VALIDITY OF MEASURING MUSCLE ACTIVATION LEVELS BY ISOKINETIC TESTING

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Abstract:

The study aimed at testing the possibility of using an isokinetic dynamometer to measure muscle activation level (AL). The AL measured with an isokinetic dynamometer and calculated as a ratio between the maximum isometric and eccentric torques was compared against the AL obtained by the double interpolated twitch method. Eighteen male students with different levels of training participated in the study. The average ALs measured by the isokinetic dynamometer (AL_ISOK) at knee angles of 55° and 60°, as well as the average AL calculated from the maximum eccentric torque independently of a knee angle at angular velocities of 60°/s (100.10±13.25%, 92.43±11.82% and 84.33±9.29%, respectively) and 120°/s (99.93±11.93%, 94.61±13.79% and 88.52±14.07%, respectively) did not differ significantly from the average ALs measured by the double interpolated twitch method (AL_TW=89.50±7.42%). Significant correlations were found between AL_TW and several AL_ISOK at the angular velocity of 120°/s. However, the correlations were negative and low to medium (from –.478 to –.609). It was concluded that the AL_ISOK were not comparable to the AL_TW and therefore seemed not suitable for the activation level measurement, although the negative correlations between the two methods still leave this possibility.

Key words: *strength deficit, isokinetic dynamometer, interpolated twitch, electrical stimulation*

Introduction

The difference between maximum isometric (ISO) and maximum eccentric (ECC) force could be used to establish the so-called strength deficit (Bührle & Schmidtbleicher, 1981). The latter shows to what extent the subject is capable of activating a muscle during a maximum voluntary contraction (MVC). Another method for measuring the ability of a voluntary muscle activation is the interpolated twitch method using single (Merton, 1954) or multiple consecutive electrical impulses (Hales & Gandevia, 1988; Suter & Herzog, 2001). There are substantial differences between the two methods. When comparing maximum ISO and ECC forces, the difference concerns the type of muscle contraction. An increase in force during an ECC contraction is linked to an increase in muscle activation on account of the stretch reflex; however, other mechanisms of increasing force operate at the same time as well, stemming from the mechanical characteristics of ECC muscle contraction. The latter include short-range muscle stiffness which can increase the ISO force by as much as 50%, muscle viscosity and a change in the force-length and/or torque-joint angle relationship (McCully & Faulkner, 1985; Rack & Westbury, 1974; Westing, Seger, & Thorstensson, 1990). Nevertheless, unpublished measurement results of elite athletes and non-athletes obtained with the method of a comparison of maximum ISO and ECC forces showed that the athletes with a higher level of strength training have a smaller deficit than those who have not trained. It therefore seems that the method effectively distinguishes the ability of voluntary activation in people with different levels of training (Bührle & Schmidtbleicher, 1981). With the interpolated twitch method force increases due to additional muscle activation by electrical stimulation and does not involve any substantial changes in muscle mechanics. For this reason the method is applied as a standard for measuring muscle activation (Gandevia, Herbert, & Leeper, 1998; Behm, St-Pierre, & Perez, 1996).

The maximum isometric (T_ISO) and eccentric (T_ECC) torque in a joint can be measured using isokinetic devices. Their wide availability makes such measurements easily accessible to a broad range of users. Compared to the method using additional stimulation, the measurement of isokinetic torque is friendlier for subjects involved in such a kind of measurements. Besides measuring the AL in sport (Cresswell & Ovendal, 2002), this method is also interesting in rehabilitation (Bryant, Pua, & Clark, 2009) and medicine (Durand, Richards, & Malouin, 1991).

To test the validity and thus applicability of measuring AL by an isokinetic device, this study will compare the size of strength deficit (activation level), measured by an isokinetic dynamometer (AL_ISOK) for knee extension, and the AL, measured using the double interpolated twitch method (AL_TW).

Methods

Sample of subjects

Eighteen healthy male students with different levels of training participated in the study (age: 24.2±2.6 years, body height: 177.4±6.4 cm, body mass: 76.2±6.8 kg). All of them volunteered for the study and signed a consent form agreeing to take part in it. The study was approved by the National Commission for Medical Ethics and conducted in compliance with the Helsinki-Tokyo Declaration.

Measurement procedure

Measurement of AL by an isokinetic dynamometer

The measurement of AL by comparing maximum torques of isokinetic and eccentric muscle contractions was conducted using the isokinetic dynamometer Technogym – REV 9000 (Technogym Spa, Gambettola, Italy). The subjects first warmed up according to a standardized protocol which consisted of 6 minutes of stepping with the left foot on a 25-cm high bench at 0.5 Hz stepping frequency. Then they sat in the knee extension isokinetic device (hip angle of 110°) and were secured in the isokinetic limb support for knee extension (left leg) and strapped across the trunk and hips to the back of the seat. As part of the warm-up protocol, they performed three submaximal ISO contractions (knee angle of 60°) on the isokinetic dynamometer which lasted for 5 seconds at intensities of 50%, 75% and 90% of the maximum which was determined subjectively by each subject. One or two trials of the isokinetic and superimposed twitch measurements were included as a familiarization protocol immediately before the main isokinetic and main twitch measurements. A detailed explanation of each main protocol was again presented to the subjects before the start.

