“ALL-OUT” TETHERED RUNNING AS AN ALTERNATIVE TO WINGATE ANAEROBIC TEST

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Abstract:
An “all-out” tethered running on the treadmill represents an alternative form of exercise used for the assessment of anaerobic capacity. Contrary to the well known and frequently used “all-out” test on the cycle ergometer (Wingate anaerobic test), there is a lack of information concerning the parameters of anaerobic capacity obtained from tethered running on the treadmill. The aim of our study was therefore to compare the parameters of anaerobic capacity (maximal and mean power, fatigue index, and blood lactate concentration) in 30-second “all-out” tests performed on the isokinetic cycle ergometer and in the form of tethered running on the treadmill, respectively. The subjects underwent in random order in two different days a period of 30-second “all-out” cycling on the isokinetic ergometer at a revolution rate of 100 rpm and tethered running on the treadmill at a velocity of 13 km/h. Analyses of the results showed that tethered running and isokinetic cycling did not differ significantly either in maximal or mean power. However, the fatigue index and blood lactate were significantly higher in tethered running than in isokinetic cycling. Taking into account the similar values of maximal and mean power production between the exercise modes examined it may be concluded that the 30-second “all-out” tethered running on the treadmill represents an acceptable alternative for the assessment of anaerobic capacity. However, in comparison with isokinetic cycling slightly higher values of fatigue index and blood lactate have to be expected.

Keys words: anaerobic capacity, cycling on the isokinetic ergometer, tethered running on the treadmill, Wingate anaerobic test

MAXIMALES DEN WIDERSTAND ÜBERWINDENDES LAUFEN ALS EINE ALTERNATIVE DES WINGATE ANAEROBEN TESTS

Zusammenfassung:

Schlüsselwörter: anaerobe Leistungsfähigkeit, Belastung auf dem isokinetischen Fahrradergometer, maximales den Widerstand überwindendes Laufen, Wingate Test
Introduction

An “all-out” load on the cycle ergometer, either in a revolution-dependent (Wingate anaerobic test) or an isokinetic mode, represents a typical form of exercise used for the laboratory assessment of anaerobic capacity. On the other hand, for many sports pedalling does not provide a really specific form of muscle activity. For most of the weight-bearing activities running seems to be the more appropriate alternative. However, with simple treadmill running it is practically not feasible to implement a time limited “all-out” task. This drawback can be avoided by modified activity termed tethered running, during which the subject in addition to running, pulls a rope attached to a waist belt and the wall behind the treadmill (Hamar, 1999). A simple computer-based system can be employed to register the drag force, running velocity and to calculate the manifested running power. Data collected reveal the strike-dependent fluctuation of force and power over time and enable the calculation of peak as well as average values of force and power for a specific period. Repeated short-term “all-out” bouts (5 to 10 seconds) of tethered running at different velocities provide data, which can be used for the construction of individual force-velocity and power-velocity curves. Similarly to other types of muscle activity there is a decline of integrated force with increased velocity. On the other hand, integrated power increases from lower velocities, reaches a maximum, and then, towards higher velocities, declines again. Maximal drag power and corresponding velocity can be derived from such a curve (Hamar, Baron, Bachl, Tschan, Tkáč, Kampmüller, & Komadel, 1992). Thus, such a 30-second “all-out” exercise as an analogue of Wingate anaerobic test (Ayalon, Inbar, & Bar-Or, 1974; Bar-Or, 1981; Bar-Or, 1987) providing maximal and mean power, allows the fatigue index to be calculated.

However, contrary to the well known and frequently used “all-out” test on the cycle ergometer, there is a lack of information concerning the parameters of anaerobic capacity obtained from tethered running on the treadmill. The aim of our study was therefore to compare the parameters of anaerobic capacity (maximal and mean power, fatigue index, and blood lactate concentration) in 30-second “all-out” tests performed on the isokinetic cycle ergometer and in the form of tethered running on the treadmill, respectively.

Methods

A group of 17 physical education students (mean age 21.8 ± 1.1 years, height 179.4 ± 5.9 cm, weight 75.3 ± 7.1 kg) volunteered to participate in the study. They underwent in random order on two different days a period of 30-second “all-out” cycling on the isokinetic ergometer at a revolution rate of 100 rpm and tethered running on the treadmill at a velocity of 13 km/h (Fig. 1). The loads employed were set at previously established maximal power produced in untrained subjects (Hamar et al., 1992; Hamar, Gažovič, & Schickhofer, 1994). The subjects started both exercises abruptly without any warm-up and stopped with a 2-minute period of 2 minutes of cooling-down.

During the load on the treadmill the subjects, in addition to running, had to pull a rope attached by means of a belt to the waist and anchored to the wall behind the device. A simple computer-based system consisting of a strain gauge, tensometer, tachodynamo, and AD convertor was employed to register the horizontal drag force, running velocity and to calculate the power (Fig. 2). From the raw data sampled at 100 Hz, 5-second interval values were calculated to plot the power/time charts. The following parameters were calculated: Pmax (initial 5-second period), Pmean (average value calculated from the entire 30-second test), and Fatigue index (the ratio of power decline Pmax-Pmin and Pmax).

In the previous study (Zemková & Hamar, 1999) the reliability of the manifested maximal running power during 30-seconds “all-out” tethered running at different velocities was verified. Test-retest correlation coefficients of maximal power ($r = 0.845$), mean power ($r = 0.916$), and fatigue index ($r = 0.879$) were similar as shown, e.g. by Montgomery, Douglass and Deuster (1989) or Nicklin and associates (1990). These values, and hence also the reliability of the running power measurement were better at the lower 8 km/h ($r = 0.926$) than at the higher 18 km/h velocities ($r = 0.848$). Analysis of the repeated measures revealed a measurement error from 5.4 to 8.7%, which is in the range comparable to common motor tests (Seger et al., 1988; Nicklin et al., 1990; Hamar, Gažovič, & Schickhofer, 1994) indicating that such a method may be applied in sport practice.

During exercise on the cycle ergometer as well as during the tethered running the parameters of heart rate were continuously monitored using the Heart Rate Monitor Polar Accurex Plus.
Blood samples from the fingertip were taken in the 6th minute of the recovery for the estimation of lactate concentration. The enzymatic method (Boehringer sets) was used for the analysis.

A paired $t$-test was employed to determine the statistical significance between the variables of isokinetic cycling and tethered running, $p < 0.05$ values were considered significant.

**Results**

The correlation analysis showed (Fig. 3) a close relationship between the parameters of anaerobic capacity achieved in the 30-second “all-out” tethered running on the treadmill and cycling on the isokinetic ergometer, such as maximal power ($r = 0.877$), mean power ($r = 0.920$), and fatigue index ($r = 0.896$).

The tethered running and isokinetic cycling did not differ significantly either in maximal power ($745.2 \pm 143.7$ W and $757.1 \pm 130.7$ W, respectively) or in mean power ($598.4 \pm 87.6$ W and $614.9 \pm 80.6$ W, respectively). However, the fatigue index and blood lactate concentration were significantly ($p < 0.05$) higher in tethered running ($30.8 \pm 6.1\%$ and $12.5 \pm 1.3$ mmol/l, respectively) than in cycling ($26.9 \pm 13.9\%$ and $10.6 \pm 1.4$ mmol/l, respectively).
Discussion and conclusions

Similar values of maximal and mean power during the exercise modes examined indicate that the 30-second “all-out” tethered running on the treadmill may represent an acceptable alternative for the assessment of anaerobic capacity. However, in comparison with isokinetic cycling slightly higher values of fatigue index and blood lactate can be achieved, in particular at higher velocities (Zemková, Hamar, & Schickhofer, 1999). This fact should be taken into consideration if such an exercise is employed.

