THE MECHANICSANDNEUROPHYSIOLOGYREASON OF THECHARACTERISTICS OF THE BILATERAL EFFORT

Abstract of the PhD thesis

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INTRODUCTION

Henry and Smith published in 1961 for the first time that maximal force of a muscle produced during unilateral contraction is higher than during bilateral simultaneous contraction of the same muscle. This difference is called bilateral force deficit, and for a long time it was thought to be applicable in all cases. Nowadays, it is almost completely accepted that bilateral deficit has mainly neural causes. It is thought that neural inhibition is in the background of decreased force during bilateral simultaneous contraction of the same muscle group. Neural inhibition may be cortical, subcortical, supraspinal, and/or spinal.

According to the researchers, the following factors are responsible for the development of the deficit: (1) excitability of the fast motor units of the dominant extremity decreases during bilateral contraction; (2) turning on the large, fast motor units is more difficult during bilateral contraction, and it becomes even more difficult when the muscle is tired; (3) disorder of reflexes inducing spinal inhibition; (4) decreased neural control, decreased excitability of motor units; (5) divided attention and inhibition between hemispheres, and limitation of their synchronisation.

However, studies did not investigate how the activity of muscles changes during different ways of relaxations or contractions of a unilateral muscle. Almost every study analyses unilateral and bilateral forces separately, but the transition from bilateral to unilateral or from unilateral to bilateral contraction were not studied. Only van Dieen et al (2003) studied the phenomenon with connecting the contractions, but only focusing on the changes in maximal force. They thought that unilateral relaxation following bilateral contraction causes increased contraction in the contralateral muscle, and contraction of the contralateral muscle following maximal unilateral contraction results in decreased contraction. This study indirectly proved that decreased and increased muscle force is caused by inhibition between motor cortex and the lack of inhibition between motor cortex. However innovative and unique their approach was, changes in muscle tension and EMG activity during the transition period were not investigated. We suggest that analysing the changes during the transition period brings us closer to solving the problem and can provide new evidence in understanding the connection between the two cerebral hemispheres. Therefore, in our study bilateral and unilateral transitions were investigated in subjects with no bilateral deficit and in subjects with bilateral deficit.

OBJECTIVES

The following hypotheses were created before the first study:

1.1. When bilateral force deficit is not seen in the case of separate contractions, transition from bilateral contraction to unilateral force causes a short latency transient change during the transition period.

1.2. Time course of the relaxation of the contralateral muscle causes various short latency temporary changes in the unilateral torque following bilateral contraction.

1.3. The time course of transition from bilateral to unilateral contraction does not affect the long latency response of the muscle remaining in contraction. Namely the unilateral torque will not be higher than the torque value measured during the separate unilateral and bilateral contractions.

The following hypotheses were created before the second study:

2.1. The bilateral torque deficit is related to the electromyography activity (EMG) deficit of the knee extensors. The direction and the extent of the changes in torque and EMG are the same in the case of linked unilateral-bilateral contractions and transition periods indicating neural control.

2.2. Study subjects with bilateral force deficit detectable with standard study procedures, bilateral and unilateral torque difference persists in case of combined bilateral and then unilateral contractions, and changes depending on the EMG activity of the muscle.
2.3. The unilateral torque is not higher than the difference between the unilateral and bilateral torque values measured by standard study procedures in case of transition from bilateral contraction to unilateral contraction. There is no difference in the changes in torque and EMG during the transition period between the non-dominant and dominant sides.
2.4. In case of unilateral contraction followed by bilateral contractions, the muscle starting the contraction later will have a higher torque. There will be a larger decrease in the torque value and EMG activity in case of unilateral contraction of a muscle on the dominant side following bilateral transition compared with the non-dominant side.
2.5. In the bilateral-unilateral-bilateral contraction model, the torque and the EMG activity of the muscles during the second bilateral contraction will be higher compared with the values in the first bilateral period. Changes in torque and EMG activity will be higher on the non-dominant side compared with the dominant side.
2.6. In case of unilateral to bilateral transition, torque value and EMG activity of the muscle in unilateral contraction will start decreasing before the contralateral muscle is activated, so before exerting a torque.
2.7. In case of unilateral to bilateral transition, torque value and EMG activity of the muscle in unilateral contraction will continue to decrease until the torque value and EMG activity of the contralateral muscle reaches the maximal value.

