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THE INFLUENCE OF ELBOW JOINT ANGLE ON DIFFERENT PHASES OF RELAXATION FROM MAXIMAL VOLUNTARY CONTRACTION

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Abstract. The purpose of the study was to find whether the early and late phases of relaxation from maximal voluntary contraction depend on the elbow joint angle and whether the influence of joint angle on relaxation depends on which optimal angle (Ao or $Ao_{(MVC)}$) was considered as a reference value. $Ao_{(MVC)}$ was the optimal elbow joint angle at which elbow flexor muscles can produce maximum voluntary force and Ao was the optimal angle at which the fastest rates and shortest time of relaxation occur. Twenty-two young, physical education male students were tested four times. The first and second sessions were done to establish optimal angles (Ao, $Ao_{(MVC)}$). The third and fourth sessions were done to measure the relaxation indices at an optimal angle, as well as at the angles that were smaller (As=optimal-30º) and larger (Al=optimal+50º). All testing sessions consisted of four trials of 2 or 3-s MVC at each angle. To assess the speed of relaxation, the following relaxation indices were measured: early, late and latest relaxation rate (ERR, LRR, and LstRR, respectively; %F/5ms), maximal rate of relaxation (MRR; %F/5ms), and half relaxation time (1/2Rt; ms). The BIODYNA dynamometer was used to measure torque versus time curve for right elbow flexor muscles. The maximum voluntary force was produced at the angle $Ao_{(MVC)}$=89.4±8.0°. The end force (EF) had the best score at 89.2°±8.4°. The optimal angles (Ao) for relaxation indices were ERR=90.9°±8.2°; LRR=88.3°±8.8°; LstRR=89.5°±9.8°; MRR=90.3°±7.5°; and 1/2Rt=87.9°±8.5°. The differences were not statistically significant. Although the Ao and $Ao_{(MVC)}$ were similar, most subjects had values for Ao that were 5°-10° smaller or larger than $Ao_{(MVC)}$. Moreover, a small difference between MVC at Ao and $Ao_{(MVC)}$ (1.1%) was accompanied by much bigger differences for relaxation indices. At Ao: ERR, LRR, and MRR were 10% to 12% higher, LstRR-25% higher and 1/2Rt 10% shorter compared to the values at $Ao_{(MVC)}$. The optimal elbow joint angle at which elbow flexor muscles produced maximum voluntary force ($Ao_{(MVC)}$) did not always coincide with the angle at which relaxation indices had the best results (Ao). Nevertheless, unlike the relaxation of single muscle following electrostimulation, the indices of early and late relaxation of elbow flexor muscles

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during voluntary contraction were not affected by joint angle in young active men independent of whether As and Al were compared to Ao or As and Al to $Ao_{(MVC)}$. *(Biol.Sport 22:89-104, 2005)*

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Introduction

Half and total relaxation time, and maximal rate of relaxation were found to be dependent on muscle length when measurements were done on isolated muscle in twitch and in tetanus [6,12,20,26]. Pagala [26]showed that the half and total relaxation time increased linearly with change length of frog sartorius muscle from 0.7 to 1.4 times rest length, and there was a bigger increase in total relaxation time than in half relaxation time. The maximal rate of relaxation [expressed in g/ms] decreased with both decrease and increase from rest length. Wallinga-de Jonge *et al.* [30] found that the maximal relaxation rate of the extensor digitorum longus (EDL, fast) and soleus muscle (slow), expressed in relative terms (s^{-1}) responded the opposite way for length change. Thus, in a muscle with a mixed fiber composition, it might be expected that the influence of muscle length on the relative maximal relaxation rate might be small. The maximal relaxation rate represents only fast relaxation and it is not known how other relaxation indices of slow and fast relaxation respond on joint angle changes. Since, different events occur during the slow and fast relaxation [10,11,12,17,29] they do not have to respond the same way.