This was followed by three consecutive, maximum T_ISO measurements at a knee angle of 60°, with the gradual (2-second) development of maximum force that the subjects had to maintain for about 3 seconds, three ECC contractions at an angular velocity of 60°/s and three ECC contractions at an angular velocity of 120°/s, with the movement amplitude ranging from 30° to 70° of the knee angle. Pre-activation was performed prior to the ECC contraction. Two seconds prior to the ECC contraction, the subjects gradually developed the voluntary activation of the knee extensor muscles by performing a concentric muscle contraction at an angular velocity of 5°/s in an amplitude of 40° to 30° in such a way that, immediately before the ECC contraction started, the maximum voluntary muscle activation was achieved and had to be maintained throughout the entire ECC contraction. The isokinetic dynamometer moved the limb support downwards at a constant angular velocity and the subjects had to resist it in the opposite direction with the maximum possible force. During ECC contractions the T_ECCs at knee angles of 50°, 55°, 60° and the maximum torque regardless of the angle were obtained at both angular velocities (T50_60, T55_60, T60_60, Tmax_60, T50_120, T55_120, T60_120 and Tmax_120, respectively) and were measured for each repetition. The AL_ISOK was calculated according to Equation 1 using the concept of *Kraftdefizit* (Bührle & Schmidtbleicher, 1981):

$$AL\_ISOK(\%) = \frac{T\_ISO}{T\_ECC} \cdot 100 \qquad \text{(Equation 1)}$$

Based on Equation 1 the AL_ISOKs were calculated for all the measured T_ECCs at both angular velocities (AL50_60, AL50_120, AL55_60, AL55_120, AL60_60, AL60_120, ALmax_60 and ALmax_120, respectively) for each repetition.

Measurement of AL using a double interpolated twitch

The AL_ISOK measurement was immediately followed by the measurement of AL_TW. The subjects were seated in an ISO knee extension dynamometer with a pressure-expansion force sensor for measuring knee extension torque. They were strapped across their trunk and hips and the angles were the same as during the previous measurement (60° knee angle, 110° hip angle). The measurement was conducted using a constant-current electrical stimulator (EMF Furlan and Co., Ljubljana, Slovenia) for stimulating *m. quadriceps femoris* through the femoral nerve. Two biphasic, symmetric and squared electrical impulses (double twitch) of 0.3 milliseconds duration of supramaximal intensity were used at an interval of 10 milliseconds. The subjects' task was to gradually generate the maximum isometric torque in 2 seconds and maintain it at this level for another 3 seconds. During this period an electrical impulse was applied. The subjects repeated this procedure several times until an adequately shaped curve was obtained showing a gradual and constant increase towards the maximum torque (plateau) and an intermediate peak during the period of preserving the maximum torque, which reflected the instantaneous increase in torque as a consequence of the electrical (twitch) stimulation. Immediately after the double electrical impulse was applied, the subjects were instructed to relax as much as possible so that the stimulation of the relaxed muscle could follow within 3 seconds after MVC. The knee had to be additionally fixed over the medial and lateral epicondyles of the femur and the hip, which was performed manually. Thus the size of the twitch during the maximum isometric contraction (TW_ISO) was obtained as was the size of the twitch during rest (TW_REST). The AL_TW was then calculated using Equation 2 (Merton, 1954):

$$AL\_TW(\%) = \left(1 - \frac{TW\_ISO}{TW\_REST}\right) \cdot 100 \qquad \text{(Equation 2)}$$

Data analysis

The data were processed by the SPSS statistical package for Windows 13.0 (SPSS Inc., Chicago, USA). The following statistical methods were used: (a) calculation of basic statistical parameters for all the variables, (b) Shapiro-Wilk's test for testing the normality of the distribution of all the variables, (c) analysis of variance for repeated measures (RM ANOVA) with the Bonferroni corrected *t*-test for the *post-hoc* comparison to establish the differences in torques and ALs among the three repetitions, different knee angles and different methods for establishing AL, (d) intraclass correlation coefficient for average measures (ICC, two-way mixed model) to test the repeatability and consistency of the torque and AL measurements, and (e) Pearson's correlation coefficient to calculate the correlation between the variables. Friedman's and Wilcoxon's non-parametric test and Spearman's correlation coefficients were used for the variables which were not normally distributed. When different conditions were analysed, the average of three repetitions was used. Statistical significance was accepted with an alpha error of 5% (two-tailed).

Results

The Shapiro-Wilk's test showed that only five variables deviated from normal distribution (p<.05). These variables were: AL50_60 in the 2nd repetition (p=.042) and T60_60 (p=.043), Tmax_60 (p=.022), AL60_120 (p=.002), and ALmax_120 (p=.012) in the 3rd repetition.

