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Gasser B[1], Püntener O[1], Hoppeler H[1], Flück M[2]

1. UNIVERSITY OF BERN, *SWISS HEALTH & PERFORMANCE LAB, Institute of Anatomy, Bern, Switzerland*
2. UNIVERSITÄT ZÜRICH, *Universitätsklinik Balgrist, Departement für Orthopädie, Balgrist Campus, Zürich, Switzerland*

Is Eccentric Muscle Work Adequately Perceived? An Analysis with BORG-Scale

Wird exzentrische Muskelarbeit adäquat perzeptiert? Eine Analyse anhand der BORG-Skala

Summary

› **Background:** The aim of this study was to analyze validity of BORG-Scale (6-20) while eccentric muscle activity. BORG-Scale is a very valid possibility to rate perceived exertion while concentric muscle activity. It allows to estimate heart rate and therefore stress for cardiovascular system in an easy applicable manner.

› **Material and Methods:** Twelve participants (28.6±10.3 years / 173.3±6.8 cm / 68.8±14.3 kg) absolved a training program on a softroboter. This consisted of a braking movement while four times 5 minutes with alternating right respectively left leg movements during nine sec eccentric muscle work with varying load (15, 25, 35, 45 kg) followed by a one sec lasting concentric back movement. During the program heart rate and BORG-scale was measured after 1, 2, 3, 4 and 5 Minutes for local exertion in the left respectively the right leg as well as in total.

› **Results:** Although in the here analyzed movements BORG-Scale was indicating alternating exertion, however the postulated relationship (heart rate=10 x BORG (6-20) - value) was not detectable.

› **Limitations and Conclusions:** The findings are explainable yet eccentric muscle activity is a Titin based and not O_2 respectively ATP coupled contraction form. Therefore, with the same load in eccentric muscle activity only around one fourth O_2 is needed what probably affects perceived exertion accordingly. Furthermore, differences in the accuracy of perception between concentric and eccentric movements seem to exist. However, study was only conducted with 12 healthy participants, as a consequence only first hints can be made and no general recommendations. Measurements of O_2, heart rate and EMG during the same protocol with larger samples could reveal more accurately factors determining rate of perceived exertion while eccentric muscle activity.

KEY WORDS:
Softroboter, Fall Prophylaxis, Cardiovascular Prevention, Rehabilitation

Zusammenfassung

› **Hintergrund:** Das Ziel dieser Studie war es, die Validität der BORG-Skala (6-20) während exzentrischer Muskelarbeit zu beurteilen.

› **Material und Methoden:** Dazu absolvierten zwölf Probanden (28.6±10.3 Jahre / 173.3±6.8 cm / 68.8±14.3 kg) auf einem Softroboter ein Belastungsprotokoll. Dieses bestand aus einer Abbremsbewegung während viermal 5 Minuten abwechselnd mit dem rechten respektive linken Bein während 8 sec bei variierender Totallast (15, 25, 35, 45 kg) gefolgt von einer 2 sec dauernden konzentrischen Rückbewegung. Während der Belastung wurde die Herzfrequenz gemessen und die BORG-Skala (6-20) jeweils nach 1, 2, 3, 4 und 5 Minuten für die lokale Belastung im rechten respektive linken Bein sowie als Gesamtbelastung erfragt.

› **Ergebnisse:** Obwohl bei den hier analysierten Bewegungen die BORG-Skala (6-20) unterschiedliche Lasten / Leistungen gut erfassen konnte, zeigte sich, dass sich der postulierte Zusammenhang (Herzfrequenz=10 x BORG (6-20)-Wert) bei der analysierten hauptsächlich exzentrischen Muskelarbeit beinhaltenden Bewegungsform verliert.

› **Limitationen und Schlussfolgerungen:** Dies ist vermutlich der Tatsache geschuldet, dass exzentrische Muskelaktivität eine Titin basierte und nicht O_2 abhängige direkt ATP gekoppelte Kontraktionsform darstellt. Dadurch resultiert bei gleicher Leistung bei exzentrischer Muskelarbeit nur rund ein Viertel des Sauerstoffbedarfs, was sich entsprechend auf die Belastungsperzeption auswirken könnte. Weiter ließen sich Hinweise finden, dass Unterschiede in der Perzeptionsgenauigkeit zwischen konzentrischer und exzentrische Muskelarbeit vorliegen. Simultane Messungen von Sauerstoffbedarf, Herzfrequenz und Elektromyographie könnten noch genauer zeigen, durch welche Faktoren die Belastungsperzeption bei exzentrischer Muskelarbeit determiniert wird.