While data on the influence of muscle length on force, half and total relaxation time, and maximal relaxation rate of isolated muscle are available, less is known about the changes of relaxation with joint angle in humans during a voluntary contraction. This lack of information is due to the difficulty of isolating the force of a single muscle from the total force and the contractile components of individual muscle from its elastic components. However, it was shown that even in this condition, length has an effect on the magnitude of the contractile response. Only the plateau of the relationship is more curved and extends to longer sarcomere lengths compared to the length-controlled experiment, and the prediction of the cross-bridge theory will not necessarily be confirmed Rassier *et al.* [28]. Since, in everyday movement task and sport activities we do not recruit single muscle or muscle fiber, but all muscles necessary to execute a task (agonist and antagonist) it is reasonable to analyze the behavior of relaxation during complex movements, like elbow flexion.

There are many factors that affect relaxation changes with elbow joint angle. First, the speed of relaxation of each elbow flexor muscle is probably different. Second, each muscle may operate on different limb (ascending or descending) of the force-length relationship reaching the plateau at different joint angle Rassier *et al.* [28]. Third, the mechanical advantage of all elbow flexors (length of the moment arm of the force exerted by a muscle) and the relative activation of brachioradialis muscle to biceps brachii muscle (BR/BB) depend on elbow joint angle Nakazawa *et al.* [25], van Zuylen *et al.* [33], and the muscle with the larger mechanical advantage receives the larger activation van Zuylen *et al.* [32]. Fourth, each muscle contains a different combination of longer and shorter fibers, and has a different tendon stiffness and compliance. All these factors suggest that relaxation of the elbow flexors from maximal voluntary contraction may not change with muscle length similar to the changes of relaxation of single muscle following electrostimulation.

The dependence of maximal voluntary contraction (MVC) on muscle length is well established and it is known that the maximum voluntary force is obtained at an optimal length ($Ao_{(MVC)}$) because of the greatest number of cross-bridges available to generate force at that length. The speed of relaxation expressed in N/s (i.e., maximal relaxation rate - MRR) is partially dependent on MVC. On the other hand, if relaxation rates were expressed in relative terms [%F/s], they would be independent of MVC. The slow (early) part of relaxation would mainly depend on the rate of Ca^{2+} uptake and the fast relaxation on cross-bridge dissociation rate Pagala [26]. If the individual cross-bridge cycles were independent of each other, their dissociation rate would be expected to be independent of the filament overlap. Thus, the optimal length of MVC can be different from the optimal angle of relaxation. Additionally, during voluntary contraction of muscle *in situ,* there are inter-subject differences in joint and muscle-tendon complex structure and architecture. As a consequence, there are also discrepancies in levers size and position. Thus, for each subject there might be a characteristic joint angle creating the best conditions for the fastest relaxation (Ao) and this might be different from the optimal angle for MVC ($Ao_{(MVC)}$).

The purpose of the study was to find whether the phases of relaxation from maximal voluntary contraction depend on the elbow joint angle and whether the influence of joint angle on relaxation depends on which optimal angle (Ao or $Ao_{(MVC)}$) was considered as a reference value.

Material and Methods

Subjects: Twenty-two physical education male students were tested four times within a period of four weeks. Their mean age, weight and height was 23.1±1.0 years, 73.3±9.3 kg, and 178.9±6.9 cm, respectively. All subjects were fully informed regarding the nature of the experimental methodology and gave their informed consent to participate. All subjects maintained their habitual level of activity during the study and were asked to avoid strenuous exercise 48 h prior to the day of measurement. A subject and one tester (always the same) were allowed in the testing room. The first and second sessions established optimal angle and the third and fourth sessions measured the MVC, end force (EF), and relaxation indices at an optimal angle, as well as at angles that were smaller (As=optimal - 30º) and larger (Al=optimal + 50º). Subjects were familiarized with the testing apparatus and the protocol on a separate occasion before testing was conducted. In that time they were also trained to exert maximal voluntary contraction (MVC) with the maximal speed of contraction and relaxation.

Measurements made during each session were done in a randomized order. Testing was done at the same time of the day ±2 h.

