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MAXIMAL VOLUNTARY TORQUE AND THE ABILITY TO FINELY GRADE SUBMAXIMAL TORQUE ARE NOT RELATED

SPOSOBNOST FINEGA URAVNAVANJA SUBMAKSIMALNEGA NAVORA NI POVEZANA Z NAJVEČJIM HOTENIM NAVOROM

ABSTRACT

Previous studies on bodybuilders have shown training-specific characteristics regarding the relationship between muscle cross-sectional area and the mechanical output of the neuromuscular system. The aim of this study was to test potential differences between an experimental group of 11 resistance-trained subjects and a matched control group of 11 normal healthy subjects in: (i) knee extensors' maximal voluntary isometric torque; and (ii) the ability of the subject to execute a dynamically graded contraction at submaximal level with the same muscle group (active torque tracking task (ATT)). Both tasks were performed by the right leg. The ATT task required the subjects to follow the predefined random-shaped torque: time curve by modifying the intensity of the knee extensors' contraction. As expected, the experimental group showed statistically significantly higher maximal voluntary contraction torque compared to the control group. However, no statistically significant differences were observed for ATT-normalised error. The findings of this study show that subjects with a background of intensive strength training express significantly higher levels of maximal knee extension isometric torque, although their precision at fine submaximal torque regulation are the same as its controls. The results suggest different underlying neuromuscular control mechanisms behind the maximal and submaximal force control. The latter should be given more research attention in future studies.

Key words: bodybuilders, knee extension, neuromuscular control, active torque tracking

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IZVLEČEK

Predhodne študije na bodybilderjih so pokazale trenažno specifične značilnosti, ki se nanašajo na odnos med prečnim presekom mišice in njeno živčno-mišično sposobnostjo za produkcijo mehanskega izhoda. Namen te študije je bil testirati potencialne razlike med eksperimentalno skupino 11-ih subjektov dobro treniranih na področju moči ter kontrolno skupino 11-ih normalnih zdravih subjektov v (i) največjem hotnem navoru iztegovalk kolena in (ii) sposobnosti posameznika, da z isto mišično skupino izvede dinamično uravnavano kontrakcijo submaksimalne intenzivnosti katere cilj je natančno uravnavanje silovitosti (aktivno sledenje navora (ATT)). Obe nalogi je merjenec izvedel z desno nogo. Pri ATT nalogi je moral merjenec z spreminjanjem intenzivnosti aktivacije iztegovalk kolena slediti pred-določeni krivulji (navor:čas), naključne oblike, kar se da natančno. V primerjavi s kontrolno skupino, so pričakovano, merjenci v eksperimentalni skupini v povprečju dosegali višje vrednosti največjega hotnega navora. Statistično pa se predstavniki obeh skupin niso razlikovali v ATT vrednostih. Rezultati te raziskave so pokazali, da osebe z večletno zgodovino intenzivne vadbe moči dominirajo v sposobnosti za razvoj največjega statičnega navora iztegovalk kolena, medtem ko se od netreniranih oseb ne razlikujejo statistično značilno v sposobnosti natančnega uravnavanja submaksimalnih navorov. Nadalje rezultati raziskave nakazujejo na različne nadzorne mehanizme v ozadju obeh sposobnosti; t.j. sposobnosti za razvoj največje mišične sile na eni strani in fine regulacije submaksimalne sile na drugi. Slednjim bi bilo v prihodnje smiselno nameniti več pozornosti.

Ključne besede: bodybilderji, iztegovanje kolena, živčno-mišični nadzor, aktivno sledenje navora

INTRODUCTION

Experimental evidence indicates that the long-term effects of resistance training are very diverse and include an increase in supraspinal neural drive (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002), the facilitation of spinal reflex responsiveness (Folland & Williams, 2007), muscle growth (Krieger, 2010; West, Burd, Staples, & Phillips, 2010), changes in muscle-tendon architecture (Narici et al., 1996) as well as modified sensory-motor integration (Wong & Ng, 2010) and muscle contractile properties (Sale, Upton, McComas, & MacDougall, 1983). All these changes in the structure and function of the biological components involved also result in changes in the biomechanical output of the body (Gabriel, Basford, & An, 2001; Gabriel, Basford, & An, 1997). However, previous studies on the chronic effects of resistance training have primarily focussed on maximal mechanical output parameters, while not so much attention has been paid to the submaximal aspects of muscle action.