SCHLÜSSELWÖRTER:
Softroboter, Sturzprophylaxe, kardiovaskuläre Prävention, Rehabilitation

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CORRESPONDING ADDRESS:
Dr. med. Benedikt Gasser
SWISS HEALTH & PERFORMANCE LAB
Institute of Anatomy, University of Bern
Baltzerstrasse 2, CH-3000 Bern
✉: gasser@pyl.unibe.ch

Introduction

In the younger past possibilities of eccentric training were recognized in a wide range of different fields from high-performance sports to rehabilitation. From a medical point of view eccentric training has many advantages over conventional training (16, 19, 21). For example for elderly persons as fall prophylaxis a high potential is attributed to this training form. Falls are in over 80-year old persons the most important reasons for hospitalization (16, 19, 21). The cardiopulmonary performance as well as the force component decreases with increasing age, whereby with training these processes can be reduced (11, 12, 29). Positive effects of eccentric training on force development, balance and practical activities of the day such as walking down the stairs could be proven in seniors (16, 20, 21).

Since some time, it is generally accepted that eccentric training requires cardiovascular system only with a share of one fourth to one fifth compared to concentric muscle contraction, implying special training possibilities especially for humans with cardiovascular affections (Fig. 1) (6, 7, 11, 18, 20, 25). In the younger past it was speculated that eccentric training disturbs Aktin-Myosin interaction through mechanical stress. Concentric muscle activity however underlays the well-known ATP coupled release of Aktin-Myosin bindings (10, 16, 20). The mechanism of eccentric muscle contraction is explained mainly with the "Winding Filament" hypothesis. PEVK region of Titin winds around the thin filament while it comes to a rotation movement and Aktin-Myosin-binding is slowly released (24). The different molecular mechanism principally implies a different perception of such activities.

Nowadays, in many gyms- and rehabilitation facilities eccentric training possibilities are more frequently supplied, whereby often BORG-Scale is used in order to estimate the intensity of muscle work. Borg-Scale has gained increased attraction and it is assumed that nowadays around 1 Mio. Persons per year are supported with this instrument (4, 8, 27). Guidelines of the most important internal medical association such as the American Heart Association use this instrument and pinpoint the relevance (5). For estimating heart rate often the formula is used that multiplication of BORG-Scale value by ten an estimation of heart rate results (5). This allows in a simple manner to estimate the requirements of cardiovascular system while exercising. Originally, BORG-Scale was developed while performing different intensities on a treadmill with mainly concentric muscle activity (5). The usage of BORG-Scale to estimate the intensity of strength training as it is nowadays often practiced in gym halls has to be critically questioned. Is it appropriate to estimate heart rate while eccentric exercises when using BORG-Scale in a standard manner.

What happens with perceived exertion with movements of eccentric muscle activity? Is it possible to use BORG-Scale to estimate heart rate with the formula BORG value multiplied by 10 as estimator for heart rate?

As hypothesis with potential falsification it shall be stated that BORG-values during movements with mainly eccentric muscle activity do not substantially differ from movements with mainly concentric muscle activity (26).

Material and Methods

Participants

Seven healthy female (27.7±6.7 year, 169±7.4 cm, 58.3±6.8 kg) and five male (30±9.6 year, 179±3.1 cm, 78.6±15.1 kg) participants absolved the program. The participants were advised to absolve the program being rested and under standard diet. The study was in line with the code of conduct for medical studies and ethics approval was obtained by the local ethics comitee.

Equipment

The Allegro Medical Softroboter (Dynamic Devices AG/ Zürich/ Switzerland) is a training and rehabilitation gear with the function of a dynamic leg press. It allows to perfrom concentric and eccentric muscle work (19) (Fig. 2). M. gluteus maximus and M. quadriceps femoris, M. biceps femoris, M. semimembranosus and M. semitendinosus has to brake eccentric force. Depending on test protocoll frequency as well as weight can be adapted.

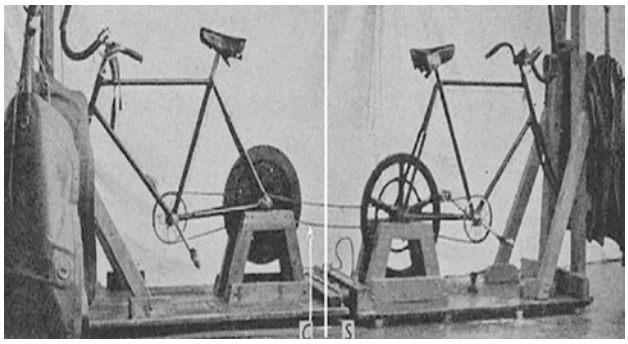

Figure 1

The original bike constructed by Abbott, Bigland & Ritchie (1952) with the possibility to perform eccentric (braking) muscle work. In the orginal version one person uses the bike conventionally (concentric muscle activity) and the other person is braking (eccentric muscle activity) (1, 12).