Optimal joint angle: To set the optimal angle, four trials of randomized 2 or 3 s MVC at three, four or five angles (depending on MVC and values of relaxation indices at different angles) were recorded. The optimal angle for MVC was an elbow joint angle at which a subject achieved maximum voluntary force. Optimal angle for relaxation indices was an elbow joint angle at which a subject achieved the fastest relaxation rates and the shortest time of half relaxation. Subjects were instructed to do MVC with a maximal speed of contraction and relaxation, as well as of a maximal force. The MVC and relaxation were recorded during four trials and then mean value was calculated. Because 90º are usually reported as an optimal angle for the elbow joint Kulig *et al.* [22], measurements during session 1 were done first at a 90º angle. Measurements were then done at an angle of 80º and 100º, assigned in random order. If MVC and relaxation indices did not change at those angles, measurements were done at a 70º and 110º. During session 2, the optimal angle setting was done again, but in an order different than during session 1. If there was any difference in the $Ao_{(MVC)}$ or Ao between the two sessions, the average value of both sessions was used for $Ao_{(MVC)}$ and Ao.

Measurements on the different muscle lengths: The third and fourth sessions were done to measure MVC, EF and relaxation indices at an optimal angle, as well as at angles that were smaller (As=optimal-30º) and larger (Al=optimal+50º) (Fig. 1). The angles optimal-30º and optimal+50º were chosen assuming that they are roughly in midrange between the optimal angle (90º) and full flexion (30º), or/and full extension (180º). The measurements were assigned in random order.

Four trials of 2 or 3 s MVC separated by 2-min rest intervals were done at three angles. The time of MVC (2 or 3 s) was also assigned in random order to minimize the chance that subjects would relax before the ending signal was given.

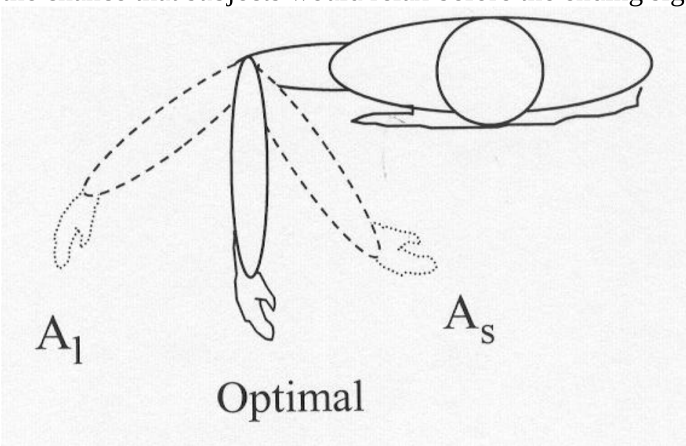

Fig. 1
Schematic view of a position of the arm and forearm at the optimal angle as well as at the angles that were smaller (As = optimal - 30º) and larger (Al = optimal + 50º)

Procedures: Right elbow flexor muscles were tested during sessions separated by at least 3 days. Each session started with a standard warm-up consisting of 20 pushups against the wall and five MVCs done as fast and hard as possible; this was followed by 5 min of rest. A trial was started and ended by a signal emitted by a computer. Since the subject may hear when the start button was pressed, the computer in random order emitted the first signal starting a trial at 1, 2, or 3 s intervals. The session consisted of four trials of 2 or 3-s MVC separated by 2 min between trials and 5 min between different angle measurements to reduce the effect of fatigue.

Tests were conducted with a subject seated with his back supported. His upper arm was in coronal plane, in long axis of the shoulder (Fig. 1). With respect to the trunk, the upper arm was at an angle of 90°. The arm and forearm were held in a horizontal plane with the forearm in the neutral position (between supination and pronation). The forearm was held in the neutral position by a mount, placed on the wrist-joint level and was strapped securely to the rotating lever arm of the dynamometer that could be fixed at various angles. The rotation axis of the elbow joint was always at the rotation axis of the equipment. Hips were stabilized with a bar, while belts stabilized shoulders and trunk. Testing was carried out with the dominant hand using the BIODYNA dynamometer. Details about the dynamometer were published elsewhere Kędzior *et al.* [21]. The whole device was adjusted to the anthropometric characteristics of each subject. When a computer gave the signal, subjects were instructed to flex the forearm as fast and hard as possible. Three or two seconds later, the next signal was emitted and they were instructed to release as fast as possible by relaxing the muscles. Output was recorded and analyzed using a specially prepared program. An effort was made to impress subjects with the importance of a maximal speed of contraction and relaxation, as well as of a maximal force. To ensure that the subject activated maximally his muscles, it was required to achieve the maximal voluntary force (MVC) value within 10% difference on five consecutive contractions. If the subject did not achieved required MVC, the trial was disregarded.

