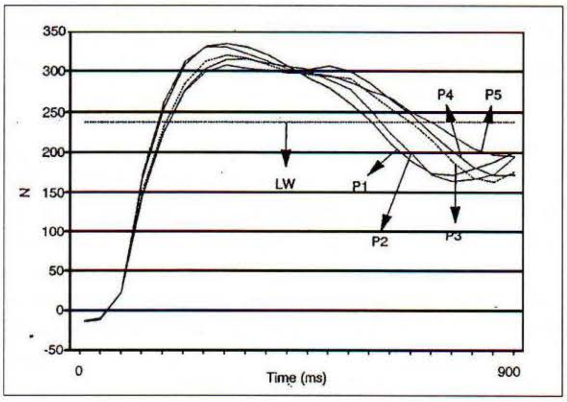

Figure 1.
Mean force-time curves for 10 subjects synchronized at 5N level at the force onset. The symbols represent: P1 to P5 are corresponding pushes (see text for explanation), LW is load's weight.

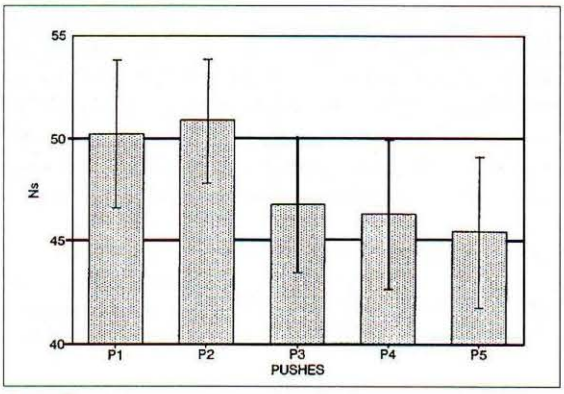

Figure 2.
Mean starting impulses in Ns and their standard deviations at the first 200 ms after force onset.

Table 1. Levels of statistical significance of force parameters between pairs of pushes

	P1-2	P2-3	P3-4	P4-5
SI	0.75	0.01	0.51	0.41
MDF	0.34	0.01	0.13	0.18
MVV	0.89	0.43	0.00	0.28

Table 1.
Statistical significance (two-tailed P value) of paired T-test between pairs of pushes for single variables (P1-2 represents the pair P1 and P2). SI - starting impulse, MDF - maximal dynamical force, MVV - maximal vertical velocity.

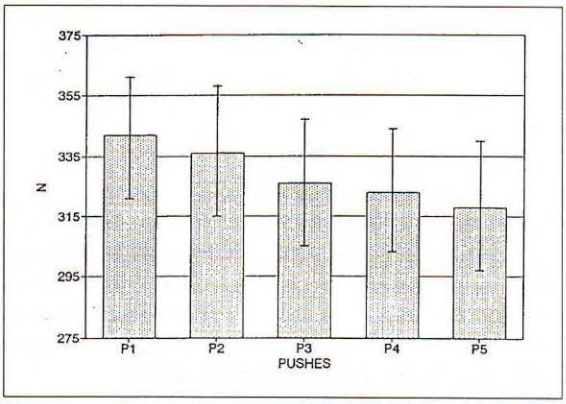

Figure 3.
Mean maximal dynamical forces in Newton and their standard deviations.

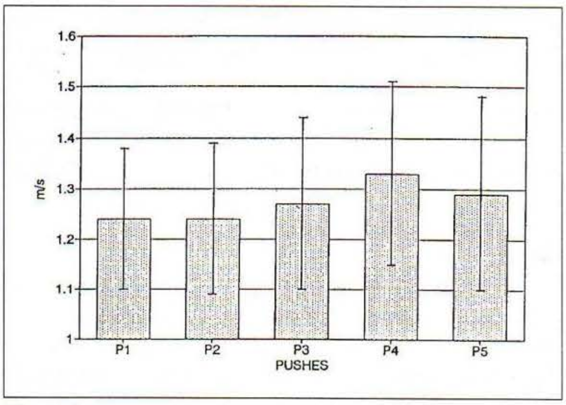

Figure 4.
Mean maximal vertical velocities in m/s and their standard deviations.