METHODS

Subjects. Second year full-time students of Semmelweis University, Faculty of Physical Education and Sport Sciences, physical educationteacher–coach participated in our study. The subjects were trained in various sports. The right leg was the dominant extremity in case of all subjects. Bilateral deficit was not present in eight subjects(age: 20.9±4.3 years; body mass: 79.3±5.2 kg; height: 181.5±4.4 cm). These subjects were selected for our first study. Eleven students participated in our second study(age: 21.78±1.41 years; body mass: 74.45±8.81 kg; height: 180.45±6.71 cm). Bilateral deficit was present in these subjects.

Study devices used. Multi-Cont II Tihanyi System (Mediagnost, Budapest and Mechatronic Ltd, Szeged) computer aided muscle examining dynamometer device with three main components including two electric servo motors (Mavilor Motors, Spain, MA-10) a driver (Lorenz BrarenGmbh, Germany,FAD 25), and a measuring cell. The steel arm functioned as a special rail which was aligned to the knee joint of the subject sitting on the device. Mounting cuffs were made of steel, the inner surface was padded, their diameter could be adjusted with a velcro. The subjects' shoulders, trunk, hip, and thighs were secured to the bench with very rigid velcro straps and a padded metal cylinder.Rectangular, bipolar, adhesive, silver-silver chloride 32x41 mm surface electrodes filled with water based gel and connected with snap fasteners were used to measure the EMGactivity of the skeletal muscles(SKINTACT F-RG, Robohardware Ltd, Hungary). The electrodes were placed on the vastuslateralis and vastusmedialis muscles in accordance with the SENIAM protocol. The operator software uses a MyoResearch XP, Master Version program(NoraxonMyoclinical 2.10, Noraxon U.S. Inc., Scottsdale, AZ, USA). Analogue signals from the surface electrodes were transmitted telemetrically to the receiver antenna by a Telemyo hardware transmitter(Noraxon U.S. Inc., Scottsdale, AZ, USA). Signal was recorded at a sampling frequency of 1 kHz by the analogue-digital converter and signal amplification was automatic. Raw EMG signals were rectified, and then data smoothing using the moving average method and filtering (high-pass 20 Hz) were performed.

The course of the study. Blood flow was increased and stretching was performed for 15 minutes, then the degree of the optimal position where force of the knee extensor muscles was maximal using concentric contraction was determined in both extremities in case of all subjects. Isometric effort was made in this degree position.

First study. The setting for the first study (SS1) consisted of separate three-second unilateral and bilateral isometric forces. The setting for the second study (SS2) consisted of a three-second bilateral contraction, then a slow, controlled relaxation had to be performed in the right knee extensors, while maximal force had to be maintained in the left knee extensors. The setting for the third study (SS3) used a relaxation as fast as possible in the right knee extensors following the bilateral contraction compared with SS2. 3 contractions were used randomly in SS1, SS2, and SS3 as well. The curve with larger torque values were selected for analysis.

Second study. The first task (T1) was to perform separate 3second unilateral and bilateral isometric knee extensions. The second task (T2) was to perform contralateral contractions with the knee extensors following a 3second unilateral contraction, so the force was finished with bilateral contraction (4second). The tasks were performed on both sides (T2a – the left is active during the whole task, T2b – the right is active during the whole task). In the third task (T3), study subjects performed maximal bilateral force which was maintained for three seconds, and then knee extensors on one side had to be relaxed as rapidly as possible after the signal of the principal investigator while maximal contraction had to be maintained in the contralateral muscles. The relaxation was performed on both sides (T3a – the left is active during the whole task, T3b – the right is active during the whole task). The first part of T4 was the same as in T3, unilateral contraction following the bilateral effort lasted for four seconds. After this, maximal activation had to be performed after the signal of the principal investigator with the previously relaxed knee extensors as fastas possible. The left extremity had to be activated during the first part of the task (T4a), and the right extremity had to be activated during the second part of the task (T4b). Three contractions were performed in all cases randomly.