When comparing the differences in torques between the three repetitions of the same condition, no significant differences (p>.05) were found except in ALmax_60, where the 3rd repetition showed significantly higher value than the 1st repetition.

The repeatability and consistency of the AL_ISOK measurements revealed to be good for the AL_ISOKs at the angular velocity of 60°/s (ICC=0.664–0.775) and excellent for the AL_ISOK (ICC=0.799–0.865) and T_ECC (ICC=0.961–0.978) at the angular velocity of 120°/s as well as for the T_ECC at 60°/s (ICC=0.913–0.958). For the three repetitions of the T_ISO measurements the ICC was 0.984.

The subjects achieved significantly higher T_ISOs (260.87±53.52 Nm) compared to T_ECCs at the knee angle of 50º and angular velocities of 60º/s (T50_60=234.70±50.28 Nm) and 120º/s (T50_120=239.24±49.89 Nm). However, the T_ISO at both angular velocities were significantly lower than the maximum T_ECC regardless of the knee angle (Tmax_60=309.47±53.71 Nm; Tmax_120=299.97±68.00 Nm), which is shown in Figure 1.

Significant differences were observed also among all pairs of T_ECCs at different angles at the same angular velocity (Figure 1). Thus, T50_60 was significantly lower than T55_60 (262.81±52.94 Nm) which was then significantly lower than T60_60 (283.93±55.08 Nm) which was ultimately significantly lower than Tmax_60. A similar relationship was observed also for 120º/s.

A comparison of the ALs showed that AL_TW (89.50±7.42%) was significantly lower than AL50_60 and AL50_120 (112.47±15.62% and

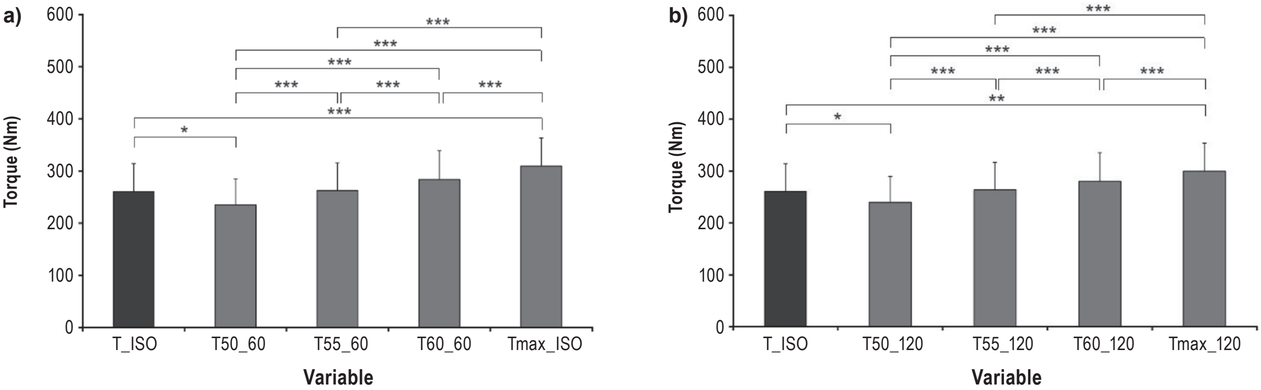


*Figure 1. Average values and standard deviations of the combined (all three repetitions together) isometric (T_ISO) and eccentric torques (T50, T55, T60 and Tmax) at the angular velocities of a) 60°/s and b) 120°/s. The asterisks denote significant differences: * – p<.05; ** – p<.01; *** – p<.001.*

109.79±11.76%, respectively). All other AL_ISOKs were not significantly different from AL_TW, as can be seen in Figure 2. Significant differences were observed also among all pairs of AL_ISOKs at different angles at the same angular velocity. Thus, AL50_60 was significantly higher than AL55_60 (100.10±13.25 %) which was further significantly higher than AL60_60 (92.43±11.82 %) which was then significantly higher than ALmax_60 (84.33±9.29 %). A similar relationship was observed also for 120º/s.

The Pearson's and Spearman's correlation coefficients revealed a high level of correlation between the T_ISO and T_ECCs (T50, T55, T60, Tmax). For the first repetition, the correlation coefficients were .785–.916 and .772–.890 (p<.001) at the angular velocity of 60°/s and 120°/s, respectively (Figures 3a and 3d), for the second repetition .760–.866 and .786–.897 (p<.001) at the angular velocity of 60°/s and 120°/s, respectively (Figures 3b and 3e) and for the third repetition .829–.867 and .820–.870 (p<.001) at each angular velocity, respectively (Figures 3c and 3f).

