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ORIGINAL REPORT

ISOTONIC AND ISOMETRIC CONTRACTIONS EXERT THE SAME AMOUNT OF CORTICOMOTOR SYSTEM EXCITABILITY IN HEALTHY SUBJECTS AND PATIENTS AFTER STROKE

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Objective: **Active, voluntary training of the centrally paretic upper limb is crucial for functional recovery after brain damage. The aim of this study was to determine whether the type of voluntary contraction has a differential influence on corticomotor system excitability in healthy subjects and patients after stroke.**
Design: **Experimental cross-sectional study.**
Subjects: **Fifteen healthy volunteers and 15 patients after stroke.**
Methods: **Participants performed dynamic isotonic and isometric voluntary wrist extensions with the non-dominant or the paretic hand, respectively, with force levels of 10%, 20% and 30% of the maximum voluntary surface electromyogram. Excitability was measured by comparing the amplitude of motor evoked potentials elicited by transcranial magnetic stimulation.**
Results: **The type of contraction did not have any effect on the amplitude of motor evoked potentials, either in healthy subjects or in patients after stroke.**
Conclusion: **Dynamic isometric and isotonic voluntary contractions seem to have the same effect on the excitability of the corticomotor system.**

Key words: stroke, rehabilitation, transcranial magnetic stimulation, isometric isotonic contraction.

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INTRODUCTION

There is increasing evidence that active, voluntary training of the centrally paretic limb is crucial for functional recovery after brain damage (1–8). In particular, repetitive training of simple movements, i.e. of single joint movements, has proven effective (1, 9, 10).

Fast movements were accompanied by a characteristic triphasic pattern of electromyographic (EMG) activity, starting with an EMG burst of the agonists to accelerate the limb, followed by a burst of the antagonists to decelerate the movement and, depending on the task, a second agonist burst to stabilize the limb in the target zone (11). Hoffman & Strick (12, 13) found that, in rapid wrist movements with short duration or lightweight load, the magnitude of the first agonist burst varied while the burst duration was kept constant. Control of torque in single joint movements is based on 2 different strategies: the speed-sensitive strategy, in which the rate of increase in contraction is modulated by varying the intensity of motoneurone pool excitation; and the speed-insensitive strategy, in which the duration of contraction, but not the rate, is varied. The choice of the appropriate strategy depends on task-specific torque requirements; however, the speed-insensitive strategy appears to be the default pattern. In contrast to movements, isometric tasks are more often controlled by a mixture of these 2 strategies (14, 15).

We know from sports physiology, that isometric (i.e. contraction without joint movement) and concentric resistance training produces the greatest measurable gain in strength when the strength test is similar to the type of training (exercise-type specificity). In other words, only the strength of the type of contraction that has been trained increases (16). For knee extensor muscles it has been shown that the integrated electromyogram-to-work ratio is significantly greater in isotonic (i.e. movement against constant resistant or without resistant) than in isokinetic (i.e. constant movement velocity) exercises. Thus, isotonic contractions resulted in a greater motor unit recruitment or in an increased firing rate, or both per work unit (17). Studies directly comparing the functional benefit of tonic isometric (i.e. constant force without movement) vs concentric dynamic (i.e. movement in the direction of the contraction, ramp-and-hold) training are lacking. Existing evidence suggests that dynamic training may be superior to isometric training (16).

Yahagi et al. (18) compared the excitability of motor evoked potentials (MEP) of the first dorsal interosseus muscle (FDI) in dependence on contraction type (isotonic vs isometric) and on background EMG activity (low vs middle). They found, for the FDI, different MEP amplitudes between isometric and isotonic contractions at the lower contraction level (5–10% of maximum voluntary contraction (MVC)), with larger MEP amplitudes in isotonic contractions. This difference disappeared at the middle contraction level (15–20% MVC).

The execution of isotonic wrist movements leads to an increase in the motor field magnitude in magnetoencephalography, as a reflection of increased efferent neuronal activity (19). Yet, it is not known whether the type of voluntary contraction

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that occurs while moving the wrist has a differential influence on corticomotor excitability in patients after stroke with central paresis. Knowledge of the possible impact of the type of contraction, however, would be important in choosing the most appropriate therapeutic strategy and for the development of new therapeutic approaches in neurorehabilitation. Using contraction types with maximal facilitatory effects in training protocols for patients after stroke may accelerate functional recovery, making the rehabilitation process more effective.