Data processing.

First study. Bilateral deficit index (BLDI) was calculated and the maximal bilateral (MBLR, MBLL) and unilateral (MULR, MULL) torque values were determined for SS1.

The torque-time curves of SS2 and SS3 were used to determine the maximal BL isometric torque (MBLR, MBLL), the value measured directly after starting the relaxation of the right extremity (BLL, BLR), the lowest torque value of the left knee extensors following the relaxation of the right knee extensors (M1), the reduction in torque value was calculated (dM1=BLL-M1), and the time while the torque value was decreasing was determined (t1). This change was called short latency response (SL). The torque value measured at the time of the complete relaxation of the right knee extensors (M2) and the time from the beginning of the relaxation were determined (t2), change in the torque value was calculated (dM2=M2-M1). When the torque value of the left knee extensors was maximal (M3) following the complete relaxation of the right knee extensors was considered to be the long latency response (LL). The change between M2 and M3 was calculated (dM3). Time from M1 to M3 was determined (t3). The following variables were determined from the torque-time curve of the right knee extensors following relaxation: the torque value in case of M1 (MR) and the percentage of this value compared with the BLR (M%), the ratio of torque reduction (RTR=dM/dt), and the half-relaxation time (1/2RT).

Second study. In case of T1–4, maximal UL and BL torque values (MULR and MULL, MBLR and MBLL) were determined using the torque-time curve, and the mean torque of the right and left legs were calculated (AULR and AULL, ABLL and ABLR) in case of T1 and the transition tasks as well. Starting and ending markers of EMG activity of contractions were recorded at the average segments.

In case of unilateral force following bilateral contraction (T3), the transition period started when the torque value decreased(BLL, BLR). Reduction in the force of the contralateral leg was recorded when the torque value of the relaxed leg decreased (M1). The reduction in torque was indicated by t1. Torque of the contralateral leg was indicated by M2 at the time of the complete relaxation of the other leg. The time from M1 to M2 was calculated (t2). The maximal unilateral torque was determined (MULL, MULR) and the mean torque was calculated (AULL, AULR). The time from M1 to the maximal unilateral value of the contralateral leg was indicated by t3. The UL period lasted till the force reduction at the end of the contraction. rmsEMGBL1 is the EMG activity measured at the beginning of relaxation, rmsEMGBL2 is the EMG activity measured during the complete relaxation of the contralateral leg (t1+t2), and rmsEMGUL is the EMG activity measured between M2 and MULL/MULR.

In case of T2 and T4, the value at the beginning of the steep decline in force (ULM1) was determined using the torque-time curve of the knee extensors during UL contraction. This was the beginning of the transition period. The value measured at the beginning of the force of the contralateral leg (ULM2) and the difference between the ULM1 and ULM2 values were determined (dM1). The elapsed time was called electromechanical delay (t1). The torque of the other leg decreased at the beginning of the contralateral contraction and reached its minimum (BLM1) in a certain time (t2). The difference between ULM1 and BLM1 (dM2) referred to the reduction in the tension of the muscle at the beginning of BL contraction following unilateral contraction. Maximal torque was determined (BLM2) in case of both knee extensors during BL contraction. ThermsEMG activity of the muscles were recorded in four intervals, window widths were different. The rmsEMGUL, rmsEMGUL1, rmsEMGUL2, and rmsEMGBL refer to the EMG activity during UL contraction, t1, t2, and BL contraction.

Statistical calculations: our results were represented by means and standard deviations. To identify significant differences after normality test we used for parametric distribution t-test for independent samples and Anova(for EMG too) or the suitable corresponsive nonparametric method. Pearson correlation we employed for the examination of the context between the selected variables. The statistical significance level was set to $p<0.05$.