No correlation was found between the AL_TW and AL_ISOKs at the angular velocity of 60°/s. However, there were some significant, but negative correlations between the AL_ISOKs at the angular velocity of 120°/s. AL_TW correlated negatively with all AL_ISOKs in the first repetition (r=–.503 to –.555; p<.05) as well as with AL60_120 in the second repetition (r=–.497; p=.036) and AL50_120 (r=–.478; p=.045), and AL55_120 (r=–.609; p=.007) in the third repetition.

The correlations between the T_ISO and AL_TW (Figure 4) were positive and significant only in the second repetition, yet relatively low at both angular velocities, 60°/s and 120°/s (r=.480; p=.044). However, the correlations between the T_ECCs and AL_TW were positive and significant at both angular velocities and in all the three repetitions (r=.551–.703 at 60°/s and r=.579–.678 at 120°/s; p<.05).

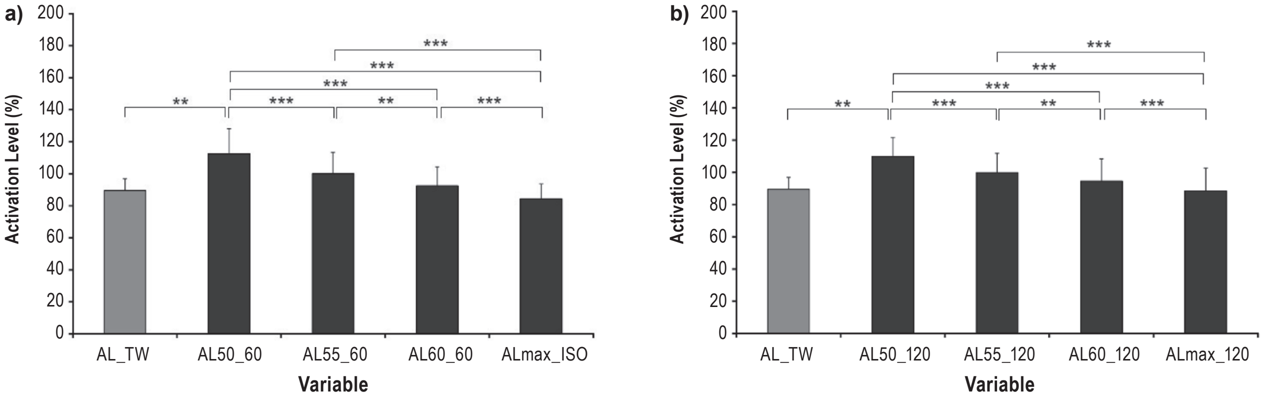
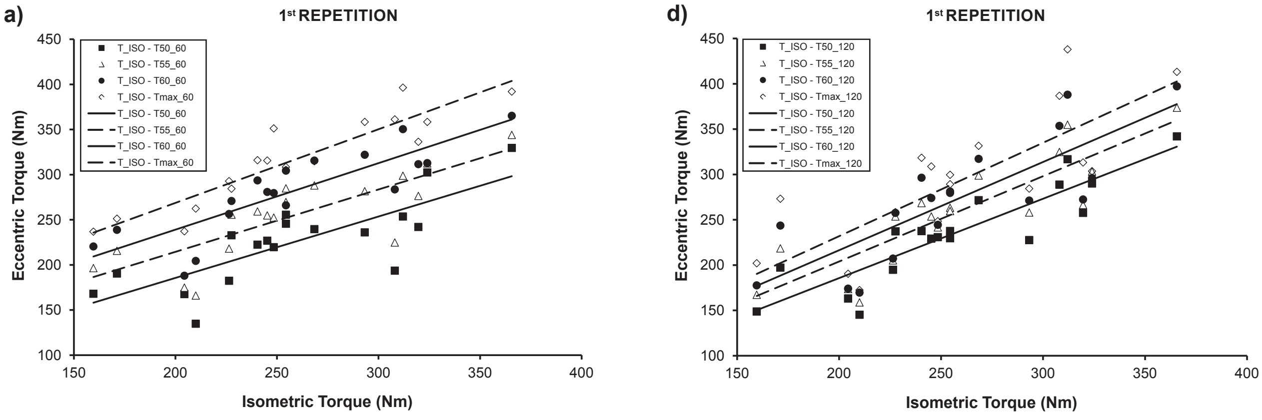


*Figure 2. Average values and standard deviations of activation levels. AL_TW was calculated from Equation 2 using the torque data of the double interpolated twitch method. AL50, AL55, AL60 and ALmax represent the combined (all three repetitions together) activation levels calculated from Equation 1 using the torque data of the method of comparison of the maximum isometric and eccentric torques at the angular velocities of a) 60°/s and b) 120°/s. The asterisks denote significant differences: * – p<.05; ** – p<.01; *** – p<.001.*