The aim of the present study was to determine whether dynamic isometric and isotonic contractions exert a differential effect on corticomotor system excitability in healthy subjects and patients after stroke, building a neurophysiological basis for further studies dealing with various training protocols and their effects on the functional outcome of patients after stroke.

METHODS

Subjects

Fifteen healthy subjects (11 women, 4 men, age 47.3 years, standard deviation (SD) 6.9, age range 34–58 years) and 15 patients after stroke (7 women, 8 men, age 59.1 years, SD 12.4, age range 35–77 years) in the subacute stage with a central arm paresis (strength of wrist extension between 3 and 4 Medical Research Council score (20)) participated in the study. Stroke was confirmed by computer tomography or magnetic resonance imaging. Functional assessment was carried out using the arm score of the Motricity Index (21) (for details see Table I).

The study was conducted in accordance with the Declaration of Helsinki. All patients and volunteers gave their written informed consent. The study protocol was approved by the local ethics committee.

Experimental protocol

Subjects performed dynamic isotonic and isometric voluntary wrist extensions with the non-dominant or the paretic hand, respectively, as rapidly as possible. Isotonic contractions consist of simple wrist extensions with no resistance, starting at the 0° position and cover the full range of motion. During isometric extensions the hand was fixed at the 0° position of the wrist. Both contractions were carried out as a ramp-up without a plateau phase. The surface EMG (sEMG) was recorded using silver/silver chloride (Ag/AgCl)-electrodes (Medtronic L0202, Skovlunde, Denmark) mounted in a bipolar fashion (distance 2 cm) over the extensor carpi radialis muscle (ECR). The sEMG-signals were amplified (programmable 4-channel amplifier, Jaeger/Toennies, Wuerzburg, Germany), rectified, integrated and displayed on a monitor as an envelope curve (MP 100A, Biopac Systems Inc., Point Richmond, CA, USA). Additionally, this envelope curve was used for triggering the transcranial magnetic stimulation (TMS). Trigger was set to 10%, 20% and 30% of the individual maximum voluntary sEMG, representing different force levels. For each trigger level and each contraction type 12–15 wrist extensions were made. We checked that the arm was fully relaxed between the contractions (controlled by sEMG). This protocol ensured that fatigue did not occur. TMS was applied using a 13-cm coil connected to a Magstim 200 magnetic stimulator (Magstim Company Ltd, Whitland, UK). The coil was positioned with its centre over the vertex. Stimulus intensity was adjusted at 120% of motor threshold, which was defined as the minimum stimulus intensity eliciting MEPs of >50 μV in at least 5 of 10 consecutive stimuli with the hand at rest (22). MEP signals were amplified, band-pass-filtered (20 Hz – 2 kHz) (programmable 4-channel amplifier) and stored on hard disk for offline analysis. After visual inspection to exclude MEPs contaminated by artefacts, at least 10 MEPs were averaged and the peak-to-peak amplitude was measured (MP 100A).

To compare the effect of contraction type at different trigger levels on the MEP amplitude a 2-way ANOVA for repeated measures was calculated separately for healthy subjects and patients after stroke. Alpha-risk was set to 0.05. In case of significant differences the Holm-Sidak *post-hoc* test was calculated to isolate which groups differ from the others. Calculations were performed using the SigmaStat software package (version 3.5, Systat Software Inc., Point Richmond, CA, USA).

Table I. *Characteristics of the patient after stroke (n = 15)*

Age (years)/sex	Stroke/side	Days since stroke	MRC	MCI
51/M	ICH / R	44	3	65
53/M	ICH / L	34	4	77
55/F	MCA / R	82	4–	71
69/F	MCA / R	24	4	77
75/F	MCA / L	73	4–	77
62/F	ACA / L	57	4	78
45/F	MCA / L	89	3	91
75/F	MCA / R	20	4	66
35/F	MCA / R	33	4	67
50/F	MCA / L	136	3	67
77/F	MCA / R	23	4–	71
66/F	MCA / L	48	4	76
53/F	MCA / R	47	4–	67
70/F	MCA / L	52	4	77
51/F	MCA / R	30	4	76

M: male; F: female; ICH: intracerebral haemorrhage in the basal ganglia; ACA: ischaemic stroke in the anterior cerebral artery; MCA: ischaemic stroke in the middle cerebral artery; R: right, L: left; MRC: strength of wrist extension according to Medical Research Council; MCI: Motricity Index, arm score (max 100).