RESULTS

Task 1. In SS1, BL torque was 1.4% and 4.6% smaller than the UL averages (not significant). The BLD index was -2.9$\pm$5.6. MBLL and MBLR were in SS2 8.3% and 6.8%, respectively; in SS3 they were 7.2% and 6.8% smaller, respectively, than in SS1 (not significant). The exertion of force in SS2 decreased to a small degree at the relaxation of the right knee extensor (BLL: -1.4%, BLR: -4.0%), and it further decreased by 7.8% with the relaxation of the right leg (dM1: -16.9$\pm$8.7 Nm, not significant). Torque increased by full relaxation of the right leg (M2: 232.0$\pm$55.8Nm) and reached the level of BLL (-0.5%). The torque of the left leg gradually increased from M1 to M3, but to a different degree

(15.7%). The difference was 7.3% (not significant) between BLL and M3. No significant correlation was found between t1 and t2, or between t1 and the half-relaxation time (1/2TR). The correlation between RTR and dM1 was linear and significant (r=-0.845, p<0.01). A significant correlation could be observed between dM1 and t1 (r=-0.792, p<0.01) and between dM1 and dM3 (r=0.794, p<0.01). No significant correlation was found between half-relaxation time (1/2RT), t2 and dM1.

MBLL and MBLR in SS3 decreased by 5.9% (BLL) and 5.3% (BLR), respectively, at the beginning of the relaxation of the right leg. After relaxation, mean torque increased by 7.7% (M2) and 13.1% (M3) compared to BLL (not significant). t2 was significantly shorter than t3 (p=0.011); t1 was significantly longer than 1/2RT (p=0.014). A significant correlation was found between 1/2RT and dM1 (r=0.856, p<0.001). No significant correlation could be found between dM1 and dM3 and t1 and dM1.

In comparing MBL and MUL for SS2 and SS3, no difference could be observed. dM1 decreased in SS2, percentage-wise, to the same extent that SS3 increased. In comparing the percentage changes in M1 and BLL, a significant difference could be found (p<0.001). For SS2, t1 and t2 were significantly longer (p=0.019) than SS3. The averages of MR, MR% and RTR were significantly higher in SS2 than in SS3 (p=0.014, p=0.008, p=0.003). 1/2RT was significantly shorter (p<0.001) than SS3.

A significant linear correlation was found between RTR and dM1 (SS2: r=-0.845, p<0.01; SS3: r=-0.87, p<0.01) and between 1/2RT and dM1 (SS3: r=-0.86, p<0.01). A significant linear correlation was observed between RTR and dM1 (SS2 and SS3: r=0.95, p<0.001). No significant correlation was found between the aggregated 1/2RT and dM1 averages of SS2 and SS3 (r=0.783, p<0.001), and logarithmic function could be matched to the series of data (y=-21.9ln(x)±112.2).

Task 2: There was no significant correlation found, either in the maximum (MULL: 273.1±49.7 Nm, MULR: 265.1±22.1 Nm) or in the average UL (AULL: 257.3±49.1 Nm, AULR: 250.1±22.2 Nm) torque. No difference was found in the maximum BL (MBLL: 226.5±34.3 Nm; MBLR: 227.9±17.1 Nm) and mean force exertion (ABL: 209.3±32.0 Nm and 214.7±17.2 Nm). The maximum and mean torque of UL and BL was significantly different in both the left (p=0.018 and p=0.013) and right knee extensor (p<0.000, p<0.002). BLDI was -15.1±6.2 and 15.8±8.1. For ULL, the rmsEMG values of both VL and VM were significantly higher (23.4%, p=0.036 and 28.8%, p=0.015) compared to BLL. The values of VL and VM in force exertion of ULR were also significantly higher (24.1%, p=0.019 and 14.0%, p=0.037) than in BLR.

As far as T2a is concerned, the mean UL torque of left knee extensors (AULL: 226.5±53.9 Nm) was significantly higher at 14.1%, than with ABLL (p=0.005). This difference was 17.1% (p=0.03) with T2b. The mean BL torques of the right knee extensors was 16.4% less (p=0.002) than with AULR (216.4±32.3 Nm). The rmsEMG means of VM and VL showed no significant disparity in either case.