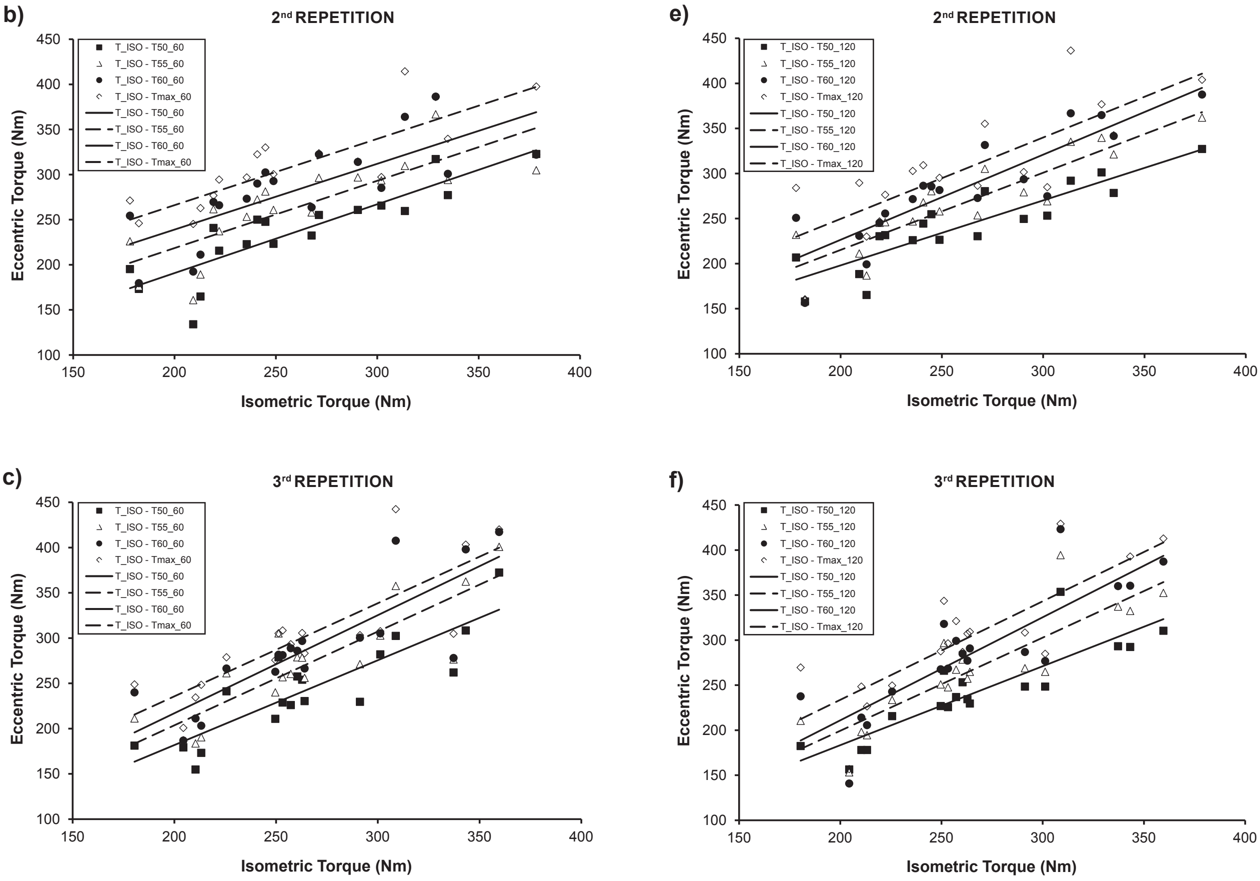
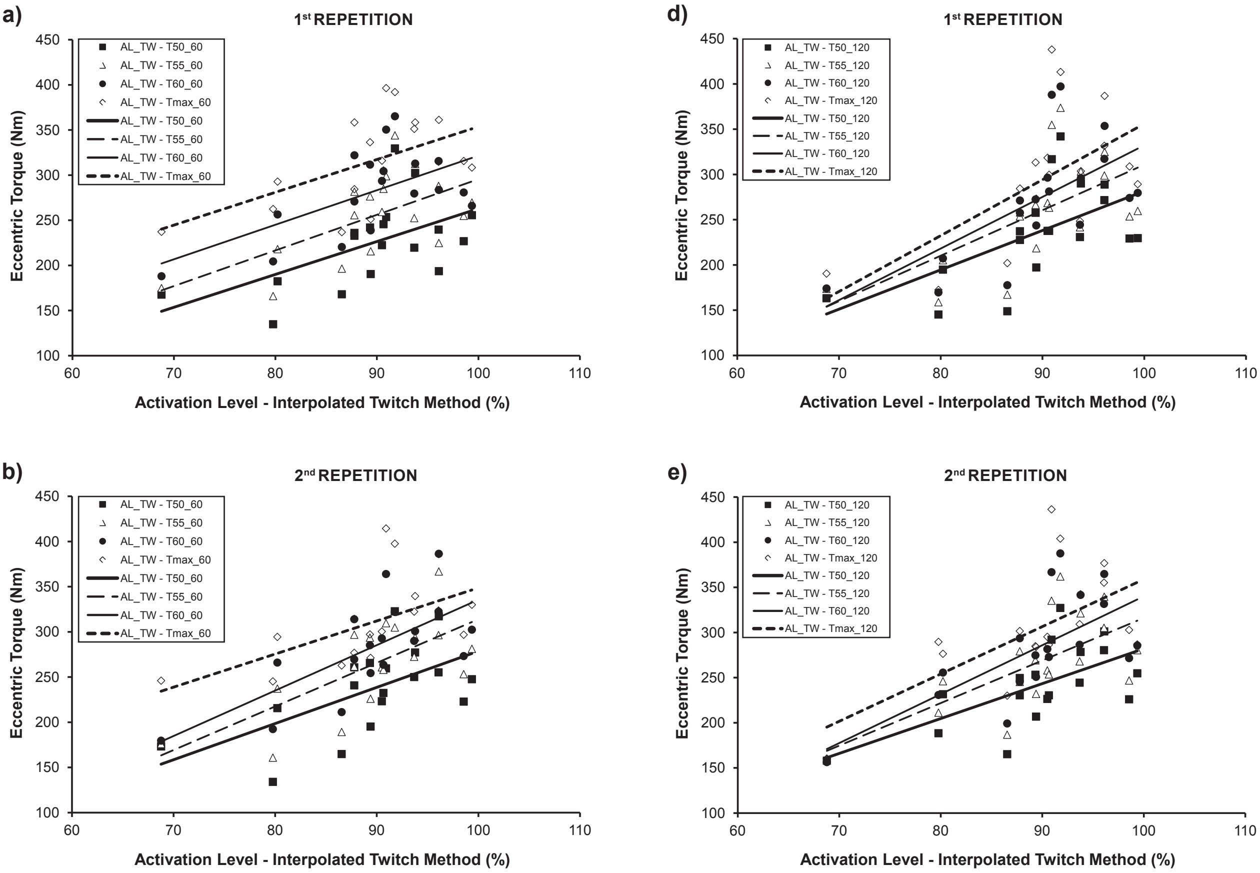