Using this method the actual state as well as the specific training effect may be evaluated, as has been shown in the case of four-week karate training focused on the improvement of anaerobic capacity (Zemková, Hamar, & Schickhofer, 1999). In contrast, no changes in the power output have been found following the same period of karate training assessed by the 30-second “all-out” load on the isokinetic cycle ergometer.

These differences may be ascribed to the specific adaptation due to the preferred exercise mode used for anaerobic training. Therefore, in order to obtain the relevant information concerning anaerobic capacity, any exercise similar to the ones used during training should be preferred, such as jumping, cycling, stair uphill running, paddling, rowing, tethered swimming, tethered running, etc. Contrary to the untrained population, in which one of the standard tests can be applied, in athletes it should be the activities which involve the same or similar muscle group and movement patterns as during sport-specific tasks.

This may be corroborated by the results of our previous study (Hamar & Zemková, 2000) in which the analysis of power during short term bouts of cycling and tethered running showed that sprinters performed significantly better on the treadmill than on the cycle ergometer and cyclists achieved higher “all-out” power during cycling than during tethered running. Thus, in some sports tethered running on the treadmill may be considered as a more specific and hence more suitable alternative for the assessment of anaerobic capacity.

This finding is in agreement with the recent reports of several authors (Lakomy, 1985; Cheetham & Williams, 1985; Cheetham, Boobis, & Brooks, 1986; Nevill, Boobis, & Brooks, 1989; Lakomy, 1994; Falk, Weinstein, Dotan, Abramson, Mann-Segal, & Hoffman, 1996; Jaskólski, Veenstra, & Goossens, 1996; Jaskólska, Goosens, & Veenstra, 1999) who documented that such a method allows the evaluation of specific sprint-running anaerobic power.

Also, the deficiency of validity that has been demonstrated by the rather moderate correlation coefficients (r = 0.69 to 0.86) between the power outputs in various forms of anaerobic tests performed on the cycle ergometer to the spring-running performance for 50 yards to 300m (Bar-Or & Inbar, 1978; Tharp, Newhouse, Uffelman, Thorland, & Johnson, 1985; Patton & Duggan, 1987), questions the suitability of cycling exercise for the sport-specific assessment of anaerobic capacity.

Therefore, tethered running on the treadmill seems to be a suitable method providing useful information concerning the ability to exert maximal anaerobic power (highest 5-second period) and anaerobic endurance (mean 30-second power and fatigue index), namely, for weight-bearing athletes. However, further studies are needed to validate this method on large samples of specific sports as well as different age groups and populations.

Taking into account no significant differences in the maximal and mean power production between the exercise modes examined, it may be concluded that 30-second “all-out” tethered running on the treadmill represents an acceptable alternative for the assessment of anaerobic capabilities. However, in comparison with isokinetic cycling slightly higher values of fatigue index and blood lactate have to be expected.
References


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Uvod

Maksimalno opterećenje na bicikl-ergometru tipičan je oblik vježbanja koji se koristi za procjenu anaerobnoga kapaciteta u laboratorijskim uvjetima. Međutim, pedaliranje za mnoge sportove nije ekvivalentna mišićna aktivnost zato što ne omogućuje specifičan oblik mišićnog rada. Za većinu aktivnosti s opterećenjem, trčanje se čini prikladnijom alternativom. Međutim, u jednostavnom slobodnom trčanju na pokretnom sagu praktično nije moguće primijeniti maksimalno radno opterećenje u ograničenom vremenu. Taj nedostatak može se izbjeći primjenom modificirane aktivnosti koja se zove trčanje na pokretnom sagu sa svladavanjem otpora (tethered running), za vrijeme koje ispitanik, osim što trči, povlači za svoj pojas pričvršćen konopac koji je pričvršćen na zid iza sagu za trčanje. U konopac je ugrađena dinamometrijska sonda. Jednostavan računalni sustav može se koristiti za praćenje sila povlačenja, brzine trčanja i za izračunavanje postignute snage trčanja. Prikupljeni podaci ukazuju na to da sila ovisna o frekvenciji korača i snage fluktuiraju u vremenu te omogućuju izračunavanje vršnih (maksimalnih) i prosječnih vrijednosti snage za određeni period. Povlačenje maksimalno trčanje na pokretnom sagu, u trajanju od 30 sekundi, sa svladavanjem otpora, kao pansen testu Wingate, također daje podatke o maksimalnoj i prosječnoj snazi, na osnovi čega se može izračunati indeks umora. Međutim, ulazno u literaturu dobro dokumentiranim i često korištenim maksimalnim testovima na bicikl-ergometru, o testu trčanja sa svladavanjem otpora nedostaju dokumentirane informacije vezane uz parametre anaerobnih sposobnosti.

Istraživanja bio uspoređili parametre anaerobnih sposobnosti (maksimalna i prosječna snaga, indeks umora i laktati u krvi) dobivenih u maksimalnom testu od 30 sekundi izvedenom na izokinetičkom bicikl-ergometru s onim parametrima prikupljenima testom trčanja na pokretnom sagu sa svladavanjem otpora.

Metode

Grupa od 17 studenata tjelesnog odgoja (prosječna dob 21,8±1,1 godina, visine 179,4±5,9 cm, težine 75,3±7,1 kg) dobrovoljno je sudjelovala u istraživanju. Prema slučajnom rasporedu ispitanici su izvodili maksimalni test u trajanju od 30 sekundi na izokinetičkom bicikl-ergometru, uz brzinu rotacije od 100 okretaja/min, i test maksimalnog trčanja na pokretnom sagu za vrijeme koje ispitanici, osim što trčali, povlačili su za svoj pojas pričvršćen konopac koji je pričvršćen na zid iza sagu za trčanje. Vrijednosti snage i snage povlačenja izračunivale se na osnovi čitaća na konopcu i jednostavnog računalnog sustava. Ukupna snaga na pokretnom sagu sa svladavanjem otpora daje podatke o maksimalnoj i prosječnoj snazi, na osnovi čega se može izračunati indeks umora.

Izračunati su sljedeći parametri: Pmax (iničijalni period od 5 sekundi), Pmean (prosječna vrijednost izračunata na osnovi cijelog trajanja testa, 30 sekundi) i indeks umora (omjer opadanja snage, razlike Pmax i Pmin vrijednosti).

Rasprava i zaključak

Za vrijeme vježbanja na bicikl-ergometru, kao i za vrijeme maksimalnog trčanja sa svladavanjem otpora kontinuirano je praćenje frekvencije srca. Uzorci krvi iz prsta uzimali su se u šest minuti oporavka kako bi se procijenila koncentracija laktata. Korelacijska analiza...
pokazala je visoku povezanost između parametara anaerobnih sposobnosti dobivenih za vrijeme trčanja na sagu u trajanju 30 sekundi sa svladavanjem otpora i vožnje na izokinetičkom bicikl-ergometru, kao što su maksimalna snaga (r=0.877), prosječna snaga (r=0.920) i indeks umora (r=0.896). Trčanje sa svladavanjem otpora i izokinetičko bicikliranje ne razlikuju se statistički značajno ni po maksimalnoj snazi (745.2±143.7 W i 757.1±130.7 W) ni po prosječnoj snazi (598.4±87.6 W i 614.9±80.6 W). Međutim, indeks umora i koncentracija laktata u krvi statistički su značajno bili veći u maksimalnom trčanju sa svladavanjem otpora (30.8±6.1% i 12.5±1.3 mmol/l; p<.05).