During T3a contraction, AULL (239.6±50.3 Nm) was significantly higher (p=0.05) at 18.4%, than the BL mean torque (ABLL) measured in the first half of the contraction. The rmsEMG of the left VL increased by 21.9% (p=0.01), and the VM by 31.6% (p=0.008). A similar difference could be observed between AULR (228.9±30.3 Nm) and ABLR (19.5%, p<0.000) in T3b as well. The EMG activity of the right VL increased significantly (25.4%, p=0.001) to the same extent as the right VM (34.6%, p<0.000).

For T4a, the mean UL torque of the left knee extensors (AULL: 229.4+39.2 Nm) increased by 21.8% (p<0.02) after the relaxation of the right knee extensor. These were proven by the rmsEMG mean of the VL and by the VM of left leg (p=0.004, p=0.001). No significant difference was observed between ABLL (188.4±38.6 Nm) and ABLL2 (189.6±36.6 Nm). The second BL torque following UL contraction decreased by 21.0% (p=0.02). The mean torque of the right knee extensors during BL contraction (ABLR2:203.2±33.3 Nm) was significantly higher (p=0.01) than during the first BL contraction (ABLR:180.8±27.9 Nm). This result was shown only by the rmsEMG mean of VM (37.2%, p<0.000). The rmsEMG means of left VL (519.2±227.0 μV) and VM (639.7±263.7 μV) were 20.5% and 28.8% higher, respectively, during the second BL force exertion compared to the first one (p=0.01 and p=0.001).

For T4b, AULR (225.3±22.6 Nm) was 19.6% higher than ABLR (p=0.001). This was also confirmed by the rmsEMG means of the right leg VL and VM (23.2%, p=0.01; 28.7%, p=0.001). Torque decreased by 17.4% (p=0.001) during BL contraction following UL contraction. ABLL (191.6±41.3 Nm) and ABLL2 (211.5±48.4 Nm) significantly differed (p=0.04). These were confirmed by the BL rmsEMG means (VL: 16.0%, p=0.01; VM: 32.0%, p<0.000). The left rmsEMG means increased during the second BL period compared to the BL phase (VL: 24.6%, p=0.01; VM: 26.7%, p=0.001).

<u>Results of task 2 in the transitions.</u> For T2a, ULM1 started to decrease before the contraction of the right leg (164.5±22.3 ms). ULM2 was 13.4% smaller (203.8±28.0 Nm) than in ULM1 (-30.8±21.9 Nm, p=0.046). BLM1 further decreased (172.0±20.4 Nm), (-31.8±21.7 Nm, p=0.009). Left rmsEMG decreased (VL: 20.0%, p=0.012; VM: 23.5%, p=0.014) within t1+t2. At the lowest value of the left leg, the right one (BLM2: 190.7±39.9 Nm) reached 85.5% of maximum bilateral torque (BLM2: 223.3±28.5 Nm). Activity of left rmsEMG in BL2 increased (VL: 14.1%, p=0.042; VM: 21.2%, p=0.013) compared to BL1.

The electromechanical delay in T2b was 243.9±132.2 ms. ULM1 (222.7±26.6 Nm) decreased to 193.6±23.7 Nm (ULM2) (p=0.019). The right leg reached its lowest torque (162.4±16.1 Nm) when the torque of the left leg reached 89.1% of its highest value (201.5±59.3 Nm). The rmsEMG decreased by t2 (VL: 27.3%, p=0.007; VM: 31.9%, p=0.001). Both ULM2 and BLM1 decreased significantly (p=0.003). The BLM2 was significantly different in both the left (233.0±35.7 Nm) and right (182.2±25.5 Nm) leg (p<0.000). The right VM rmsEMG showed a significant 21.9% increase from its lowest (BL1) value (p=0.02).

There was no significant difference found in BLL, M1 and M2 in T3a during the relaxation of the right leg. Following this, the maximum torque of left leg MUL (257.7±47.3 Nm) was significantly higher than in MBLL (p=0.039) and BLL (+59.7±35.7 Nm, p=0.003). A significant difference was found between M1 (190.8±39.7 Nm) and MUL (p=0.002). There was no significant difference between the rmsEMG means of left leg.