In general, from the biomechanical point of view, measurements of maximal voluntary contraction (MVC) torque are among the most commonly studied in athletes (Cronin & Sleivert, 2005; Riganas, Vrabas, Papaevangelou, & Mandroukas, 2010; Smith, Norris, & Hogg, 2002; Wilson & Murphy, 1996) as well as patients (Pua, Bryant, Steele, Newton, & Wrigley, 2008). In sports, special attention has been devoted to assessing the rate of torque development (Ferreira, Schilling, Weiss, Fry, & Chiu, 2010; Glatthorn, Berendts, Bizzini, Munzinger, & Maffiuletti, 2010; Glatthorn, Gouge, et al., 2011; James, Navas, & Herrel, 2007; McLellan, Lovell, & Gass, 2011), which is another aspect of the maximal neuromuscular function. However, the neuromuscular control of submaximal forces has been studied to a much smaller extent in the sports population (Smits-Engelsman, Smits, Oomen, & Duysens, 2008).

Although maximal force represents an important ability in sports as well as in daily activities, managing low-to-moderate forces accurately and perceiving them appropriately is also practically important. For example, this ability deteriorates under the influence of fatigue (Missenard, Mottet, & Perrey, 2009) or central neural deficits (Kriz, Hermsdörfer, Marquardt, & Mai, 1995; Kurillo, Gregoric, Goljar, & Bajd, 2005; Kurillo, Zupan, & Bajd, 2004). We know from basic neurophysiological studies that the underlying mechanisms of maximal and submaximal force production differ (Enoka, 2008). Therefore, a parallel investigation of these two functional abilities can provide us with a better insight into the long-term training effects on muscle function than if we observe the MVC-related variables alone.

Active tracking methods have been developed to test the ability to finely regulate muscle force and movement. Common to all active tracking methods is that a tested subject attempts to follow the predefined reference dynamics of the muscle force (Bock, Vercher, & Gauthier, 2005; Kriz et al., 1995; Kurillo et al., 2005, 2004) or joint position (Carey, Oke, & Matyas, 1996; Chung, Cho, & Lee, 2006; Maffiuletti, Bizzini, Schatt, & Munzinger, 2005) based on visual feedback. These methods were initially used for the assessment and therapy of neurological patients, thereby using motor tasks related to hand dexterity (Chung et al., 2006; Kurillo et al., 2005, 2004). Further, some researchers expanded their use to other body segments and even to closed kinetic chain activities (Maffiuletti et al., 2005). With the active tracking methods, the calculated variables used to quantify the distance between the reference signal and the real signal from the force/position sensor can be employed as a measure of the movement accuracy (Carey et al., 1996). Moreover, from the methodological point of view the total duration of the measurement and the accommodation protocol is very important for the active tracking variables to be reliable (Rošker, Kalc, & Šarabon, 2010).

To our knowledge, no study has investigated the relationship between maximal muscle force and the parameters of dynamic active tracking tasks. There is also a lack of research about the ability to control low muscle forces in long-term resistance-trained subjects. We believe that by filling this gap we can make an important contribution to the basic apprehension of muscle force control and the specific effects of resistance training on it. The aim of this study was therefore to test the potential relationship between the maximal voluntary isometric torque and the ability to execute a dynamic finely graded contraction at submaximal level. In addition, regarding these two outcome variables we were interested in testing differences between a group of resistance-trained subjects and a match group of normal healthy subjects.

METHODS

Participants

Twenty-two males without any history of neuromuscular and cardiovascular disorders participated in the study. Half of them were a mixed group of resistance-trained subjects (body builders, power lifters and weight lifters; training history 8.8 ± 5.3 years) – i.e. an experimental group (age 25.4 ± 6.1 years; height 184.9 ± 4.3 cm; weight 102.6 ± 7.3 kg) while the other half were normal subjects with no special training history – i.e. a control group (age 25.4 ± 3.8 years; height 180.9 ± 5.3 cm; weight 77.8 ± 6.0 kg). The participants gave their written consent to participate in the study. All procedures conformed to the 1964 Declaration of Helsinki and were approved by the Committee for Medical Ethics at the Ministry of Health (Slovenia). Before performing the tests the whole procedure was presented in detail to each subject separately.