Figure 3. Correlations between the isometric (T_ISO) and each eccentric torque (T50, T55, T60 and Tmax) at the angular velocity of 60°/s (a, b, c) and 120°/s (d, e, f) in the 1st (a, d), 2nd (b, e) and 3rd (c, f) repetition. All correlations were significant (p<.001).



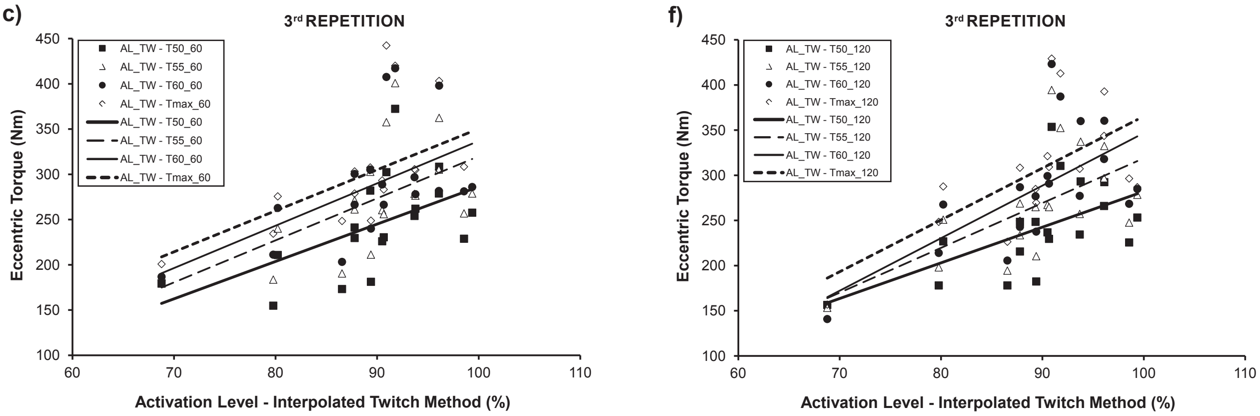


Figure 4. Correlations between the activation levels (AL_TW) and each eccentric torques (T50, T55, T60 and Tmax) at the angular velocity of 60°/s (a, b, c) and 120°/s (d, e, f) in the 1st (a, d), 2nd (b, e) and 3rd (c, f) repetition. All correlations were significant (p<.05).

Discussion and conclusions

The muscle deficit which is determined based on a comparison of the maximum eccentric force and the maximum isometric force could be connected with the AL (Bührle & Schmidtbleicher, 1981). Therefore, in the present study the muscle AL, which was measured using the double interpolated twitch method (AL_TW) was compared to the ratios between the eccentric isokinetic torques during maximum contractions at different velocities and the torque during isometric contractions to analyse a possible use of isokinetic testing for AL measurement. It was established that the average AL_ISOKs at knee angles of 55° and 60° and from the maximum eccentric torque independently of a knee angle at the angular velocity of 60°/s and 120°/s did not differ significantly from the average AL_TW. The previously mentioned would represent a good starting point for using isokinetic dynamometry to measure AL, if the correlation coefficients between AL_TW and AL_ISOKs were significant at the angular velocities of 60°/s and/or not significantly negative at 120°/s.