A significant increase was found in T3b contraction of the right leg in M1 (180.6±27.6 Nm) and M2 (220.4±34.8 Nm) (p=0.007). All these were also confirmed by the rmsEMG means, where VM increased (p=0.017). A significant difference between BLR (191.8±32.5 Nm) and MUL (p=0.018) and between MUL and M1 (p=0.03) could be observed.

In T4a, the mean of left ULM1 (231.1±46.3 Nm) declined by 43.2+24.9 Nm (18.4%) (p=0.033), 212.4±75.0 ms prior to right leg contraction. This was backed up by the decrease in left leg rmsEMG (UL1) mean in t1 (VL: 15.5%, p=0.011; VM: 14.3%, p=0.015). The torque of the left leg started to increase (peak) when the right leg (BLM1: 168.8±30.0 Nm) reached 79.1% of maximum torque (BLM2: 213.4±38.1 Nm). Values of left leg, VL and VM increased significantly (18.6%, p=0.004; 21.5%, p=0.004), reaching the lowest rmsEMG.

In T4b contraction, ULM1 (221.2±21.2 Nm) declined by 35.2+14.1 Nm (15.9%, p=0.001) until the beginning of the left leg contraction (ULM2) (t=107.4±130.7 ms). The decline continued (BLM1: 156.4±14.6 Nm, 15.3%, p=0.002). Right rmsEMG decreased significantly (VL: 41.1%, p=0.001; VM: 32.8%, p=0.009) between UL1 and BL1, then increased in the BL2 period (VL: 37.3%, p=0.005; VM: 33.3%, p=0.009). Right (174.4±27.7 Nm) and left (229.0±47.9 Nm) torque was significantly different (23.8%, p=0.01) in BLM2.

DISCUSSION

Task 1. Although it was supposed that the maintained contraction of one muscle and the relaxation of the contralateral muscle is considered as a dual task of the central nervous system and results in a short latency response in the force exertion of the muscle in contraction, the non-significant changes (increases and decreases) do not allow us to draw the conclusion that the sharing of the task would be the primary reason for the bilateral deficit. At the beginning of relaxation, the dominant stopping of the activation of fast motor units are assumed. The activity of these motor units on the two sides cannot be more easily separated than that of the slower and smaller motor units of lower threshold being disconnected later.Earlier, van Dieen et al (2003) did not observe this phenomenon as the rate of relaxation response did not have to be controlled by the tested subjects, so no sharing of attention resulting from the dual task could be observed. The new finding originating from our new research perspective highlights the accuracy of our idea. Our results unambiguously prove that controlling the relaxation of a muscle initiates a similar process on the opposite side as well, which is a short-term process. The increase in the torque indicates that this effect ceases to exist and the muscle which is still in activation exerts a similar size torque as it did during the unilateral contractions. As a consequence, there is no long latency effect of the slow, controlled relaxation on force exertion in the contralateral muscles.The correlation between RTR, representing the dynamism of relaxation, and the short latency transition response (the decreasing and increasing of torque) allow us to draw the conclusion that the changes occurring in the homologue muscles of the limbs are influenced mainly by the inhibition and facilitatemechanisms which exist between the hemispheres of the brain.

Task 2:Results in T2 contradict the results of van Dieen et al (2003), who, during the bilateral contraction following the unilateral contraction, found the same amount of EMG decrease parallel to the decrease of the torque. The difference between the two results can have two reasons. (1) The separated and connected unilateral and bilateral contraction exposes a different control task on the central nervous system. The change in the task, from unilateral to bilateral contraction, appears differently in the interaction of the two brain hemispheres, and supposedly the inhibitioneffect will be smaller. (2) In our research protocol the subjects had to activate their relaxed-state muscles as fast as possible, thus, the maximum torque had to be reached during the shortest possible time. This was not a required condition in the research of van Dieen et al (2003).