RESULTS

The type of contraction did not have any effect on the MEP amplitude in healthy subjects ($p=0.128$, $F=2.617$, $df=1$) or in patients after stroke ($p=0.172$, $F=2.076$, $df=1$). An example of MEPs of a healthy subject and a patient after stroke is seen in Fig. 1. For details of MEP parameters see Table II. The data show that there is a difference in favour of isometric contractions with higher MEP amplitudes. However, this is only a tendency and the *p*-values are far from being significant. Whereas in healthy subjects the force level had no significant effect on the MEP amplitudes, the amplitudes differed in patients after stroke between 10% and 20% (unadjusted $p=0.0166$) and between 10% and 30% of maximum sEMG (unadjusted $p=0.00125$), but not between 20% and 30% sEMG. The lack of further facilitation in healthy subjects is in accordance with previous data (23).

DISCUSSION

These results clearly show that dynamic rapid isotonic and isometric contractions did not exert a differential effect on corticomotor system excitability in healthy subjects or in patients after stroke. This was the case for the 3 force levels tested.

Yahagi et al. (24) found a difference in MEP amplitude of the FDI between isotonic and isometric contraction in spite of identical background EMG activity levels with a greater ampli-

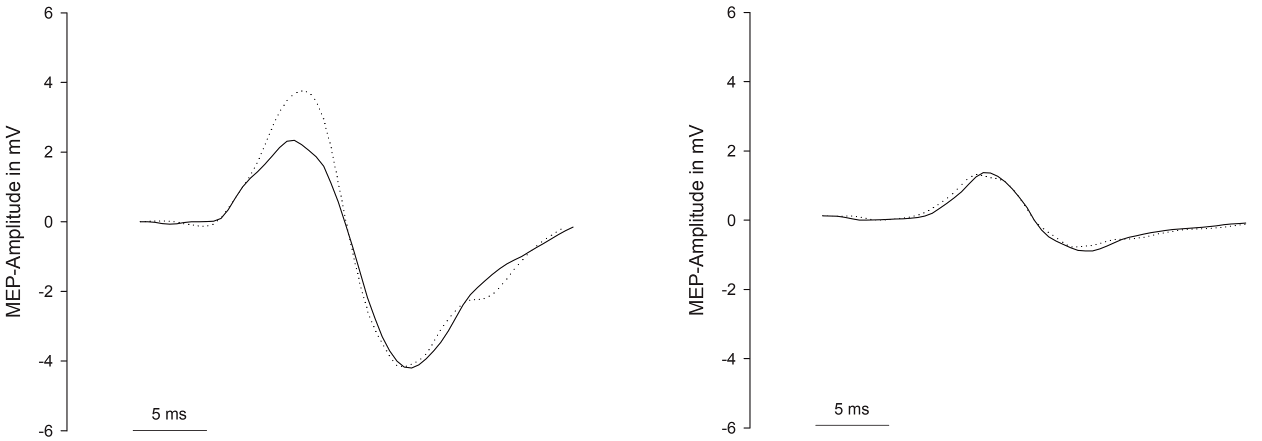

Fig. 1. Examples of motor evoked potentials (MEP) during contractions with 10% of maximum voluntary contraction. Left: healthy subjects. Right: patients after stroke. Solid line: isometric contraction. Dotted line: isotonic contraction.

Table II. *Amplitudes (mean (SD)) of the motor evoked potentials in mV during isometric and isotonic wrist extensions with different force levels of the maximum surface electromygraphy of the extensor carpi radialis muscle*

Force level (%)	Isometric	Isotonic
Healthy subjects		
10	4.82 (1.41)	4.62 (1.71)
20	4.97 (1.79)	4.50 (1.91)
30	4.97 (1.72)	4.53 (1.62)
Patients after stroke		
10	2.42 (1.38)	2.32 (1.14)
20	2.84 (1.60)	2.56 (1.22)
30	2.95 (1.68)	2.73 (1.38)

SD: standard deviation.

tude in isotonic contraction. This difference disappeared with increasing force. The authors suggest that this result indicates a greater cortical control of isotonic contractions than isometric ones. However, in a proximal muscle (deltoid muscle) the MEP amplitude was different in isotonic and isometric contractions at low (5–10% MVC) and middle (15–20% MVC) force levels. A possible explanation for this phenomenon was that the hand muscle would be expected to receive larger compound excitatory post-synaptic potentials from motor cortex cells than would proximal muscles.