The ALs measured in the present study using the double interpolated twitch method are not congruent with the AL values obtained by other authors (Babault, Pousson, Ballay, & van Hoecke, 2001; Beltman, Sargeant, van Mechelen, & de Haan, 2004; Gandevia, et al., 1998; Kent-Braun & Le Blanc, 1996; Rutherford, Jones, & Newham, 1986; Strojnik, 1995; Yue, Ranganathan, Siemionow, Lui, & Shagal, 2000). The reasons for this incongruence between the study results can be explained by the use of different methods in those studies. Strojnik (1995) used the method of a superimposed train of electrical impulses which, compared to other methods, yielded lower AL values (79.1% to 89.6%). On the other hand, the use of the single interpolated twitch method usually shows a nearly 100% muscle activation (Gandevia, et al., 1998; Kent-Braun & Le Blanc, 1996; Yue, et al., 2000), whereas the use of double or several interpolated twitches yields slightly lower, yet still high AL values (93±5%) (Beltman, et al., 2004). The differences are also due to the fact that the researchers investigated different muscles. It seems that in large muscles, such as the *m. quadriceps femoris*, the AL values are lower than in small muscles such as the *m. adductor pollicis*. Last but not least, the AL differences between the studies could also stem from the different samples of subjects (Belanger & McComas, 1981, in Suter & Herzog, 2001), as ALs may depend on the subjects' level of training and the type of sport they do.

The present results correspond to the results of a study conducted by Babault et al. (2002) where a similar AL (87.9±5.1%) was measured during knee extension (at an angle of 55°) based on the stimulation through the femoral nerve (supramaximal stimulus) and the single interpolated twitch method. Their subjects achieved slightly higher isometric torques (327.4±52.0 Nm) compared to the subjects in the present study (260.87±53.52 Nm). It can therefore be concluded that the AL values established in this study using the double interpolated twitch method adequately reflect the subjects' ability as regards the maximum voluntary activation of the knee extensor muscles.

Based on the positive and significant correlation between the AL measured by the interpolated twitch method and the eccentric torques it can be established that, as a rule, the subjects with a high AL developed higher eccentric torques than those with a low AL (Figure 4). The results also show a certain degree of systematic behaviour as the correlation coefficients between ALs and eccentric torques at both angular velocities increase concurrently with the increase in the knee angle. This means that the correlation between AL and the achieving of high eccentric torques grows stronger proportionately to the widening of the angle and thus also to lengthening of the muscle. One explanation of such behaviour could involve muscle mechanics. It can be concluded that during the eccentric isokinetic muscle contraction the serial elastic elements stretch to a greater degree due to a higher eccentric force. This indicates that the torque-angle curve moves towards larger angles compared to the relevant curve in the isometric muscle contraction. This means that isometric torque at an angle of 60° should be compared to eccentric torque at an angle exceeding 60°. Another reason could be a better stability of the activation mechanisms at higher amplitudes due to the longer delay from the moment the eccentric contraction starts to the amplitude where the measurement is conducted. After the stretching starts, different mechanisms become involved such as short-range muscle stiffness, myotatic reflex, Golgi tendon reflex (McCully & Faulkner, 1985; Rack & Westbury, 1974; Westing, et al., 1990), transitory accelerations and vibrations of the isokinetic device which can operate at various intensities during the transitory period, thus causing inconsistent behaviour of the subject and, ultimately, decreasing correlation coefficients in the relevant period. After this transitory period, we can conclude that more stable conditions of muscle contraction are established which at larger angles (a longer period after the start of stretching) are expected to cause more systematic behaviour of subjects, thus resulting in higher correlation coefficients.

The non-significant (at 60°/s) and/or the significantly negative (at 120°/s) correlation between the ALs measured by the isokinetic dynamometer and those measured by the double interpolated twitch method is contrary to what was expected. This means that the subjects who were capable of better activating the *quadriceps femoris* muscle according to the interpolated twitch method achieved lower ALs when the method using comparison of the maximum isometric and eccentric torques with an isokinetic dynamometer was used. There may be several reasons for the negative correlations. Eccentric knee extension torque under maximal voluntary conditions may not represent the maximal torque-producing capacity (Westing, et al., 1990) due to a reduced neural drive to the agonist muscles (Westing, Cresswell, & Thorstensson, 1991). When a sudden stretch is applied to the fully activated muscle and its velocity is maintained over a longer range of motion, two distinctive phases of torque development may be observed (Linnamo, Strojnik, & Komi, 1998) – an initial torque increase followed by a substantial torque decrease. According to this behaviour, the eccentric action in the present study was limited to the angles of that first phase (30°–70°) to exclude possible negative trends on the torque-angle curve. As short range stiffness (immediate response) and stretch reflex (acting with a short delay) depend on the muscle activation prior to muscle lengthening (Houk & Rymer, 1981), this may influence torque response to muscle stretch. In this study it was observed that subjects with the higher activation level measured by the interpolated twitch technique developed higher eccentric torques, but failed to develop higher isometric torques. This could consequently mean a higher short-range stiffness and reflex responses, producing greater eccentric torque increase over the isometric level and thus a lower activation level when comparing maximal eccentric and isometric torques.