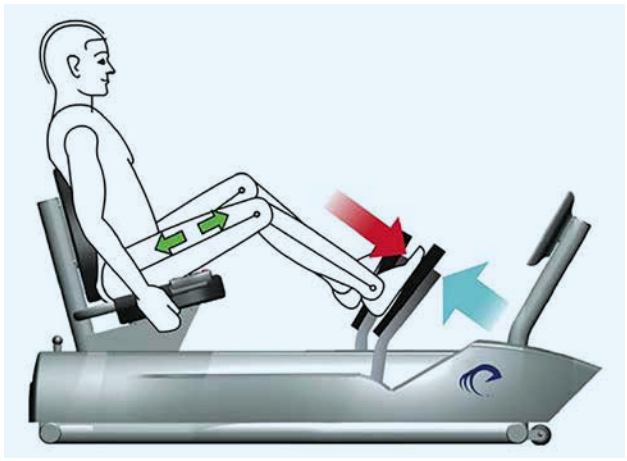

Figure 2

The modern version of a softroboter. Depending on the program mainly braking power eccentric muscle work (blue) or mainly concentric work (red) is performed. Legs are paralell but in contrast to a bike not coupled (20).

Measurements and Test Protocol

All participants absolved for times a protocol with 15, 25, 35 and 45 Kilogramm load. While 5 minutes, eccentric movements (9 seconds), followed by short concentric movements (1 second) were performed. The short phase was for the movement back. Both legs were separately coupled during the whole exercise and legs had to move parallel back. The movement back in the knee angle was calibrated and was 5-90 degree. Softroboter was individually calibrated with an angle mass. Angle was calibrated for each participant with an angle mass in order to calibrate the individual braking mass. Concentric back movement (5-degree knee angle) was only possible to make when an angle of 90 degree was reached. The braking distance was around 0.5 Meter, yielding depending on intensity to a maximum performance of 6.1 to 18.7 Watt. Participants got a direct feedback on a screen concerning their coordination on a Grey curve showing the optimal movement pattern. X-axis was representing the time while y-axis was showing the angle. During measurement the gray curve was similarly shown with a red curve showing the movement of the right leg and a blue curve showing the movement of the left leg. This allowed the participants to optimize the movements. After 1, 2, 3, 4 and 5 minutes the respective BORG-scale value for the left and the right leg as well for the total exertion was questioned. During the whole-time ›

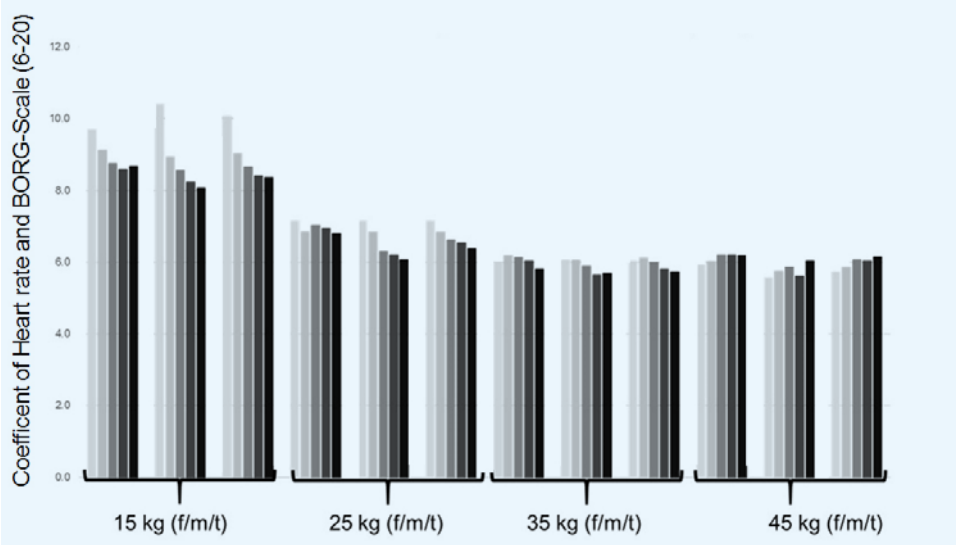

Figure 3

Coefficients between heart rate and reported BORG-Scale values separated between samples. Female, male and Total (f/m/t) from left to right, whereby the coefficient of heart rate and BORG-Scale after 1, 2, 3, 4 and 5 minutes for the four intensities.