Data recording and analysis: A BIODYNA dynamometer was calibrated on two different lever arms of the dynamometer using known weights (50, 100, 250, 500, and 1000 N). Within a tested range, the calibration was linear. Angles were measured with a precision rotational potentiometer and force output with a strain gauge having a constant response time, interfaced with a computer allowing for electronic differentiation. An electric signals produced by the strain gauge and potentiometer were analyzed at a frequency of 1000 Hz per channel using an A/D converter (ADC 774JE, B-B Company). The range of momentum (torque) measurements was 190 Nm. The torque transducer was zeroed to eliminate passive elasticity prior to each collection. If the subject started to push on the torque transducer before the trial, a computer showed an error and the torque transducer had to be zeroed. Computer software was developed to determine the onset of force generation, defined as the first sample to exceed the resting force level by 5% of MVC. The isometric force-time curve (F-t curve) was analyzed at 5-ms intervals. The threshold for force slope (relaxation) was 5% from the end force (EF), which was the isometric force, recorded when the second signal (ending the exercise) was emitted. The end force, rather than MVC, was chosen as a reference force for relaxation parameter estimation, because a force decrease may occur during a MVC sustained for 3 s (Fig. 2). After a computer digitized the analog force signal, the force production and relaxation of the test contractions were analyzed and all relaxation indices listed below were computed:

1) Relative rate of early relaxation was calculated as a percentage of end force (EF) decreased within the early relaxation time, and expressed in %EF/5ms to compare with the maximal relaxation rate. Since the level of the threshold force was 5% of the EF, the early relaxation time was the time needed for the EF to decrease from 95% to 80%. Because some subjects obtained the maximal relaxation rate between 80% and 75% of EF, the range between 95% and 80% was chosen to differentiate fast relaxation from early (slow) relaxation.

2) Maximal relaxation rate was computed by finding the highest value for the slope of the tangent to the F-t curve at 5-ms intervals during the relaxation phase (descending arm of the F-t curve) and expressed in %EF/5ms.

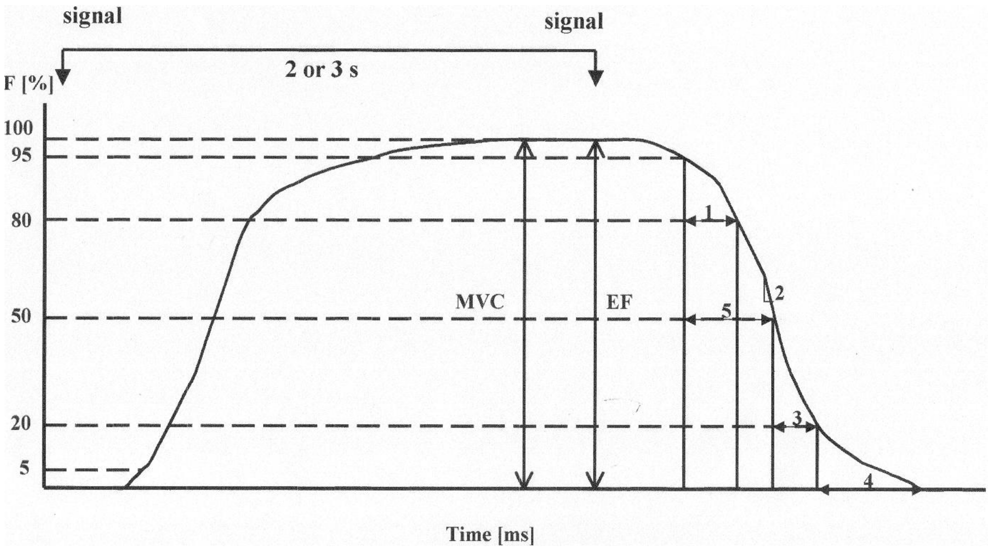

Fig. 2
Diagram describing the different indices measured in the study; MVC-maximal voluntary contraction; EF-end force; 1-early relaxation time; 2-maximal relaxation rate; 3-late relaxation time; 4-latest relaxation time; 5-half-relaxation time. The rates were calculated as –dF/dt and expressed in %F/5ms