As far as T3 is concerned, the conclusion can be drawn that the fast relaxation of the muscle on one side following BL contraction was supposed to result in an increase in the supra-spinal centres regulating contraction, and the inhibition effect which exists between the two hemispheres ceased to exist in both hemispheres to the same degree. It seems that the relaxation of one of the contralateral homologue muscles causes different changes in the central control than the contraction in the connected opposing muscle following UL contraction.

The results T4 imply that the second BL contraction increased the irritability of the central regulation on both sides. We might have supposed that an almost 12 second contraction could result in a decline of attention and a decrease in force exertion, but our research findings show that no fatigue occurred; thus, this cannot be the cause of the bilateral deficit. It seems that the unilateral contraction following the bilateral one has a facilitateeffect on the second bilateral contraction, which is also manifested in the increased EMG activity of the muscles.

Conclusion of Task 2 in transitions. If unilateral contractions follow each other, then either a kind of modulation is created as a result of the mutual effect of the two hemispheres in transition, or the irritability of the motor unit increases. We cannot completely accept the conclusions drawn from the results of van Dieen et al (2003). Namely, the statement that one of the reasons for bilateral deficit is the declining irritability of the centres or the decreased neural stimulation can be accepted, but all these might be modified by the mutual effects of the dominant and non-dominant sides. On the other hand, an important reason for sharing attention might be the changes in regulation, which can be proven only by analysing the transient changes.

Based on our results the following decisions can be formulated:

1.1. The hypothesis can be considered valid as short latency and temporary changes were observed in both tasks.

1.2. We accept the hypothesis.

The slow, controlled relaxation of the right knee extensor resulted in a temporary decrease in (transitional) torque in the contralateral muscle during contraction. The rate of decline was influenced by the time of relaxation.

The fast relaxation in the right knee extensors following maximum isometric bilateral force exertion caused the transitional, fast increase of torque in the unilateral counteracting of the left knee extensor. The rate of this increase in the torque changed in relation to the time of relaxation.

1.3. We accept the hypothesis.After the decline in torque caused by the slow relaxation, the torque of the contralateral muscle returned to the unilateral level. It returned to its unilateral level after the increased torque caused by the fast relaxation. The bilateral deficit in both cases equalled the data measured during the separate contraction.

2.1. The hypothesis is considered validated as the EMG activity during the bilateral knee contraction carried out with the traditional testing procedure (separate contractions) was significantly lower (similar to the torque) than during the unilateral contraction. The change in the EMG activity in the linked unilateral-bilateral contraction had the same direction that the torque had. The rate of change was also similar in most cases.

2.2. The hypothesis can be accepted only if a bilateral contraction was followed by a unilateral one. The bilateral-unilateral rate changed on the non-dominant side after bilateral contractions following unilateral ones, mainly for muscles of the non-dominant side.

2.3. The hypothesis is considered accepted. The contralateral muscle relaxation following the bilateral contraction resulted in an increase in torque in both muscles, reaching the data values measured in the separate contraction. The increase in EMG activity had the same direction and rate of the torque. The EMG activity during the maintained unilateral contraction had nearly the same values for both muscle as the data measured during separate contractions. The changes in the dominant (right) and non-dominant (left) side muscles were identical.

2.4. The hypothesis is partially accepted.

When the knee extensors of the dominant side were linked with the non-dominant unilateral contractions – although the maximum bilateral torque was higher than on the contralateral side – the difference was not significant. On the contrary, the maximum bilateral torque of the knee extensors on the non-dominant side was significantly higher than those of the dominant side. In contrast with our hypothesis, torque decreased at the same rate in muscles of both sides when the contralateral muscle joined the contraction. The maximum bilateral torque of the muscle on the non-dominant side increased at such a rate that it equalled that of the unilateral one, so the bilateral deficit ceased on this side. The EMG activity of the VL and VM muscle on the non-dominant side also increased and equalled the activity of the unilateral contraction. As a consequence, the residual active state of the dominant side muscles had a facilitateeffect on the activity level and force exertion of the dominant side muscles as well.