Uzme li se u obzir da se nije pokazala statistički značajna razlika u ispoljenoj prosječnoj i maksimalnoj snazi između korištenih modaliteta vježbanja, može se zaključiti da je maksimalno trčanje na pokretnom sagu u trajanju od 30 sekundi sa svladavanjem otpora prihvatljiva alternativa za procjenu anaerobnog kapaciteta. Međutim, u usporedbi s izokinetičkim bicikliranjem, mogu se očekivati više vrijednosti indeksa umora i koncentracije laktata u krvi.
ALTERATIONS OF RESPONSES TO TRANSCRANIAL MAGNETIC STIMULATION DURING REPEATED ISOMETRIC CONTRACTIONS

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Abstract:
Ten healthy male students (age 22.1±2.3 years), without neurological disorders, volunteered for the study. Muscle fatigue of the first dorsal interosseus muscle was studied during repeated isometric voluntary contractions until exhaustion. Transcranial magnetic stimulation was used to elicit motor-evoked potentials and mechanical responses in the exercised muscle. The averages of 6 responses were analyzed pre-exercise, every 25 contractions during the exercise and during the recovery phase. The average of isometric contractions until the fatiguing of a subject was 175 repetitions. During the protocol, amplitudes of mechanical as well as electrophysiological responses changed significantly (P<.001 and P<.002, respectively). A potentiation of the electrophysiological responses was prominent only at the beginning of the task while twitch force remained increased until the final fatiguing. Both measures were depressed after the task termination. However, diminishment of electromyographic responses remained more prominent. During the recovery phase twitch force fully recovered, while electrophysiological potentials remained depressed (P<.05). During and after the fatiguing task, modulations of mechanical and electrophysiological responses to transcranial magnetic stimulation were not parallel. Additional qualitative analysis of the electrophysiological responses revealed a systematic shift from biphasic responses in pre-tests to polyphasically shaped ones during the fatigue and recovery phase. This phenomenon could indicate a shift from monosynaptic to oligosynaptic corticospinal projections which could namely cause temporally different recruitment of the motor units. The modulatory mechanism is most probably of supraspinal origin while F wave as a measure of peripheral excitability did not show significant modifications through the experiment.

Key words: central fatigue, brain stimulation, motor-evoked potentials, twitch

REAKTIONSÄNDERUNGEN AUF TRANSKRANIALE MAGNETISCHE STIMULATION WÄHREND WIEDERHOLTEN ISOMETRISCHEN KONTRAKTIONEN

Zusammenfassung:
10 gesunde Studenten (im Alter 22.1±2.3 Jahre) ohne neurologische Störungen nahmen an der Studie freiwillig teil. Die Ermüdung des ersten dorsalen zwischen den Knochen liegenden Muskels wurde während wiederholten isometrischen freiwilligen Kontraktionen bis zur Erschöpfung untersucht. Die transkraniale magnetische Stimulation wurde angewandt, um motorisch-provozierte Potenziale und mechanische Reaktionen im betreffenden Muskel zu bekommen. Die durchschnittlichen Werte von 6 Reaktionen wurden vor der Übung analysiert, nach jeder 25sten Kontraktion, sowie während der Übung und während der Erholungsphase. Die durchschnittlichen isometrischen Kontraktionen bis zur Ermüdung des Probanden betrugen 175 Wiederholungen. Im Laufe des Protokolls änderten sich wesentlich die Amplituden der mechanischen und der elektrophysiologischen Reaktionen (P<0.001 und P<0.002). Die Potentiation von elektrophysiologischen Reaktionen war nur am Anfang der Aufgabe zu merken, während die erhöhte Reaktionskraft bis zur endgültigen Erschöpfung blieb. Die beiden Werte nahmen nach der Aufgabe ab. Die Abnahme der elektromyographischen Reaktionen war aber auffälliger. Während der Erholungsphase wurde die Reaktionskraft völlig zurückgewonnen, aber die elektrophysiologischen Potenziale blieben niedrig (P<0.05). Während und nach der Aufgabe waren die Modulationen von mechanischen und elektrophysiologischen Reaktionen auf transkraniale magnetische Stimulation nicht parallel. Eine zusätzliche Qualitätsanalyse elektrophysiologischer Reaktionen brachte zum Vorschein eine systematische Änderung von biphasischen Reaktionen vor den Tests zu polyphasischen Reaktionen während der Ermüdungs- und Erholungsphase. Dieses Phänomen könnte auf die Änderung von monosynaptischen zu oligosynaptischen kortikospinalen...
Projektionen hindeuten, was nämlich zur Folge eine zeitlich verschiedene Rekrutierung motorischer Einheiten haben könnte. Der Modulatormechanismus ist höchstwahrscheinlich supraspinalen Ursprungs, während die F Welle, als eine Größe der peripheren Erregbarkeit, keine wesentlichen Modifikationen während des Experiments aufzeigte.

**Schlüsselwörter:** zentrale Ermüdung, Gehirnstimulation, motorisch provozierte Potenziale, Zucken.

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**Introduction**

Fatigue of the motor system is characterized by a decrease in force generated by the neuromuscular system during sustained or repeated muscle activity. It can be divided into peripheral and central fatigue. A contribution to fatigue coming from mechanisms proximal to the neuromuscular junction is known as central fatigue and vice versa (Gandevia, 2001). During the last fifteen years transcranial magnetic stimulation (TMS) has been used by some investigators concerning the corticospinal mechanisms of fatigue. Reports are in disagreement about the modification of motor-evoked potentials (MEP) during and after a prolonged muscular activity (Taylor & Gandevia, 2001). This inconsistency most likely derives from the very different types of experimental protocols employed in these studies (Rollnik, Schubert, Albrecht, Wohlfarth, & Dengler, 2000; Löscher & Nordlund, 2002; Taylor, Petersen, Butler, & Gandevia, 2000). The increasing body of literature relating to central fatigue has been devoted to the identification of the underlying physiological mechanisms for MEP modulation (Mazzocchio, Rothwell, Day, & Thompson, 1994; Taylor et al., 2000). This paper should point out the complex nature of the MEPs and subsequent twitch (TW) responses while the neuromuscular system is to be found in a potentiation or depression state.

The present study was therefore designed to investigate the altering of neurophysiological and mechanical responses to TMS during repeated fatiguing isometric contractions. Before and after the exhausting motor task M wave (MW) was analysed as a measure of efferent peripheral excitability. Additionally, in a few subjects only F waves (FW) were measured in order to test the possible effect of spinal excitability changes.

**Methods**

Experiments were performed on 10 healthy male students (aged 22.1±2.3 years) with no neurological disorders. They volunteered for the study, were highly motivated and had considerable experience in maintaining voluntary contraction. They all gave their full informed consent and the experimental procedure was carried out in consistence with the Tokio-Helsinki declaration.

**Muscle contraction and electromyography**

Experiments were performed on the first dorsal interosseus muscle (FDI). The subject was lying in a supine position and his right upper extremity was positioned into an isometric brace (Figure 1). The forearm and 3rd, 4th and 5th fingers were firmly fixed and held in a pronated position. The thumb was fixed in a position of 60º radial abduction. The tested 2nd finger was positioned into a channel which had its axis aligned with the metacarpo-phalangeal joint of the 2nd finger (direction for radial/ulnar...
abduction). Through the channel, the 2nd finger was attached to a force transducer whose output was displayed on-line on an oscilloscope and fed to a computer. The oscilloscope signal was displayed above the subject in order to provide visual feedback of the sustained muscle tension. When the skin had been prepared, silver/silver chloride surface EMG electrodes were glued over the FDI as described by Ridding and Taylor (2001). An active EMG electrode was placed above the muscle belly, while the reference was attached to the interphalangeal joint of the second finger. Resistance under all electrodes was below 5 kΩ. Data capture was done by Synergy (Oxford Instruments, UK) a system for neurophysiological measurements, whereas later calculations were carried out using the software that we have developed on our own for the purpose of this experiment.