3) Relative rate of late relaxation was calculated as a percentage of EF decreased within the late relaxation time, and expressed in %EF/5ms. The late relaxation time was the time needed for the force to decrease from 50% to 20%EF.

4) Relative rate of latest relaxation was calculated as a percentage of EF decreased within the latest relaxation time, and expressed in %EF/5ms. The latest relaxation time was the time needed for the force to decrease from 20% to 0%EF.

5) Half-relaxation time was the time needed for a 50% fall in EF.

Reliability: Because motivation and readiness for the test Baumgarten and Jackson [1] affect the reliability of measurements of any time index during voluntary movement in man, four sessions were conducted within 2-4-weeks. During each session, the isometric force and relaxation were recorded during four maximal trials. Because the mean value is usually the best indication of a subject's typical performance, the mean value of the four trials was calculated. From a statistical point of view, the mean of the trial scores is also more reliable than the best score Heinonen *et al.* [15]. Sessions 1 and 2 were used to assess day-to-day reproducibility of optimal angle setting. Session 3 and 4 were used to assess reproducibility of the measured indices at an optimal angle, as well as at angles that were smaller (As=optimal-30º), and larger (Al=optimal+50º).

Statistical methods: Data are reported as mean values and standard deviations (SD). ANOVA for repeated measurement was used to calculate the difference between three angles. If an interaction was found, a post hoc Tukey test was used to compare mean values. P<0.05 was considered statistically significant. As a measure of day-to-day reproducibility, the intraclass correlation coefficient (ICC) was determined Baumgarten and Jackson [1].

Results

Table 1
Reproducibility of measured indices (ICC=intraclass correlation coefficient) at optimal, smaller (As), and larger (Al) joint angles

	As	Optimal	Al
End force	0.867	0.962	0.953
Maximal voluntary contraction	0.913	0.952	0.954
Rate of early relaxation	0.827	0.862	0.866
Rate of late relaxation	0.875	0.910	0.939
Rate of latest relaxation	0.917	0.943	0.841
Maximal relaxation rate	0.826	0.924	0.925
Half-relaxation time	0.795	0.831	0.828

For day-to-day reproducibility the ICC for the optimal angle setting was 0.901. Table 1 gives the values of ICC at three joint angles. For all measured indices, the ICC was greater than 0.825 except 0.795 for the half-relaxation at As. Generally, the reproducibility of measured indices was very good with the highest values at long muscle. Nevertheless, for data analysis, the mean value for the two days was used to minimize unpredictability.

The maximum score (MVC) for elbow flexion with forearm in the neutral position was found at an elbow flexion angle of 89.4°±8.0°, which is called in the present paper $Ao_{(MVC)}$. When optimal muscle length was found for each index of relaxation separately (the angle at which the rates of relaxation achieved the highest value and the half relaxation time the lowest value), the average value of angle (Ao) was almost the same as for MVC ($Ao_{(MVC)}$). These angles ranged from 87.9° to 90.9° for EF, early relaxation rate, late relaxation rate, latest relaxation rate, maximal relaxation rate, and 1/2Rt; these differences were not statistically significant. However, for most subjects, Ao was 5° or 10° either smaller or larger than $Ao_{(MVC)}$. Only 4 of 24 subjects (16.6%) obtained the fastest rate of maximal and late relaxation at the same angle as the MVC; for the latest relaxation rate it was 6 subjects (25%); for 1/2Rt, 8 subjects (33.3%); and for the early relaxation rate, 9 subjects (37.5%).