One of the most common sequelae of patients after stroke is the loss of dexterity. Therefore, we decided to use a coarser movement at the wrist, thereby activating muscles lying proximal to the FDI. Since there is a high correlation between sEMG and force (25), the 3 force levels in our study (10%, 20% and 30% of maximum sEMG) are in a comparable range to the study of Yahagi et al. (24). Nonetheless, we could not reproduce the described differential effect of contraction type on corticomotor excitability. The main difference between the 2 studies is that we have used a rapid tonic movement, whereas Yahagi et al. (24) used a slow one.

The relationship between force and cortical activity has been investigated in numerous neurophysiological studies. A direct relationship between discharge rates of cortical neurons and static or dynamic force was found in single-cell recordings from the primary motor cortex in monkeys. A positron emission tomography study in man revealed a correlation of peak force in a dynamic force generation with the overall activity of the primary motor and sensory cortex, the posterior part of the dorsal bank of the cingulated sulcus, the ventral part of the posterior supplemental motor area, and the cerebellar vermis (26).

A comparison of brain activation during tonic isometric, dynamic (ramp-and-hold) isometric and dynamic isotonic contraction of the right ankle muscles showed a higher activation in the left primary somatosensory cortex for the dynamic isotonic contractions than during the dynamic isometric contractions. Furthermore, both dynamic tasks elicited higher activation in the left premotor area, left supplemental motor area, left primary motor cortex, right cerebellum, left precuneus and right fusiform gyrus than did the tonic task (27). Whereas the activation pattern during tonic contractions is substantially different from that during dynamic contractions, which require a higher and more widespread cortical activation, the difference in brain activation between the dynamic contraction types seems to be small and caused only by the different somatosensory input. The higher activation during dynamic tasks may be related to the increased cortical demand for initiation and surveillance of the contraction (27). Even though these are data from the legs, which are involved in completely different motor tasks from those of the upper extremities, this could be an explanation for the negative finding in our study, because we have compared contraction types with the smaller difference in brain activation. Whether or not the differences in brain activation between tonic and dynamic contractions are detectable by TMS is a matter for further study. The view that the data from the legs may be relevant for the upper extremities is supported by the data of Pfann et al. (28), who showed that a single set of control rules applies to different joints in rapid, single degree-of-freedom movements.

For methodological reasons we have controlled only for the background EMG activity and not for joint position. It has been shown for the ECR at rest that the joint position of the wrist influences corticomotor excitability. Already a sensory discrimination task (identifying the joint position), however, facilitates much more (29). Even though we cannot rule out an influence of different joint positions, the much stronger facilitatory effect of voluntary contractions makes the impact of joint positions on the results of this study negligible.

Considering our negative findings, the choice of a specific type of contraction during motor practice in the rehabilitation of patients after stroke may be guided by other known physiological training effects. In particular, the exercise-specificity of training has to be considered, i.e. the highest gain can be achieved by the exercise-type that has been trained. Moreover, isometric strength training resulted in the steepest power increase measured in the same joint angle in which healthy subjects have trained (16, 30, 31). Ada et al. (32, 33) found that patients after stroke demonstrated a differential loss of isometric strength in the shortened range of elbow flexors and extensors. It may be speculated that this specific weakness could be overcome by training of isometric contractions at the joint angle of minimum strength.

Patients after stroke often have multiple associated diseases, such as cardiovascular disease, that have to be considered when designing training. Isometric exercise increases blood pressure, heart rate, myocardial contractility and cardiac output. Thus, this type of training is associated with an increased pressure load to the heart. In contrast, isotonic exercises lead to an increased volume load. Training with dynamic components seems to produce the most beneficial effects concerning peripheral cardiovascular adaptations. These adaptations include a modest decrease in resting blood pressure, reduced increase in blood pressure and sympathetic nerve activity during a given workload, enhanced baroreflex function, increases in muscle capillary-to-fibre ratio, possible improvements in lipid and lipoprotein profiles, and increases in glucose and insulin responsiveness (34).

To summarize, dynamic isometric and isotonic voluntary contractions seem to have the same facilitatory effect on the corticomotor system in healthy subjects and patients after stroke. The choice of an appropriate contraction type for therapeutic exercises should be guided by the patient's individual functional deficit considering the exercise-specificity of training and the cardiovascular effects. It must be kept in mind that this study deals with the immediate effects of a therapeutic intervention. Long-term effects of training with different contraction types should be addressed in further studies. In addition, the question as to whether there are differential changes in other cortical functions, such as intracortical inhibition or facilitation, should be addressed with a paired pulse TMS study.

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