Experimental design

Each participant underwent a set of tests starting with anthropometric measurements of body height and weight, subcutaneous fat tissue and muscle mass measurements (Bioscan 916s, Maltron International, Essex, UK). This was followed by a standardised 20-minute warm-up. After that, a subject was seated on an isometric knee extension measurement chair (S2P Ltd., Bled, Slovenia) with their hips fixed at 90° and the distal part of the right shank attached to a measurement lever arm at a knee position of 60° flexion, the arms were beside the body, gripping the handlebars to ensure good stabilisation of the upper body (Figure 1). All the tests were performed unilaterally with the right leg, which was also the kicking leg for all the subjects. In this position, a set of three introductory maximal voluntary contractions (MVCs) was carried out. The repetitions were separated by 10-second rest intervals. This was followed by a set of three regular MVCs with the same protocol, separated by 90-second rest intervals. The peak average torque on a one-second time interval was calculated for each repetition. The repetition with the highest value was used for later analysis of inter-group differences and correlations, while all three repetitions were included in the repeatability analysis.

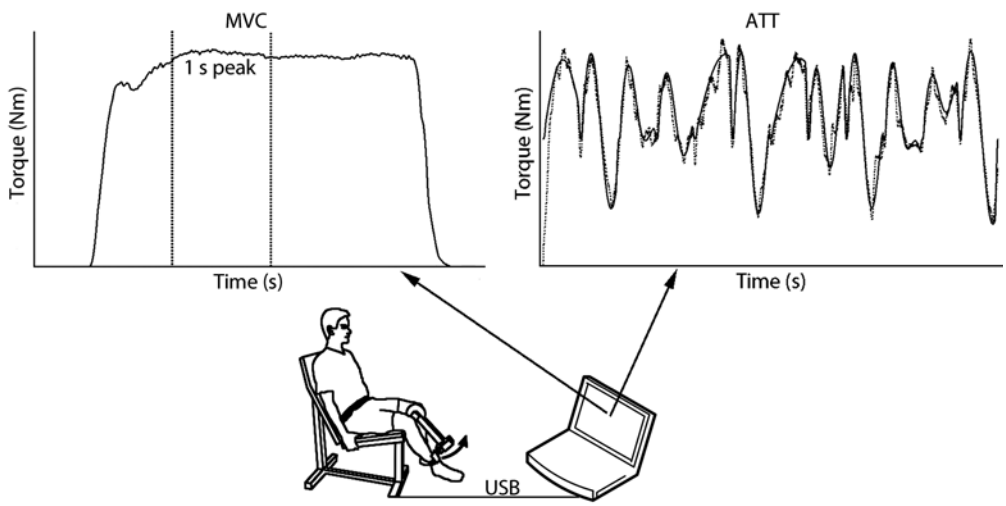

Figure 1. An example of the MVC and ATT tasks. Both tasks were performed on an isometric knee extension chair connected to a laptop via a USB interface. The solid line on the ATT graph is the pseudo-random curve (reference) and the dotted line is produced by a subject who tries to follow it as precisely as possible.

Further, using the same set-up, a subject performed the task of active torque tracking (ATT) using the knee extensors' contraction of submaximal torque. The ATT was performed with a pseudo-random curve that a subject had to follow as closely as possible. The pseudo-random curve was generated as the average of three sine signals with an amplitude range between 0 and 60% of the MVC and a frequency between 0.1 and 1 Hz. The range of the pseudo-random curve was adjusted for each subject separately, while the frequency and curve pattern were the same for all the subjects. A normalised error (ATTE) (Jones, 1995; Kurillo et al. 2004) was observed for the evaluation of the ATT. It was calculated as

$$ATTE = \sqrt{\frac{\sum_{i=0}^{n} \frac{(G_i - X_i)^2}{MVC^2}}{n}}$$

where *ATTE* is an ATT-normalised error, *G* is the vector of values of the reference curve, *X* is the vector of values of the curve produced by the subject, *MVC* is the maximal voluntary contraction and *n* is the number of samples of the measurement. The first and last second of the measurement were removed prior to the analysis. The average of the three repetitions of the ATTE was used for later analysis of inter-group differences and correlations, while the ATTEs of all three single repetitions were included in the repeatability analysis.