The possibility of errors in the measurement and data processing procedures should by all means be acknowledged along with the limitations of the measurement device or measurement methods, but the reliability analysis showed this was not the case. The RM ANOVA did not show significant differences among the three repetitions of torque and AL measurements (except in one case) and the ICCs turned out to be higher than 0.913 for torque measurements (T_ISO and T_ECC) and higher than 0.664 for the AL_ISOK, which means good to excellent repeatability and consistency. Additionally, high correlation coefficients between T_ISO and T_ECCs support this view.

The method of comparison of the maximum isometric and eccentric torque using the isokinetic dynamometer would therefore be much closer to that employed by Bührle and Schmidtbleicher (1981) if the eccentric and isometric torques had not been measured separately but in the same action and if the eccentric torques had been measured at a smaller amplitude so that, after the maximum isometric torque was generated, a short eccentric muscle contraction would follow. However, the isokinetic measurement device used here did not permit such programming. It would also be interesting to observe the differences which could occur if the maximum isometric torques were measured at different angles, e.g. 55° and 65°. It is also not necessary that the AL_TW was measured accurately because during the stimulation of the femoral nerve, the M-wave was not measured by an EMG signal which would show whether the muscle was maximally stimulated every single time. Although there is no direct proof of maximal electrical stimulation of the muscle, the intensity of the electrical stimulation, the comparison with other researchers, the authors' past experience and the analysed curve shapes all underpin our conclusions.

The study aimed at testing the possibility of using an isokinetic dynamometer to measure activation level by comparing maximum isometric and eccentric torques. Its comparison with the activation level, obtained by the double interpolated twitch method did not yield comparable results pointing out that the suggested approach would not work. However, significant but negative correlations between AL_TW and AL_ISOKs at the angular velocity of 120°/s still leave a possibility of using isokinetic dynamometry for evaluating activation levels as far as the results are appropriately transformed, which would be interesting to examine more deeply in future studies.

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VALJANOST MJERENJA RAZINE MIŠIĆNE AKTIVACIJE IZOKINETIČKIM TESTIRANJEM

Cilj je ovoga istraživanja bilo testiranje mogućnosti korištenja izokinetičkoga dinamometra za mjerenje razine mišićne aktivacije (AL). Razina mišićne aktivacije mjerena pomoću izokinetičkoga dinamometra i izračunata kao omjer između maksimalne izometričke i ekscentrične zakretne sile uspoređena je s razinom mišićne aktivacije, dobivenom pomoću metode superponirane stimulacije mišića (*interpolated twitch method*). Osamnaest studenata različitih razina treniranosti sudjelovalo je u ovom istraživanju. Prosječna vrijednost mišićne aktivacije mjerene pomoću izokinetičkoga dinamometra (AL_ISOK) pri kutovima koljenoga zgloba od 55° i 60°, kao i prosječna vrijednost mišićne aktivacije izračunate iz maksimalne ekscentrične zakretne sile neovisno o kutu u koljenom zglobu pri kutnoj brzini od 60°/s (100.10±13.25%, 92.43±11.82% i 84.33±9.29%) te pri kutnoj brzini od 120°/s (99.93±11.93%, 94.61±13.79% i 88.52±14.07%) nije bila značajno različita od prosječne vrijednosti razine mišićne aktivacije izmjerene pomoću metode superponirane stimulacije mišića (AL_TW=89.50±7.42%). Značajne korelacije utvrđene su između razine mišićne aktivacije AL_TW i nekoliko vrijednosti izmjerenih izokinetičkim dinamometrom (AL_ISOK) pri kutnim brzinama od 120°/s. Ipak, korelacije su bile negativne i niske do umjerene (od –.478 do –.609). Zaključeno je da razine mišićne aktivacije izmjerene dinamometrom (AL_ISOK) nisu usporedive s razinama izmjerenima metodom superponirane stimulacije mišića (AL_TW) te se zbog toga čini da izokinetički dinamometar nije prikladan za mjerenje razine mišićne aktivacije, premda negativne korelacije između tih dviju metoda još uvijek ostavljaju tu mogućnost.

Ključne riječi: *deficit jakosti, izokinetički dinamometar, superponirana stimulacija mišića, električna stimulacija*

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