**Transcranial magnetic stimulation**

A figure-of-eight coil (9.5 cm external diameter) powered by Magstim 200 stimulator (Magstim Company Ltd, Whitland, UK) was used for the TMS. The coil was held in an optimal position over the left part of the scalp for evoking MEPs in the target muscles of the right hand. The induced current flow was in a posterior-to-anterior direction, which should activate the cortico-spinal tract transsynaptically (Di Lazzaro, Oliviero, Profice, Saturno, Pilato, Insola, Mazzone, Tonali, & Rothwell, 1998). The proper spatial relationship between the coil and the subject’s head was secured using a stereotactic pneumatic brace of the author’s own production (Figure 2). The intensity of the stimulus was 30% above the motor threshold for the FDI. The threshold was defined as the lowest intensity evoking at least five out of 10 trials of above 100 µV peak-to-peak amplitude. The trials in whose background the EMG activity was present (amplitudes larger than 50 µV) in the 100 ms pre-stimulus time period were rejected off-line. Mechanical responses of the FDI were measured concurrently as a force: time curve detected by the force sensor positioned perpendicular over the muscle belly (Figure 1). The argumentation for such a modification of the classical TW was provided by the previous pilot study. It has been based on the fact that TMS is non-selective in its nature (divergent corticospinal control) and hence it is not possible to selectively activate the 2nd finger abductors only. As a result net torque around the joint would have been affected by many other muscular factors and not purely by agonist tension (antagonist activation, activation of proximal muscles, temporal delay, etc.). Stores of 6 responses were constructed for every time point of the experimental. Peak-to-peak amplitudes of the averaged MEPs and peak force of the TW were analyzed.

**Figure 2. Maintenance of the head position using a mechanical brace and stereotactic manipulation handle based on pneumatic mechanisms of fixation. By the use of the two technical expedients it was possible to secure a controlled spatial relationship between the brain and a stimulation coil. It is an important issue when concerning the site of stimulation and its potential impact on motor output.**

**Electrical nerve stimulation**

In order to check the appearance of changes in the peripheral neuromuscular factors as a result of fatigue, M waves were measured prior to the beginning of the fatiguing task and immediately after exhaustion. In a relaxed subject the ulnar nerve was stimulated at the wrist using a single supramaximal electrical stimulus (symmetrical, square, biphasic, width 0.2 ms). The strongest response out of three consecutive stimulations was used for further calculations of peak-to-peak amplitudes. Additionally, F wave of the FDI was measured in four subjects. It is the EMG response of the homonymous muscle, which appears as a result of the antidromic volley after the supramaximal stimulation of the peripheral alpha motoneurone axons. During the first (onset of the task) and the last ten contractions FWs were measured and stores were constructed for further analyses. The amplitude was analyzed. Parameters of electrical stimulation were the same as for MW though stimulation was done at the moment of a voluntary contraction.
Experimental protocol

When summed up, the preparation procedure included EMG electrode placement and positioning of a subject onto a therapeutic table with his head and the right upper extremity properly fixed. Initially, the threshold for TMS was determined and pre-measurements of MWs and MEPs were carried out. Afterwards, the maximal voluntary contraction of the FDI was initially identified by means of the 2nd finger torque. Following that, the subject were asked to proceed with voluntary contractions of 75% of the estimated maximum. Feedback of a dynamometer signal was provided to subjects while performing the task. Then, the subjects repeated cycles of 6 seconds of active contractions and 4-second pauses, alternately. As the force began to fall below the pre-set value, the feedback signal served only as a time sequencer, while the subject tried to perform his best. The task was terminated when the voluntary force had fallen below 60% of the maximum. Hence, the “point of exhaustion” depended on an individual.

TMS-evoked MEPs of FDI were studied during prolonged repeated isometric voluntary contractions. TMS was applied during the rest intervals between two subsequent voluntary contractions (note the marks on the abscissa in Figure 3). The averages of 6 responses were analyzed repeatedly (pre-exercise, every 25 contractions, during the recovery phase). A prolonged effect of fatigue was traced during the recovery phase 3, 5 and 10 minutes after exhaustion.

The peripherally evoked potentials were measured only twice in the four subjects who took part in the subsequent experiment that involved FW measurements. At the beginning of the task and during the additional ten repetitions of muscle contractions, after 60% of the borderline the task could not be accomplished anymore.

Analysis of data

Statistical significances of differences between peak-to-peak amplitudes of MEPs and amplitudes of the concurrently measured TWs elicited during the repeated isometric contractions were estimated using the repeated measures of analysis of variance (ANOVA). As post-hoc tests of the two variables and as the main test for the estimate of FW and MW pre/post differences, the Student’s t-test was used. In order to test potential discrepancies between the behavior of MEPs and TWs the analysis of covariance (ANCOVA) was introduced.

Results

The main results are presented in Figures 3 and 4. The average number of isometric contractions up to fatiguing of a subject was 175 repetitions (maximum 225 reps, minimum 110 reps). During the protocol MEP amplitude and TW force changed significantly (p<.001 and p<.002, respectively). The results of the post hoc t-tests are presented in the graph (Figure 3). Thus, filled shapes (squares - MEP, circles - TW) indicate statistically significant modulations of responses related to the introductory measurements. It can be noticed that MEPs are augmented at the very beginning and then they significantly decrease from the 25th repetition on. At first, this phenomenon is very steep and afterwards it progresses moderately, so that MEPs’ amplitudes are significantly attenuated (to 60% of the control value captured before the onset of the task) at the point of exhaustion. Ten minutes after the termination of the task, the reduced MEPs had not recovered completely (P<.01). However, the restorative tendency could be identified. The mechanical responses to TMS behaved in a different way. The amplitudes of TWs were enlarged at the onset of the exercise and remained such until the very end of it. Any significant depression of the mechanical responses could not be seen.
earlier than three minutes after exhaustion. In this late phase of recovery, mechanical and physiological parameters behaved similarly. To infer, both measures related to TMS evoked responses which were depressed at the end of the fatiguing exercise. However, MEP diminishment remained more prominent. During the recovery phase TW fully recovered in its amplitude, while MEP remained depressed. These differences between the measures were confirmed by ANCOVA as well.

The amplitude of the MW in FDI, elicited by the wrist ulnar nerve stimulation after a prolonged repeated isometric fatiguing voluntary contraction, did not differ significantly from the same stimulation applied before this exhausting protocol (Figure 4). The values remained actually unchanged and the variability of the results was low. Although additional control measurements were performed in four subjects only, FWs showed no systematically behavioral patterns among the subjects. Intra-individual variability among single responses was very high at the same test point.

Discussion and conclusion

While repetitively performing 6-second isometric contractions of the FDI that were separated by short 4-second pauses, initial enhancement of responses to TMS took place. As the subject proceeded with the exercise, mechanical and electrophysiological evoked responses started to behave in a strikingly different way. Therefore, during and after the fatiguing task, the modulations of the MEP and TW evoked by TMS were not parallel. The MEP depression was not strictly mirrored in TW. However, 3 and 5 minutes after the fatigue point, both responses were significantly depressed. Peripheral efferent and spinal mechanisms seemed not to be affected during the exhaustive exercise.

It was already demonstrated by Balbi and associates (Balbi, Perretti, Sannino, Marcantonio & Santoro, 2002) that MEP elicited by TMS increased soon after a non-exhaustive voluntary contraction of the target muscle. They showed that maximal facilitation of the response was provoked by the shortest and strongest muscle contraction. The results of the present study are consistent with these observations, namely, obvious initial facilitation of the responses was observed during the first contractions. Many possible underlying mechanisms for the MEP augmentation could be taken into account. Theoretically, the site of increased facilitation could be peripheral or central as well as afferent or efferent.