During the ATT test, visual feedback was provided to a subject using a PC computer screen (17 inch screen size) that was placed 1.5 metres away from the subject's eyes. The visual feedback was refreshed every 100 ms. Three 20-second introductory ATT tasks with 30-second rest intervals were carried out. The purpose of the introductory repetitions was to learn the task and gain a feeling for the required range of the knee torque. After the introductory ATTs, every participant performed three 60-second experimental ATTs (Figure 1) separated by 60-second rest intervals.

All tests and signal analyses were carried out using custom-made software modules (LabView 2010, National Instruments, Austin, Texas, USA), MVC and ATT measurements. All signals were acquired with a sampling frequency of 4 kHz.

Statistics

All statistical analyses were performed using the SPSS 18.0 software. All data are expressed as means ± standard deviation. All parameters were tested for a normal distribution with the Shapiro Wilk test for small samples. The between groups differences were tested using an independent t-test. Intra-class (ICC) and two-tailed Pearson's correlation coefficients (r) were used to test repeatability and observe the inter-relation between the two tests, respectively. The ICC was set as follows: model – two-way random, type – absolute agreement and confidence interval – 0.95 (Müller & Büttner, 1994). The ICC for single measures ($ICC_{2,1}$) and average measures ($ICC_{2,k}$) were calculated. Statistical significance was accepted at the $p < 0.05$ level.

RESULTS

All the parameters used were normally distributed. Descriptive statistics are presented in Table 1. The high value of kurtosis for the MVC parameter of the experimental group reflects a high peak and narrow distribution with a high probability of extreme values, while the distribution of the control group is wider. Distributions of the ATTE are very similar for both groups and are wider than the normal distribution.

Table 1: Descriptive statistics for the experimental (E) and control (C) groups. BH – body height, BM – body mass, FM – fat mass, MM – muscle mass, MVC – maximal voluntary contraction and ATTE – active torque tracking error. Statistical significance is denoted as $p < 0.05$ (*) and $p < 0.01$ (**), respectively.

Parameter	Group	N	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	t-test
Age (years)	E	11	20.2	40.3	25.4	6.1	1.70	3.07	.537
	C	11	21.2	31.4	25.4	3.8	0.69	-1.38	
BH (cm)	E	11	179.8	195.2	184.9	4.3	1.30	2.69	.069
	C	11	171.7	190.2	180.9	5.3	0.08	0.15	
BM (kg)	E	11	92.3	113.7	102.6	7.3	0.15	-1.21	.000**
	C	11	68.3	89.6	77.8	6.0	0.40	0.36	
FM (%)	E	11	9.6	22.1	12.2	3.5	2.67	7.78	.046*
	C	11	8.8	11.5	9.9	0.9	0.55	-0.45	
MM (kg)	E	11	41.4	51.3	46.1	3.1	0.29	-0.72	.000**
	C	11	30.8	40.4	35.2	2.8	0.27	-0.08	
MVC (Nm)	E	11	358.1	567.5	422.9	54.7	1.95	5.34	.006**
	C	11	167.9	419.6	330.7	83.1	-1.12	0.19	
ATTE (units)	E	11	0.015	0.035	0.024	0.007	0.52	-0.74	.201
	C	11	0.015	0.029	0.021	0.005	1.02	0.23	

Tests of the differences between groups of anthropometric factors showed statistically significant differences in body mass, fat mass and muscle mass, while body height was not statistically significantly different (Table 1). The experimental group showed statistically significantly higher MVC values compared to the control group, while no statistically significant differences were observed for the ATT (Table 1).

Pearson's correlation coefficient between the MVC and the ATT was 0.003 ($p \geq 0.05$) (Figure 2). The $ICC_{2,1}$ for the MVC was 0.976 and the $ICC_{2,k}$ for the MVC was 0.992, while the $ICC_{2,1}$ for the ATT was 0.737 and $ICC_{2,k}$ for the ATT was 0.894.