Table 2
Relaxation characteristic for three joint angles

	As	$Ao_{(MVC)}$	Ao	Al
End force (N)	300±62*#	350±65	346±62	237±51*#
MVC (N)	309±62*#	363±67	359±75	247±51*#
Rate of early relaxation (%F/5ms)	2.96±0.77	3.15±0.66	3.53±1.05	3.11±0.86
Rate of late relaxation (%F/5ms)	3.46±1.26	3.28±1.12	3.63±1.42	3.21±1.01
Rate of latest relaxation (%F/5ms)	1.32±0.65	1.22±0.69	1.52±0.75	1.24±0.47
Maximal relaxation rate (%F/5ms)	5.26±1.02	5.21±1.03	5.80±1.24	5.10±1.13
Half relaxation time (ms)	64±15	62±13	56±13	66±16

$Ao_{(MVC)}$ - optimal angle taken as the angle at which the maximum isometric voluntary force was produced; Ao - an optimal angle at which fastes rates and lowest time of relaxation (half relaxation time) occured; As - an angle smaller than the optimal by 30º; Al - an angle larger than the optimal by 50º;
*P≤0.05 statistically significant compared to $Ao_{(MVC)}$;

#P≤0.05 statistically significant compared to Ao; Values are means ±SD

As the data in Table 2 show, there is only 1.1% difference in MVC and EF values between Ao and Ao$_{(MVC)}$, which is accompanied by at least 10% to 12% difference in 1/2Rt, in the early, late, and maximal relaxation rate, and 25% in the latest relaxation rate (P>0.05).

MVC and EF decreased at both sides of Ao (P≤0.05)(Table 2). Compared to Ao$_{(MVC)}$, MVC droped at As and Al by 14.9% and 32.0%, respectively. For EF, the reductions were 14.3% and 32.3%, respectively.

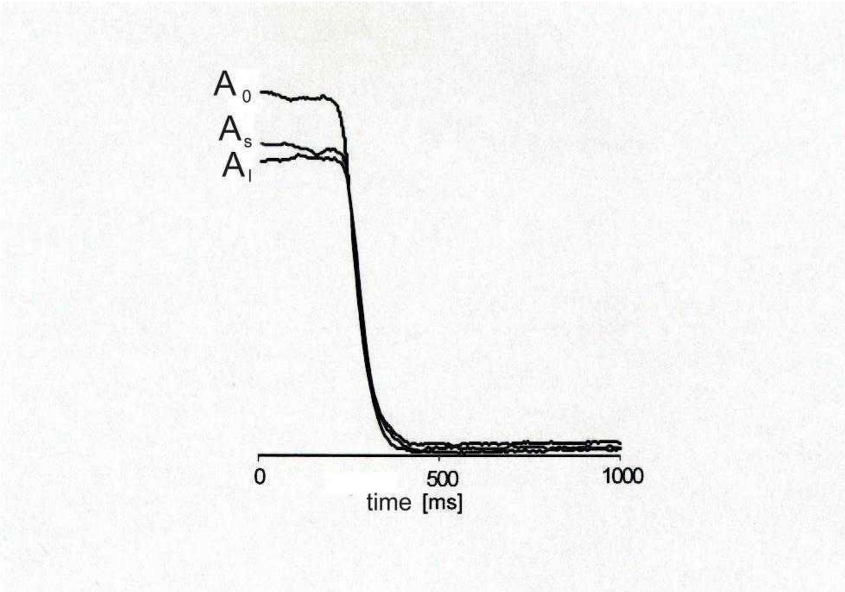

Fig. 3
Typical records of relaxation at the three joint angles from a single subject;. Ao=optimal angle; A_L=optimal + 50º; As=optimal - 30º. 0 ms = emission of a signal ending a trial and starting relaxation

Fig. 3 shows typical records of relaxation at three joint angles As, Ao$_{(MVC)}$, and Al. Relaxation did not show a significant change in steepness with increasing length. The influence of muscle length on relaxation phases is slight when force and relaxation are normalized to the peak value, and when $Ao_{(MVC)}$ is taken as a reference angle. Measured indices characterizing slow (early relaxation rate, ERR) and fast relaxation (late relaxation rate, LRR; maximal relaxation rate, MRR), as well as the latest relaxation rate (LstRR), and half relaxation time (1/2Rt) did not change significantly in short and long muscle length (Table 2). Recorded changes did not exceed 8% and were less than 6% for most indices.