Most studies dealing with post-contraction facilitation of the MEPs propose cortical mechanisms as responsible for the introduced phenomenon. In their investigation, Mazzocchio and associates (1994) concluded that tonic voluntary contraction of the target muscle decreased the threshold of indirect activation (trans-synaptic recruitment) of corticospinal neurones, but not for direct stimulation of their axons. Supportively, Ridding, Taylor and Rothwell (1995) discussed the voluntary drive reducing the excitability of inhibitory circuits in cortical areas that project to the active muscle. However, a high incidence of an enhanced muscle spindle discharge after the voluntary contraction suggests that more peripheral factors such as muscle “history” should be taken into account when interpreting changes in modulations of corticospinal excitability (Wilson, Gandevia, & Burke, 1995). Nevertheless, when FWs during the first 10 voluntary contractions were compared to the subsequent FWs, no obvious tendency of change was present. But, it should be remembered that the fluctuations of FWs were rather high. Such analysis of non-averaged data might thus be questionable.

Besides all the above-mentioned mechanisms, the mechanical response to TMS additionally depends on the mechanical status of the muscle-skeletal system. Thus, the captured response is an integrated event comprising...
corticospinal excitability, functioning of the excitation-contraction coupling at the periphery, and finally initial stiffness of the muscle. The latter would be normally sustained at a relatively high level throughout the voluntary task, thus serving as a basis for the higher TW force. Although MEPs returned to the control values after the first 25 contractions, TW amplitudes remained significantly above the initial level. There are two main potential reasons for the discrepancies observed. First, because of the increased muscle stiffness lower activation of the muscle tissue could result in relatively constant mechanical responses. Second, temporal desynchronization of the input volley acting onto the spinal motoneurons would possibly cause polyphasic evoked responses detected by surface EMG (an effect of volume conduction), hence the smaller peak-to-peak amplitude of the MEPs.

After a subject had fatigued, depression of responses took place. These changes were statistically significant and were more prominent in MEP than in TW. At the end of the exercise there was a 40% average reduction in the MEP amplitude according to the control values, while, on the other hand, TW was not yet attenuated at that moment. However, from the 3rd minute of the recovery phase on, both responses to TMS behaved in a similar way. Taylor, Buttler, Allen, and Gandevia (1996) suggested decreased intracortical facilitation and increased intracortical inhibition after the fatiguing task. In the experiment being discussed here FW as a peripheral measure was not modulated as a result of fatiguing exercise, although elicited at the two intervals of the highest MEP alterations. It is very difficult to evoke H reflex in the intrinsic hand muscles. Even if there are methodological problems of comparing FW and HW while they are not equally sensitive to changes in motoneuronal excitability (Hultborn & Nielsen, 1995, 1996), FW is frequently used as a valid measure for this purpose in the intrinsic hand muscles such as FDI. Nevertheless, the results of our experiment are consistent with other studies probing H reflexes during the fatiguing task in other than the intrinsic hand muscles (Ljubisavljevic, Milanovic, Radovanovic, Vukcevic, Kostic, & Anastasjevic, 1996). If summed up, it seems very likely that the actual site responsible for the modulation of the EMG responses to TMS while exercising were supraspinal centres. In the context of peripheral mechanisms possibly, at least in part, responsible for MEP modulations changes in axonal excitability of alpha motoneurones should be additionally considered (Burke, Kiernan, & Bostock, 2001; Chan, Lin, Pierrot-Deseilligny, & Burke, 2002). As MW measured at the two most extreme points (means of MEP and TW changes) showed no significant alterations, it can be concluded that efferent peripheral excitability was not influential.

One of highly important underlying mechanisms for MEP potentiation could be afferent input from the periphery to the central system. Namely, sensory-motor integration is one of the most prominently developing research areas in human neurosciences. If the main concepts of this field are summed up, it can be concluded that there could be no volitional movement unless the sensory input precedes it. Taylor and associates (2000) tested the effect of ischaemia on the modulation of post exercise MEP depression. They showed that ischaemically sensitive group III and IV muscle afferents did not mediate depression of responses to motorcortical stimulation after a fatiguing exercise. On the other hand, gating of signals coming from the large fibre afferents (Ia, II, large cutaneous fibres) is probably one of the most responsible mechanisms, which could strikingly affect the excitability of supraspinal centres (Abbruzzese, Marchese, Buccolieri, Gasparetto, & Trompetto, 2001; Chen, Corwell, & Hallet, 1999; Hirashima & Yokota, 1997; Inghilleri, Berardelli, Crucu, Manfredi, Priori, & Rothwell, 1995). The role of sensory input for motor control in the fatiguing task has been demonstrated recently (Rollnik et al., 2000). It showed how, using somatosensory manipulation, a decrease in the central drive can be overcome at the fatigue point.

Finally, the MEP measured with surface electrodes is an integrated response that besides corticospinal excitability depends also on other factors such as spatial and temporal summation of the surface EMG signal. Additional qualitative analysis of the MEPs revealed a systematic shift from biphasic responses in the pre-tests to polyphasically shaped ones during the fatigue and recovery phase. This phenomenon could indicate a shift from monosynaptic to oligosynaptic corticospinal projections, which could namely cause temporally different recruitment of the motor units. A group of Pierrot-Deseilligny (Gracies, Meunier, & Pierrot-Deseilligny, 1994; Pauvert, Pierrot-Deseilligny, & Rothwell, 1998) suggested spinal premotoneurons as the modulators of the
descending motor commands. Corticospinal fibres are thus able to activate “propriospinal” neurons which act onto the alpha motoneurons. If this circuitry is modulated, it can affect the final output characteristics of the efferent volley and possibly detected MEPs. Any geometrical modifications of the EMG potentials to TMS (as a result of desynchronization) would affect amplitudes of responses, but no changes would be seen in mechanical responses providing the same population of muscle fibres recruited.

To infer, prolonged repetitive isometric voluntary contractions induced initial augmentation and subsequent depression of responses to TMS. Based on the results, peripheral factors can be excluded from having a role in the modulations. Mechanical responses to TMS did not strictly mirror MEPs, moreover, they behaved strikingly differently at some points. Cortical mechanisms are most possibly responsible for the global behavior of the evoked responses. Their level of excitability is very likely highly influenced by the afferent input. Discrepancies between TWs and MEPs could be explained by the modulation of cervical propriospinal system and by the mechanical explanations related to the role of muscle stiffness in TW force production.

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Šarabon, N.: ALTERATIONS OF RESPONSES TO TRANSCRANIAL MAGNETIC STIMULATION DURING REPEATED ISOMETRIC CONTRACTIONS


PROMJENE ODGOVORA NA TRANSKRANIJALNU MAGNETSKU STIMULACIJU ZA VRIJEME PONOVLJENIH ISOMETRIČKIH KONTRAKCIJA

Sažetak

Uvod

Posljednjih petnaest godina neki istraživači koriste transkranijalnu magnetsku stimulaciju kako bi istražili kortikospinalne mehanizme umora. Njihovi izvještaji ne slažu se oko modifikacije motoričkih evociranih potencijala za vrijeme i nakon produžene mišićne aktivnosti. Naše je istraživanje stoga osmišljeno kako bi se ispitala promjena neurofizioloških i mehaničkih odgovora na transkranijalnu magnetsku stimulaciju za vrijeme ponavljane iscrpljujuće izometričke kontrakcije. Status perifernih modulatornih mehanizama testiran je valovima M i F.

Metoda

Eksperiment je proveden na deset zdravih studenata (u od dobri do 22±2.3 godine) bez ikakvih neuroloških poremećaja. Mišićni umor prvog dorzalnog interkostalnog mišića proučavao se za vrijeme ponavljane voljne izometričke kontrakcije (ponavljane kontrakcije u trajanju 6 sekundi s pauzom u trajanju 4 sekunde). Ispitanici su ovu aktivnost izvodili sve dok su bili sposobni proizvoditi mišićnu silu veću od 60% njegovog početnog maksimuma. Transkranijalna magnetska stimulacija korištena je kako bi se izmjerili motorički evocirani potencijal i mehanički odgovori u aktivnom mišiću. U prosjeku je šest odgovora analizirano prije vježbe, te sva 25. kontrakcija za vrijeme vježbe i u fazi oporavka.