Discussion

It was expected that superimposed ES of MTB during fatigue could benefit all the observed parameters. The results show, however, that superimposed ES had no significant effect on MDF and SI. The behaviour of the latter is slightly different from MDF, with a peak seen for the second measured push, which may be explained by neuromuscular facilitation (14) and is also in agreement with other investigators (17). Both parameters were obtained at the very beginning of the movement. In this phase MTB is not the prime mover (7), so the eventual gain of its force may not be necessarily observable. On the other hand, this early phase of the push shows a significant decrease in observed MDF and SI. It is hard to say which mechanisms were dominant, causing fatigue, because there was no additional monitoring. There are many possible fatigue mechanisms (4), but it seems that the energy resources should not have a decisive role (1). However, this fatigue may be attributed to the proximal part of the kinetic chain (m. pectoralis major, m. deltoideus).

The most impressive results were obtained from the maximal velocities of the weights. They can be divided into two parts: without and with superimposed ES. For the first three pushes, relatively constant maximal velocities are observable, even though the other two parameters show significant negative tendencies. Due to these changes the maximal velocity should decrease as well. Since the maximal velocities remain quite unchanged, it may be speculated that there is a velocity – limit of muscle shortening, which may be responsible for a rested muscle being unable to overcome a certain velocity even if there is still some acceleration path left. This means that the same velocity can be obtained in fatigue also, but with less acceleration and a longer acceleration path. It may also be concluded that the time needed to pass the distance, is more subject to fatigue, than the maximal velocity itself (13).

The most interesting result of this study is the maximal velocity gain during P4 and the lesser one during P5. This can be mainly contributed to the superimposed ES of MTB. With the means of ES it is possible to activate more motor units and/or cause them to work at higher firing frequencies. Fast motor units have a higher activation threshold and normally may not be fully voluntary activated. The superimposed ES helps to activate primarily this type of motor units and thus increase the ratio of activated fast to slow - twitch motor units. The result may be higher maximal velocity of the weight (19). Of course, these results may be also influenced by motivation, but this seems less likely. One reason is that the subjects were encouraged throughout the whole series of pushes and the other is an extremely high correlation in maximal velocity between P3 and P4. There is no strait explanation for decreasing in MVV from P4 to P5. It seems that both, an exhaustion as well as a fall of concentration after P4, might explain that.

There is a considerable observable qualitative change in force production, between the first and the second half of the push, during fatigue and superimposed ES. The second half dominates, which implies changes in intermuscular coordination. It is possible to conclude that the role of MTB becomes a crucial one during fatigue. With the extension of the elbow, the effect of superimposed ES on MTB was increased (18).

There are also biomechanical reasons for greater force during the second half of the push. The velocity at the end of the first half of the push was smaller in each next push. According to Hill's equation (10), a muscle can produce greater force at lower velocity. With greater force a MTB tendon is additionally stretched, which may cause greater maximal velocity of the weight (12). But it does not seem to play a substantial role in velocity improvement, because of the relatively small force changes.

It is also worth to mention that the contraction times were of sufficient length (average 0.45 – 0.60 sec), to permit application of full contractile capability, even in fatigue. With lower weights these times would be much shorter, which might cause different courses of the maximal velocities.

It is concluded that superimposed ES of MTB has a positive effect on maximal explosive vertical pushes in fatigue. There is no evidence of its influence on the first half of the push. The main result is a greater maximal velocity of the weight, as the superimposed ES of MTB was introduced. With superimposed ES, the force level during the second part of the push was greater and took a longer time course. The reason for these improvements may lie in a greater activation of MTB through superimposed ES. Since the muscles' activation is one of the factors that may be effectively trained in relatively short period of training (15), this may find its practical application in sports training, especially, when such artificial additional muscle's activation is employed as a diagnostical tool for the muscle's activation assessment.

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