When Ao was taken as a reference value, the changes of relaxation indices caused by muscle shortening or lengthening were greater than the changes recorded in respect to $Ao_{(MVC)}$. Compared to Ao, muscle lengthening (Al) caused a 12% decrease in the early, late and maximal relaxation rate and an 18% decrease in the latest relaxation rate, and an 18% increase of 1/2Rt. For As, the changes were 16% for the early relaxation rate, 5% for the late relaxation rate, 9% for the maximal relaxation rate, 13% for the latest relaxation rate, and 14% for 1/2Rt. None of the differences was statistically significant.

Discussion

The new findings of the study is, that unlike the relaxation of single muscle and muscle fiber following electrostimulation, the indices of early and late relaxation of elbow flexor muscles during voluntary contraction are not affected by joint angle in young active men independently of which optimal angle (Ao or $Ao_{(MVC)}$) was considered as a reference value.

The optimal angle for MVC of elbow flexor muscles with the forearm in the neutral position ($Ao_{(MVC)}$=90º) is in agreement with findings from other studies Clarke *et al.* [5], Doss and Karpovich [8]. In most subjects this angle did not coincide with the optimal angle for relaxation indices (Ao), however the average values of both angles were similar. In spite of only one-percent difference in MVC and EF values between the two angles, the relaxation indices changed 10% or more. As a result, faster rates of relaxation and shorter 1/2Rt were recorded at the Ao compared to $Ao_{(MVC)}$. Since the differences were not statistically significant, some uncertainty exists if the small variations in angle difference are not due to measurement problems. Based on the ICC values, the reproducibility of measured relaxation indices was very good. Moreover, in spite of the good reproducibility, for data analysis the average value of the two days measurements was taken to avoid unpredictability. Nevertheless, still there is a question if the small variations in angle difference have physiological and practical meanings.

The values of half relaxation time and early relaxation rate at the optimal angles are similar to those recorded by Jaskólska and Jaskólski [19] and Jaskólska

[18] for digit flexor muscles, while the values of late relaxation rate and maximal relaxation rate are lower. These discrepancies might result from the fact that the experiments were performed on different muscle groups that differ in degree of use, function and morphology, and/or muscle fiber composition (which may be related to muscle function). Compared to the elbow flexor muscles, digit flexor muscles have longer tendons and as muscles responsible for fine precision movements, have more ST motor units. The ST muscles were found to have better elastic energy recoil Bosco *et al.* [4], Wells [31] which may influence muscle relaxation Gowitzke and Milner [13].

It is well documented that when a muscle is at a shorter- or longer-than-optimal length, its force is reduced Bigland-Ritchie *et al.* [2], Kulig *et al.* [22], Petrofsky and Phillips [27], Leedham and Dowling [23]. Our results are supported by the classic ascending-descending strength curve of the elbow flexors as reviewed by Kulig *et al.* [22]. Since to our knowledge, the behavior of the early, late and latest relaxation rates with muscle length was not tested during voluntary movements, it is difficult to compare our results with those from the literature. Thus, a comparison is made with the results obtained on isolated muscle stimulated electrically. Even if there are a different experimental conditions during voluntary contraction and electrostimulation, it is reasonable to do such comparison to find what is the difference between the influence of muscle length on relaxation of a muscle stimulated electrically and the influence of joint angle on relaxation from a voluntary contraction. In spite of the fact, that the magnitude of the changes at smaller and larger joint angle was bigger when they were compared to Ao, than when compared to $Ao_{(MVC)}$, the changes of relaxation speed with elbow joint angle did not reach statistical significance, independently on the phase of relaxation.