Rezultati

Prosječan broj izometričkih kontrakcija prije nastupanja umora kod ispitanika bio je 175 ponavljanja. Za vrijeme vježbe, amplitude mehaničkih, kao i električkih odgovora značajno su se mijenjale (p<.001 i p<.002). Potencijal električkih odgovora bio je istaknut samo na početku zadatka dok je sila kontrakcije još bila visoka sve do nastupanja konačnog umora. Obje su se mjere smanjile nakon završetka zadatka. Ipak, smanjenje elektromiografskih odgovora bilo je veće. U fazi oporavka sila kontrakcije se u potpunosti oporavila, dok je elektrofiziološki potencijal i dalje ostao smanjen (p<.05).

Rasprava i zaključak

Za vrijeme i nakon umarajućeg zadatka, modulacija mehaničkih i električkih odgovora na transkranijalnu magnetsku stimulaciju nije tekla paralelno. Dodatna kvalitativna analiza električkih odgovora pokazala je sistematičan prijelaz sa bi-fazičnog odgovora, zabilježenog u mjerenju prije testa, na poli-fazičan odgovor koji se javlja u fazi umaranja i oporavka. Ovaj fenomen može ukazivati na prijelaz s monosinaptičkih na oligosinaptičke kortikospinalne projekcije što, naime, može uzrokovati vremenski različitu selekciju i aktivaciju motoričkih jezgara. Amplituda vala M, dobivena stimulacijom ulnarnog živca zgloba šake nakon produžene ponavljanja umarajuće voljne izometričke kontrakcije, nije se značajno razlikovala od iste dobivene stimulacijom primijenjenom prije ovog iscrpljujućeg testa. Val F, kao mjera perifernih pobuđenosti, nije pokazao značajne modifikacije za vrijeme eksperimenta. Na temelju dobivenih rezultata moguće je isključiti utjecaj perifernih faktora na ove modulacije.

Mehanički odgovori na transkranijalnu magnetsku stimulaciju nisu striktno odražavali električki odgovori, što je u nekim točkama mjerilo. Za ukupni obrazac evociranih odgovora najvjerodostojnije su odgovorni kortikalni mehanizmi. Čini se da je razina pobuđenosti evociranih odgovora snažno pod utjecajem aferentnog ulaza. Nearsrmjer između mehaničkih i električkih odgovora mogao bi se objasniti modulacijom cervikalnog proprio spinalnog sustava te mehaničkim objašnjencima izvornim s ulogom mišićne čvrstoće u produkcijskim mišićnim trzajama.
HOW CAN DYNAMIC RIGID-BODY MODELING BE HELPFUL IN MOTOR LEARNING?
– LEARNING PERFORMANCE THROUGH DYNAMIC MODELING

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Abstract:
The purpose of this research project was to bridge the gap between motion analysists and athletes and coaches by establishing a platform for the communication amongst the three parties. The first part of this project depicted that: 1) differences amongst the external view (motion analysists), internal sight (athletes) and internal sight from external view (coaches) were caused by the inertial (environment-fixed) and the non-inertial (body-fixed) system; 2) joint rotations were not identical with the muscular moment, therefore, passive rotations can occur; 3) critical phases in a skill control, which can be revealed by using modeling simulation, should be emphasized during learning; and 4) dynamic modeling has the potential to link and to unify the three views and supply a more holistic picture of human motor control. Based on these results, a learning model was constructed in the second part of the project. The essence of the model is to supply learners with the control signal (muscle moments) obtained from individual anthropometrical data and should-be-learned kinematics. Such an individualized learning process consists of: 1) obtaining kinematic characteristics of a should-be-learned skill using motion capture, 2) substituting the model’s anthropometrical data with a learner’s data, and applying inverse dynamic analysis to the model for obtaining muscle moments – the individualized control signal, and 3) applying the control information in the skill learning. The model was validated in a motor learning study. The study unveiled that dynamic modeling is well suited for improving communication with athletes and coaches as well as for improving efficiency of learning.

Key words: kinematics, anthropometry, muscular moments, passive phase, critical phase

Zusammenfassung:
Die Absicht dieses Projekts war, die Kluft zwischen den Bewegungsanalysisten, den Sportlern und Trainern zu überbrücken, um eine Plattform für die Kommunikation zwischen den drei Parteien herzustellen. Im ersten Teil des Projekts wurde klar, dass 1) die Unterschiede zwischen der äußeren Sicht (den Bewegungsanalysisten), der inneren Sicht (den Sportlern) und der inneren Sicht aus äußerem Betrachtungspunkt (den Trainern) von (umweltgebundenen) Inertialsystemen und (körpergebundenen) Nicht-Intertialsystemen verursacht sind; 2) dass die Gelenkrotationen mit den Muskelmomenten nicht identisch sind, weshalb passive Rotationen aufkommen können; 3) dass man Nachdruck auf kritische Phasen der Fertigkeitskontrolle während des Erwerbs setzen sollte, was man mit Hilfe der Modellierungssimulation erzielen kann; 4) dass die dynamische Modellierung imstande ist, die drei Sichten zu verbinden und zu vereinigen, um dadurch das holistische Bild von der menschlichen motorischen Kontrolle zu gewinnen. Aufgrund dieser Ergebnisse, wurde im zweiten Teil des Projekts ein Lernmodell entworfen. Der Kern des Modells ist, den Lernenden ein Kontrollsignal (Muskelmomente) zur Verfügung zu stellen, das sich aus individuellen anthropometrischen Angaben und einer noch-zu-erwerbenden Kinematik ergibt. Ein solcherart individualisierter Erwerbsprozess setzt voraus, dass 1) man die kinematischen Eigenschaften einer zu erwerbenden Fertigkeit mit Hilfe der Bewegungserfassung bestimmt, 2) dass man die anthropometrischen Angaben des Modells mit denen des Lernenden ersetzt, und
Introduction

One of the major goals in the study of motor learning is to understand which influential parameters are involved in the maximization of learning (Schmidt, 1988). Therefore, biomechanical researches in motor learning should be focused on this point. One useful approach is to combine objective methods with subjective means (Magill, 2001). Objective methods are related to an external view, whereas the subjective means (experiences) are related to internal sight. Due to the diverse points of view, there are some communication disturbances among coaches, athletes and motion analysists, and the teaching method based on personal experience is widely used. However, the rationale for decisions or the understanding based on personal experiences may differ from one educator to another (Magill, 2001). This concern was confirmed by a quantitative research (Shan, Sust, Simard, Bohn, & Nicol, 2004). Hence, improving the communication amongst coaches, athletes and motion analysists plays an important role in helping motor learning to step out of experience and into an objective and quantitative transaction.

In order to eliminate the communication barriers, the origination of the misunderstandings should be firstly located. The first part of this research project demonstrated that the inertial (environment-fixed) and non-inertial (body-fixed) systems as well as the coupling of body segments established the differences amongst the motion analysists, coaches and athletes. Because of the non-inertial forces and segmental coupling, joint rotations are not identical with the muscular moments; hence passive rotations (McGeer, 1990) can occur. All these facts imply the divergence of the motion analysis description (kinematic characteristics) of a skill and the controlling experience of an athlete.