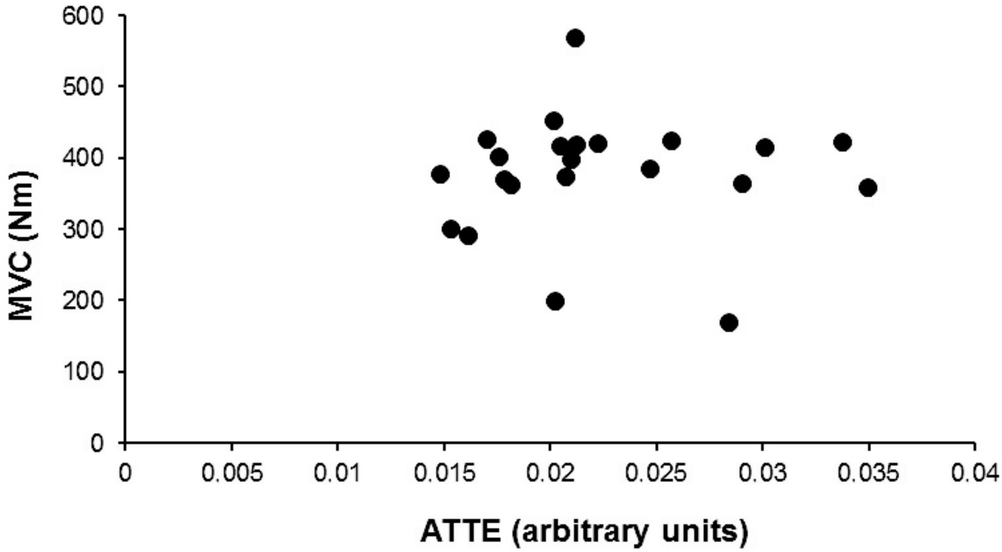

Figure 2: Scatter plot of MVC : ATTE (r = 0.003).

DISCUSSION AND CONCLUSION

Our study tested the relationship between the maximal voluntary isometric torque and the ability to execute a dynamic finely graded contraction at submaximal level. In addition, regarding these two outcome parameters, we were interested in testing potential differences between a group of resistance-trained subjects and a matching group of normal healthy subjects. The results showed the absence of a correlation between MVC torque and the ATTE. Further, significant differences between the two groups of subjects were found in the MVC, although no inter-group differences were present in the ATT.

Both high and low intensity strength training have been shown to have positive effects on submaximal force control regarding precision, steadiness and endurance (Hortobágyi, Tunnel, Moody, Beam, & DeVita, 2001; Justin, Strojnik, & Šarabon, 2006; Tracy & Enoka, 2006). These are all separate force control entities that play an important role in functional movement activities. In a study of seniors by Seynnes et al. (2005) isometric force steadiness, but not accuracy, was found to independently predict chair-rise time and stair-climbing power and explained more variance in these tasks than any other variable they measured (maximal torque, rate of torque development or electromyography parameters). The inter-variable relationships led them to conclude that improving steadiness in submaximal muscle force might help reduce functional limitations or disability. Further, Tracy and Enoka (2006) reported the positive effects of force steadiness training on functional improvements. In their training protocol they used low resistance loads (30% MVC) but the subjects were closely supervised and instructed to focus on the steady execution of the repetitions. Another study by Hortobágyi et al. (2001) showed that in older adults low- and high-intensity resistance training result in quadriceps force accuracy and steadiness improvements that are comparable in size. It is important to point out that all these studies used constant force matching tasks in their evaluation procedure, which is different from the ATT tasks in general as well as specifically from our ATT task with a semi-random torque : time curve. In any case, these data are probably the closest as regards the relevance of training-related effects on submaximal force control. The results of our study support the data mentioned above, although they also expand the knowledge in this field. Based on our results we may conclude that a resistance-training history does not affect the ability to accurately dynamically track small forces.