Some results from isolated muscle suggested that there might be greater changes in the late phase of relaxation with muscle length, compared with the early phase of relaxation. This is because the late relaxation shows a change in sarcomere length and is mostly controlled by the dissociation rate of cross-bridges Gillis [12], Gurfinkel *et al.* [14], Pagala [26], which are reduced at a long sarcomere Edman and Flitney [10], Curtin and Edman [7], Lou and Sun [24]. As a result accelerated deactivation induced by shortening and “give” Edman [9], would no longer operate and late relaxation could proceed at slow rate, characteristic of strict isometry Huxley and Simmons [17]. An initial, isometric step of relaxation (called early relaxation) seems to be regulated by the rate of Ca^{2+} uptake insignificantly altered in stretched muscle Pagala [26].

The reason for lack of significant changes of relaxation, independently of the phase of relaxation, might be the large variability resulting from the wide range of inter-subject strength and time differences. Moreover, the similar behavior of early and late relaxation with muscle length might be related to the muscle fiber composition of tested subjects. Wallinga-de Jonge *et al.* [30] found that the changes of relative maximal relaxation rate of fast extensor digitorum longus muscle and slow soleus muscle respond in opposite ways relative to the change in length. From the figures presented by Wallinga-de Jonge *et al.* [30], it can be also seen that the early relaxation of soleus (slow) muscle was only slightly faster at short length and did not change at long length. Late relaxation (relaxation from 50% of maximum tension to zero) was faster at short lengths but slower at long lengths. On the other hand, muscle length did not affect relaxation of the fast extensor digitorum longus. Thus, the resultant changes in relaxation rates of muscles with a mixed fiber composition could be small, what was found in the present study.

Moreover, when relaxation of muscles in their anatomic environment during isometric voluntary contraction is considered, the level of activation, architecture of muscle-tendon complex, and tendon stiffness can affect the measurements. As Nakazawa *et al.* [25] and van Zuylen *et al.* [33] found, with the extended elbow, the relative activation of the brachioradialis to biceps brachii muscle (brachioradialis/biceps brachii, BR/BB) was smaller than with the flexed elbow. They found also that the mechanical advantage (a length of the moment arm of the force exerted by a muscle) of all elbow flexors decreased with extension. But there was the smallest decrease for the BB muscle indicating that the contribution of the BB muscle to the elbow flexion torque increases with the extension of the elbow joint. If, additionally, the muscle with the larger mechanical advantage receives the larger activation van Zuylen *et al.* [32], each elbow flexor muscle can receive the larger activation at a different elbow joint angle. The BB muscle, as the most effective muscle at the extended elbow angle, could supposedly receive the larger activation at that angle. Additionally, during voluntary contraction antagonist muscle are also involved and all agonist and antagonist muscles may have a different relaxation rate and also they may not relax at the same time. Each agonist and antagonist muscle can also occupy different parts of force-length relationship in vivo. It was found that most muscles whose in situ force-length have been determined appear to operate primarily on the ascending or descending limb of the force-length relationship, reaching the plateau toward the end of the range of joint motion Rassier *et al.* [28]. Also the passive force of the muscles working on the ascending part of the force-length relationship appears at short muscle length, whereas passive force of muscle operating on the descending part appears only at long muscle. Supposedly, muscles involved in the elbow flexion contain a combination of longer and shorter FT and ST fibers and have a tendon and aponeuroses of a different compliance and stiffness Huijing *et al.* [16]. Thus, they may differ in elastic energy reuse Bosco *et al.* [3,4]. If elastic energy is released during relaxation it may affect relaxation rate Gowitzke and Milner [13].

All these factors explain why relaxation of elbow flexors from maximal voluntary contraction did not change significantly with elbow joint angle. However, it cannot be excluded that there would be bigger changes of the relaxation speed with muscle length when testing a different muscle group and/or the different subjects (having more homogenous muscle fiber composition).

Conclusions

The elbow joint angle at which maximum voluntary force was developed ($Ao_{(MVC)}$) did not always coincide with the angle, at which relaxation indices had the best results (Ao), and the magnitude of the changes at an angle smaller and larger than the optimal was bigger when they were compared to Ao than when compared to $Ao_{(MVC)}$. However, unlike the relaxation of single muscle and muscle fiber following electrostimulation, the indices of early and late relaxation of elbow flexor muscles during voluntary contraction were not affected significantly by the joint angle in young active men independently of whether As and Al were compared to Ao or As and Al to $Ao_{(MVC)}$.

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