Precedent studies (Bernstein 1967, first published 1940; Schmidt, 1975, 76; Kelso, 1984; Turvey, 1977, 1990) unveiled that simplifying motor learning is actually to discover ways to reduce the degrees of freedom of a skill, which could be reached by supplying the following information to learners: specific muscles to be used, the actual force, and detailed timing of the control (Shea & Wright, 1997). This identifies the recognition of a control pattern and not the kinematic characteristics of a skill as the common base of communication. Unfortunately, the descriptive motion analysis obtained from a motion capture (external view) could not meet the aims. However, the desired control parameters could be derived from dynamic and inverse dynamic modeling. This justifies that dynamic modeling could be a potential avenue to reach the goals. Therefore, the purpose of this study is to apply inverse dynamic analysis into the motor learning practice to see if it could serve as a platform to unify the different views, as such to improve the efficiency of motor learning. It was hypothesized that the abstracted control pattern from the modeling could supply a common basis of communication, link the experience with objective measures and increase the efficiency of learning.

Method

For the purpose of deriving the control signals from a captured skill, dynamic and inverse dynamic modeling should be employed. As suggested, the modeling could also provide modified control signals (internal sight) according to individual anthropometric uniqueness and kinematic characteristics of a skill (external view). Based on this consideration, a flight phase learning model that focuses on a control signal was constructed. The essence of the learning model was a dynamic rigid body model, which supplied the control relevant information to the learners. The learning model consists of two parts: 1) constructing a skill using motion capture and biomechanical modeling in order to receive the control signals of the skill from a professional and 2) adapting the control to an individual learner based on the learner’s anthropometric characteristics. The mechanism of the model is illustrated in Figure 1. The model could be applied in two ways: to replicate a skill and to create a new skill. The steps for duplication are as follows:
1. A skill is studied and a dynamic model is constructed by inputting the kinematic and anthropometric data of a master.
2. The anthropometric data of a master is substituted with that of a learner so as to check if the skill can be transferred to the learner without overload.
3. Critical phases (for emphasizing) and passive phases (for neglecting) are identified.
4. The motor control relevant information such as muscular moments, critical phases and passive phases are displayed to the learner.

The application for creating a new skill is identical to the above procedures with the exception of step two. The alteration of anthropometric data will be replaced by the adjustment of kinematic data (known as model simulation), enabling alternative new or modified skills to be constructed and the related muscle activities and load information could be supplied to the learner in advance.

The model was validated in a learning course at the University of Muenster. Twenty sport students (divided into two groups) participated in the trial. The experiment examined two aspects of learning, namely, knowledge and performance. The first group learned the skill in a conventional way with visual information only (Figure 2). The second group was provided with muscle control information additional to the visible information (Figure 3). The main control pattern and phases obtained from Figure 3 were:
- short extension of shoulder and hip, flexion of knee;
- flexion of shoulder and hip (only two joints necessitate control because of the passive knee rotation);
- extension of all joints; and
- unfolding the body.

After studying the supplied information, each subject was given five chances to practice the skill. Besides the supplied visual information (Figure 2 for the control group and Figure 3 for the experimental group), no other feedbacks were supplied for both groups before or between trials. Each trial was recorded using a video camera for expert evaluation. After five attempts, each subject filled out the Questionnaire part I (Figure 4). The information sheets were exchanged between the two groups upon the completion of the Questionnaire part I in order to contrast the two methods. Without further practice, Questionnaire part II (Figure 5) was completed and data analyses based on the video and questionnaire were conducted. Because of the independent samples and non-parameter nature of the questionnaire, the U-tests were applied to reveal the differences between the...
Figure 3. Learning information for group two.
two methods (Fleischer, 1988). For the purpose of judging the successes in learning objectively, all the video recorded material of the attempts were analyzed by experts. The evaluations were executed according to the following criteria:

1) An agreement of the joint controls with the given picture (timely coordination among joints).
2) A deviation from the target movement (the landing position).

With the aim of quantifying the evaluation, the movement execution of each trial was arranged on a scale of 0-10, with 10 representing an outstanding execution.

**Results**

The experimental outcome proved the method supplying both kinematic and muscle control information to be superior. In the students’ opinion, the second method (kinematic and muscle control information) leads to a better understanding of the skill. The subjective knowledge comparison is illustrated in Figure 6. The results revealed that there are significant differences ($p<0.05$) in the mental interpretation of the skill (Q1, Fig. 6), knowledge improvement throughout the trials (Q3, Fig. 6) and accuracy of the estimation of the learning effect (Q4, Fig. 6). Using the muscle

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**Motor Learning Questionnaire**

(Trampoline skill - vertical take-off and landing on the back)  
**Part I**

**Classification of scale:** Positive numbers define a high self-assessment, while negative numbers represent low self-assessment.

Example: In evaluation #3, a positive number on the rating scale means that the knowledge status is improved by practical attempts, a negative number shows little agreement between the movement conception and movement execution is present.

**Name:**

**Knowledge Evaluation:**

1. I can imagine the skill based on the visual information supplied.  
2. Before movement execution, I have confidence that I am able to complete the movement well.  
3. Did your movement conception change by practical testing (after one or more attempts)?  
4. I can estimate exactly how my course of motion corresponds with the visual representation.  
5. I felt uncertain/nervous at the time of execution of the movement.  
6. Which joint(s) do you concentrate on during the course of motion?  
   - Shoulder  
   - Hip  
   - Knee  
   - Ankle  
7. I had the impression that I control the movement rather well.

**Figure 4. Questionnaire of subjective evaluation, part one.**

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**Motor Learning Questionnaire**

(Trampoline skill - vertical take-off and landing on the back)  
**Part II**

(1: kinematics (kin.) info only, 2: kin. + muscle control info (dyn.), 3: No difference)

**Name:**

**Method Comparison:**

1. Which method could have been more helpful for your mental translation of the skill?  
2. Which method will you suggest to others for teaching the skill?

**Figure 5. Questionnaire of subjective evaluation, part two.**
control information, subjects from group two paid significantly higher attention (p<0.05) to the control of shoulders and neglected ankle control (p<0.01). Other perspectives lacked such significant differences (p>0.05).

The second part of the questionnaire was concerned with the subjective comparison of the two representations, whereby one method was not practised, but only mentally constructed. It was to decide, which source of information assisted (or would have helped) the students during the movement conception more. The results were in favor of method two, as regards the first question, half of the students were in favor of method two (Figure 7); however, there were 25% who perceived no differences between the two methods. The situation changed dramatically in the second question. 80% of the neutral group migrated to favor the second method. This change indicates that some students did not fully accept method two during trials; nevertheless, they considered that method two possessed more potential in improving the motor learning efficiency.

As for the objective analyses, it was shown that the second method resulted in a better performance. Specialists granted higher ratings to the performance of the muscle control group than the conventional method group (Figure 8). Although the superiority is not significant (p=0.16), a stronger approximation to the target exercise was achieved. The significant level of 16% denotes an improvement in learning for over 80% of the cases, which confirms the supremacy of method two.
Discussion and conclusions

One of the problems for motion analysists in practice is how to communicate with practitioners, especially in the discussion of airborne movements. The description based on kinematic characteristics is often contradictory to the practitioners’ experience. In fact, such a description could not interpret the movement control of practitioners because of the incompatibility of the systems (inertial and non-inertial) and the physics chain effect (Shan et al., 2004). In order to overcome the problem, a common communication base is vital. One potential solution may be in the muscular moments derived from individual anthropometric data and kinematic characteristics with the help of inverse dynamic analysis. The purpose of this study was to verify that the muscular moments obtained through inverse dynamics could improve the communication and simplify the motor learning process. The verification was done both subjectively and objectively.

From the subjects’ input, the following points were revealed:

- Question 1 unveiled that utilizing the muscular moments as control signals positively influenced the creation of a conception of a new movement, namely the procedural knowledge (how to do, Magill, 2001). In comparison to method one, a significant improvement was seen.

- Concerning the movement control, it was revealed that the subjects who learned through method two gained more knowledge than those who learned through method one. Although the difference was not significant (p>0.05), it signified a tendentiously higher self-assurance in method two regarding the success of completing the movement.