The differences in the MVC between the group of resistance-trained subjects and the group of controls in our study were most probably a combination of neural and muscular factors. However, these differences in the underlying mechanisms were not reflected in the accuracy of submaximal force control measured by the ATT task. Long-term overloading of the muscle, which also takes place in the case of resistance training, results in increased muscle mass that can be an outcome of muscle fibre hypertrophy (D'Antona et al., 2006; Gollnick, Parsons, Riedy, & Moore, 1983; Gollnick, Timson, Moore, & Riedy, 1981) or even hyperplasia (Antonio & Gonyea, 1993). Accordingly, slow muscle fibres have turned out to be less susceptible to hypertrophic stimuli than fast muscle fibres (D'Antona et al., 2006) when a high intensity overloading is involved. However, Putman et al. (Putman, Xu, Gillies, MacLean, & Bell, 2004) showed that a combined strength and endurance training regimen can also lead to a significant fast-to-slow fibre-type transitions and attenuated hypertrophy of type I fibres. The predominant response of the type II fibres after heavy resistance training (the group of resistance-trained subjects) in comparison to everyday use (the group of control subjects) can also be expected on the basis of Henneman's size principle (Henneman, Clamann, Gillies, & Skinner, 1974) according to which small motor units (i.e. small muscle fibres) precede the recruitment of large motor units as the muscle force increases. In the context of the results of our study, we can assume that the MVC differences are at least partly due to the fast fibre hypertrophy, while the predominant activation of slow twitch fibres in the ATT task might have defied the absence of inter-group differences.

Apart from the muscles as peripheral effectors, neural mechanisms on which their activation depends are also responsible for voluntary muscle force/torque production. St Clair Gibson, Lambert, and Noakes (2001) note that these control processes differ significantly between maximal and submaximal force production. Using a model of upper extremity, Ehrsson and colleagues (2000) recorded a distinctly different pattern of cerebral activity when the subjects were performing a power or a precision motor task. In addition to the contralateral hemisphere primary motor cortex which is active in both motor tasks, also the contralateral premotor and parietal areas as well as some ipsilateral hemisphere areas engage in the case of a precision task. Additional evidence for a different supraspinal motor control of precision and power tasks was found in animal models (Fluet, Baumann, & Scherberger, 2010). In this context of the neural drive specificity we should also consider the (non)specificity of the strength training effects. A recent intervention study (Vila-Chã, Falla, & Farina, 2010) showed that low-resistance (30% MVC) training results in increases in the motor unit discharge rate and motor unit conduction velocity. These results indicate that resistance training has the potential to change the neuromuscular control of low intensity muscle contractions. However, in the opposite case of quadriceps weakness after knee meniscectomy, the activation failure was only reflected in an MVC decrease, while no impairments were present for submaximal force control (Glatthorn, Berendts, et al., 2010). Our data are in line with this existing knowledge since an extremely low level of correlation between the ATT and MVC was observed. This suggests that these two tests measure two completely different functional abilities. It is therefore most likely that the underlying mechanisms of neuromuscular regulation in these two tasks might also differ significantly.

Last but not least, we would like to point out that the technical and methodological verification of the semi-random curve ATT method had been tested in advance. In our previous publications, we observed repeatability problems when using a cyclic type of reference curves for ATT tasks (Rošker et al., 2010; Šarabon, Rošker, & Kalc, 2010). Based on the outcomes of this study, we have developed a semi-random curve ATT measurement with which we minimised the acute learning effect and improved repeatability. We revaluated the repeatability of this method again in this current study and confirmed the acceptably high values of ICC. On the other hand, the high repeatability of the MVC is already well known (Morton et al., 2005; Rainoldi, Bullock-Saxton, Cavarretta, & Hogan, 2001). We can therefore conclude that no repeatability or sensitivity problems can explain the results of our study.

Let us mention another ATT methodological aspect. It is well known that neuro-muscular control is modified by the influence of fatigue (Behm, 2004) which also results in the decayed precision of the submaximal force production (Singh, Arampatzis, Duda, Heller, & Taylor, 2010). In our experiment, we used only up to 60% of the MVC for one minute, which was an easy task for all the subjects and no fatigue was reported. We might have expected a significantly different picture if we had used absolute criteria for setting the ATT limit values. However, in this case the ATT task would have become a strength endurance test and we could hypothesise that the potential inter-individual differences would depend strongly on the absolute MVC values.

In conclusion, we could say that neuromuscular strength, as one of the basic functional abilities of the human body, has an important athletic as well as everyday life value. Regarding the latter, the precise regulation of submaximal muscle force is sometimes even more important than maximal mechanical output. We believe there is a gap in the research literature regarding studies addressing submaximal strength tasks and the effect of different types of training on the quality of their execution. In our future research, we plan to focus on the effects of specific training modalities (strength, co-ordination, balance etc.) on the ability to control submaximal muscle forces. Further, we would like to gain a better insight into the underlying control mechanisms involved in this kind of sensory-motor tasks.

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