2.5. Our hypothesis is partially accepted.

The torque in the second bilateral contraction was significantly higher only when the relaxed muscle was contracted again. Namely, when the knee extensor on the right side was activated after the relaxation, the second bilateral torque was higher than that of the first one, while the torque of the contralateral knee extensors on the left side equalled that of the first one. A similar result was obtained when the muscle on the left side was reactivated following a relaxation.

On the other hand, the EMG activity of the VL and VM muscles were significantly higher in most cases during the second bilateral contraction compared to the first one. The results imply that the irritability of the dominant side muscles having been relaxed with a bilateral contraction and then re-contracted, had little or no influence on the non-dominant muscle being re-contracted at the same time.

2.6. Our hypothesis is accepted. In all four tasks (T2a,b and T4a,b), the relapse of the torque in the muscle contracted unilaterally and the relapse of the EMG activity started 150-300 seconds before the activation of the contralateral muscle.

2.7. Our hypothesis is accepted with the correction that the increase in both the torque of the other muscle and EMG activity started at 80-90% of the activated state of the contralateral muscle. There was no difference between the dominant and non-dominant side in this respect.

CONCLUSION

Four new task adjustments not previously used by anyone else were applied in our research to study the bilateral and unilateral contractions:

1. The transitional task from bilateral to unilateral contraction in subjects with and without bilateral deficit.
2. Two different types and the time of (fast and controlled) relaxation of the dominant leg following a bilateral contraction in subjects with bilateral deficit.
3. A comprehensive survey of transitions during unilateral contraction following a bilateral force exertion and during a bilateral contraction following a unilateral one.
4. A unilateral contraction following a bilateral contraction that was followed by a repeated bilateral contraction.

<u>The application of the new testing methods made the following analysis possible:</u>

1. The interaction between the two contralateral muscles and the motor centre regulating their contractions exist even when the bilateral deficit cannot be demonstrated. The conclusion is that the activity and the effects of inhibition neurons participating in the communication between the two hemispheres of the brain is task or time dependent. However, the effect is short and transitional; it does not influence either the lack or presence of an existing bilateral deficit or its rate.

2. Linked unilateral-bilateral contractions following each other were much more suitable for proving that there is a difference between the dominant and non-dominant sides

as far as bilateral deficit is concerned when the traditional unilateral and bilateral contraction is studied separately.

3. The unilateral contraction of muscles on the dominant side has a facilitateeffect on the bilateral contraction of muscles on the non-dominant side, which is proven by the fact that a bilateral deficit ceased to exist on the non-dominant side when the unilateral contraction of the right knee extensor muscles were followed by the bilateral contraction of the muscle on the left side. The change in the EMGactivity of the muscles suggests that this process is caused by the modification which occurs in central nerve regulation.

4. Facilitation appears on the dominant side as well in the repeated bilateral contraction after the unilateral contraction following a bilateral one. It manifests itself in the fact that the bilateral deficit ceases to exist on the dominant side as well during the second bilateral contraction. Modification in nerve regulation is shown by the increased EMG activity of the muscles on the right side and by the fact that the level of EMG activity is as high as it was during the unilateral contraction. It seems that the linked and repeated unilateral-bilateral contractions decrease the activity of the inhibition neurons between the hemispheres of the brain.

5. For the bilateral deficit, the fast relaxation of the contralateral muscle following a bilateral contraction results in a decrease in muscle contraction on the other side compared to the situation in which there was no bilateral inhibition. The decline in the joint contraction can be attributed to the fact that the two hemispheres of the brain need a certain period of time to separate the joint task.

6. An analysis of the changes in EMG activity and in the torque during the transition between the unilateral and bilateral contractions provides new information about the nerve communication of the same-side limb muscles and their effects on each other. Based on this information, it can be stated that the inhibition effect appears 150-300 milliseconds earlier on the contralateral side, before the activation of the muscles on the other side.

7. It can also be stated, thanks to the new examination and analysis process, that the inhibition effect of the contralateral muscle contraction linked to the unilateral contraction of the other side finishes when nearly reaching its maximum level of activity.

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