- Question 3 clarified that an intensification of the movement conception was seen through practice in both groups. However, a significantly higher intensification (p<0.05) was found again in group two. The result portrayed a more swift knowledge-gaining process utilizing method two as opposed to method one, because the procedural knowledge is almost identical with the task-intrinsic feedback (the control feeling, Magill, 2001). Therefore, method one, which was mainly dependent on the subjects’ previous motor control experience in a learning process, was less effective.

- Likewise, the estimated agreement of one’s movement with the information supplied in group two was significantly more enhanced than that of group one. Therefore, the knowledge of muscle control was able to provide subjects in group two with an improved estimation of to what extent their movements correspond with the visual representation. The negative rating scale of group one unveiled that the subjects did not know, on average, how their movement precipitated.

- The answer to question 5 demonstrated the presence of a tendentiously safer feeling (not significant, p>0.05) in the traditional information method group.

- According to the subjective evaluation of the attempts, there were two significant discrepancies (p<0.05) in the movement control (Q6 - shoulder and ankle, Fig. 6). The attempts of group two neglected to control the foot movements since method two did not supply information for this. Because of the small influence of the foot movements on the total passage, the information regarding foot joint control was consciously omitted so as to direct the concentration of the learning onto other joint controls substantially. The desired additional attention of the movement control was observed on shoulder-control in group two. Unfortunately, this desired attention could not be acknowledged for the hip and knee joint movements by the subjects. This revealed that both groups set their attention of movement control on hip and knee.

- The last point in the questionnaire, however, exposed one advantage for method one, even though it was not significant (p=0.11). The grade of satisfaction with the learning effect
was higher in group one than in group two. It is no wonder that the more one knows, the more divergence will be identified, and the stronger the dissatisfaction.

The positive influence of method two on the learning of the movement can be further acknowledged with the analysis of Questionnaire part II. In question one, 50% of the subjects consented to the ascendancy of method two. Only 25% of the subjects supported the opinion of the traditional representation already being sufficient for the formation of the movement conception. The rest of the subjects (25%) did not observe a difference between the two methods. An interesting development was seen in the response to question two. 70% of the subjects favored method two, 25% remained in favor of method one and only 5% stated that both methods were equal. According to the neutral subjects, the cause was the abundance of information given in method two. It was difficult to understand the connection between the movement and the information supplied in a short period (during the experiment). Nevertheless, most subjects reflected an elevated reasonability in method two for the understanding of their movement control. If one completely understood the information supplied, the preference/advantage would be given to method two.

The supremacy of method II was further confirmed by objective evaluation. The objective analyses expressed a higher percentage of subjects in group one (5 or 50%) than in group two (2 or 20%) who showed no hip joint overstretching in the initial phase, which was a critical phase. Without the required hip over-extension at the beginning, the subjects could only achieve the landing position by producing angular momentum during the jump. Thus, the subjects who did not execute this hip over-extension would also not fulfill the precondition for the execution of the skill. Likewise, the initial knee flexion was achieved by fewer subjects in group one. Instead, the simultaneous flexion of hip and knee, a non-standard development in the sense of an approximation to the target exercise was detected. These included the active knee rotation in passive phase, which was also a critical phase during the learning of the skill.

The significance level of objective evaluation is only 0.16, which challenges the validity of the method. This raises a fundamental inquiry – how could we evaluate a training method in kinesiology? Mathematically, the significant level is chosen arbitrarily. A consideration on the nature of a problem is a crucial factor for the decision. There are circumstances where a significant level of 0.1 might be appropriate (Hardyck & Peterinovich, 1969). The above suggests that kinesiologists should consider the problems of the nature of movement science for any interpretation using a defined significant level, i.e. we need to distinguish the domains dealing with basic human motor skills with high responsibilities or risks (e.g. medicine) from those without them (e.g. sports). Unfortunately, the statistical significant levels commonly chosen in medical and biological sciences ($p<0.01$ and $p<0.05$) are widely applied in scientific publications. Such strict criteria are used to prevent treatment-induced errors, e.g. if we set our limits at 0.01, we expect to make one error in every 100 inferences. Unlike medical practitioners, kinesiologists usually explore advanced human motor skills as well as their potentials. Such skills are often mastered by only a few people among us and are not the basic skills that maintain life and/or daily activities. Every experienced coach or practitioner knows that the bias existing among individual physical conditions achieves a success rate far below 95% for any complex motor skill acquisition, even by applying the same means and learning environments. Therefore, if we set our level of confidence so strictly, we run the risk of overlooking many of the real differences that exist among different training methods (Type II error of using statistics). Judging from the practitioner’s point of view, a method, which would be considered to be very productive bringing 70% of students to a successful level.

Regarding the comparison of the subjective estimations as well as the objective evaluations, it can be summarized that the information of muscular moments does ease the communication amongst the three parties and simplify motor skill learning.

A biomechanical analysis of joint muscular moments in an airborne movement is well suited for improving communication with athletes and coaches as well as for improving efficiency of learning by supplying control information.
References


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Sažetak

Uvod

Svrsna ovog istraživačkog projekta bila je premoći jazu između znanstvenika koji se bave istraživanjima pokreta te sportaša i trenera uspostavljanjem platforme za komunikaciju između trijumu skupina. U prvom dijelu projekta (Shan i sur., 2004) utvrđeno je da: 1) su razlike između vanjske perspektive (analitičari pokreta), unutarnjeg pogleda (dojam sportaša) i unutarnjeg gledišta izvanjske perspektive (treneri) uzrokane inercijalnim (nepomičan u odnosu na okolinu) i neinercijalnim (nepomičan u odnosu na sportaševu tijelo) sustavom, kao i uparivanjem segmenta tijela; 2) rotacije zglobova nisu jednake mišićnim momentima, stoga se mogu pojaviti pasivne rotacije; 3) kritične faze u kontroli vještine, koje se mogu otkriti korišćenjem segmenta tijela; i 4) dinamičko modeliranje može poslužiti kao platforma za povezivanje i ujednačivanje trih skupina različitih pogleda te pridonijeti stvaranju cjelovitije slike o ljudskoj motoričkoj kontroli. Stoga, radi uspostavljanja što bolje komunikacije sa sportašima i trenerima, analitičari pokreta bi trebali stati na deskriptivnoj razini, koja nudi jedino kinematičke parametre vještine. Takva deskripcija dokazano odstupa od sportaševog osjećaja kontrole ili trenerova iskustva.

Iskusni su treneri svjesni da je za pojednostavljivanje motoričkog učenja ključno učeniku/prestaviti znanje o tome koji su specifični mišići uključeni u pokret, kolika je sila potrebna te kakvo je stvarno vremensko-prostorno usklađivanje (timing) nužno za motoričku kontrolu. Ti aspekti pokreta pripadaju kontrolnim parametrima i mogu se izvesti iz dinamičkog i inverzno-dinamičkog modeliranja. Takav scenarij sugerira da se dinamičko modeliranje može koristiti kao platforma za unapređenje komunikacije između trih skupina različitih pogleda te pridonijeti stvaranju cjelovitije slike o ljudskoj motoričkoj kontroli. U drugom dijelu projekta (predstavljenom u ovom broju) konstruiran je model za učenje koji je utemeljen na razmatranjima iz prvog rada. Bit je modela opskrbiti onoga koji uči upravljačkim informacijam - mišićnim momentima. Takve se informacije mogu pojedinačno priskrbiti primjenom inverzne kinematičke analize na konstruiranom modelu tako da individualne antropometrijske karakteristike i kinematički parametri koje treba naučiti budu ulaz za modelnu analizu. Na taj se način dizajniran individualiziran program učenja koji sadrži: 1) dobivanje kinematičkih karakteristika vještine, koje su korisne u između trih skupina različitih pogleda te pridonijeti stvaranju cjelovitije slike o ljudskoj motoričkoj kontroli.