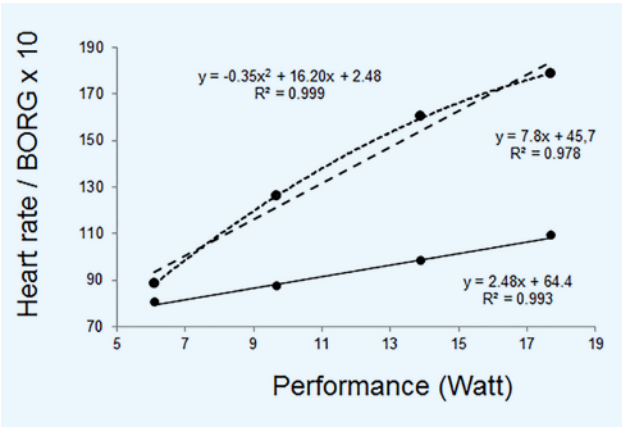

Figure 4

Relationship of heart rate (full line) and reported BORG-values x 10 in the four different protocols with differing intensity. The broad line equals the linear regression. The thin interpuncted line equals a polynominterpolation 2. Degree. Performance equals the physically measured performance with the softroboter.

heart rate was measured with a Garmin Fenix 3 HR (Kansas/USA) Sportwatch. It allowed exporting data to a TCX-file allowing analyzing with excel or graph pad prism.

Statistical Procedures

For all four intensity levels mean and SD of heart rate and BORG-Scale were calculated. Between the different localization (left leg, right leg, total) bivariate correlations (Spearman correlation coefficient) for all four intensities were calculated. In order to analyze a potential increase of heart rate respectively BORG-scale while five minutes exertion (15, 25, 35 and 45 kg load) a linear regression was calculated. To analyze the relationship of performance and heart rate respectively of BORG-scale, linear regressions were calculated. Additionally, between BORG-scale and performance a polynominterpolation 2. Degree was calculated. In order to quantify steadiness of coordination difference (delta) between the determined force of the program and the effective force was calculated. Furthermore, in order to determine the relationship of heart rate and reported BORG-scale were calculated. Calculations were made with Graphpad Prism 5.0 (GraphPad Software, Inc., La Jolla, California, USA) and Microsoft Excel (Microsoft Inc., Redmond, Washington, USA).

Results

Table 1 shows the mean and the SD of the measurements. Four females were unable to perform the highest intensity level during the whole 5 minutes. The stop was after two to three minutes. Data of participants that had to stop were used as long as possible.

There was hardly a difference between the left and the right leg in the rate of perceived exertion. In all samples (female, male and total) the four intensities of the correlative relationship between the rapported BORG-values of the left and the right leg and total between 0.95 and 1. This pattern is followed when analyzes are conducted between right leg and total exertion as well as left leg and total exertion.

The multiplication value, for the here conducted analyses respectively eccentric movement was around 6 (heart rate and BORG-values).

To get more hints concerning the coordination pattern additionally the error of coordination was analyzed (Fig. 5). Therefore the delta between the force given by the program and the effectively performed force was calculated each 0.005 seconds during the 5-minute program yielding to 60000 data points (Fig. 5). It was shown, that the deviation with increasing force in eccentric movement (below the zero value of x-axis) was asymptomatically converging. In contrast to the concentric movement (above the zero line of x-axis), revealing a relatively constant deviation between force determined by the program and effective force.

Discussion

The aim of the study was to analyze the cardiac load as well as the rate of perceived exertion during eccentric (braking) muscle activity with BORG-Scale. Oxygen consumption and therefore breath frequency coupled with usage of working musculature is one of the most important factors determining physical exhaustion (4, 25). This should affect rate of perceived exertion and therefore values on BORG-Scale while eccentric muscle activity (1, 2, 3, 17, 25). BORG-Scale is a good and valid possibility to rate the perceived exertion in endurance sports. There are hints, that the Scale is also adequate for concentric strength training (28, 29). The Scale entails a range between 6-20 respectively 60 and 200 beats per minute, implying a base heart rate of 60, which was also partly found in the conducted analysis (Fig. 4) (4, 5). To mention, the performance was very low due to the slow movement with cyclic-eccentric muscle activity. Limits of the results are the small analyzed sample and the fact that four female participants were not able to finish the highest intensity (Tab. 1). It was detected that the small sample of healthy

participants had heart rates for all four intensities in the end of the exertion with values of 79.7±16.5 to 115±18.2 beats per minute which are only in a low to moderate range while parallel highest reported BORG-values were detected (Tab. 1). The linear relationship between heart rate and performance might be lost for higher ranges of heart rate. However, based on the analyses also a not linear relationship with a plateau for higher heart rates are possible (Fig. 4).

Concerning validity of results, it has to be mentioned that also from other side based on different haemodynamic relationships compared to concentric movements lower values of BORG-Scale were reported (1, 2, 3, 15). In the estimated regression lines the postulated relationship between performance and heart rate respectively BORG-Scale can be embedded that several times a smaller amount of oxygen was shown to be necessary yielding to a lower felt rate of perceived exertion (7, 9, 13, 24).

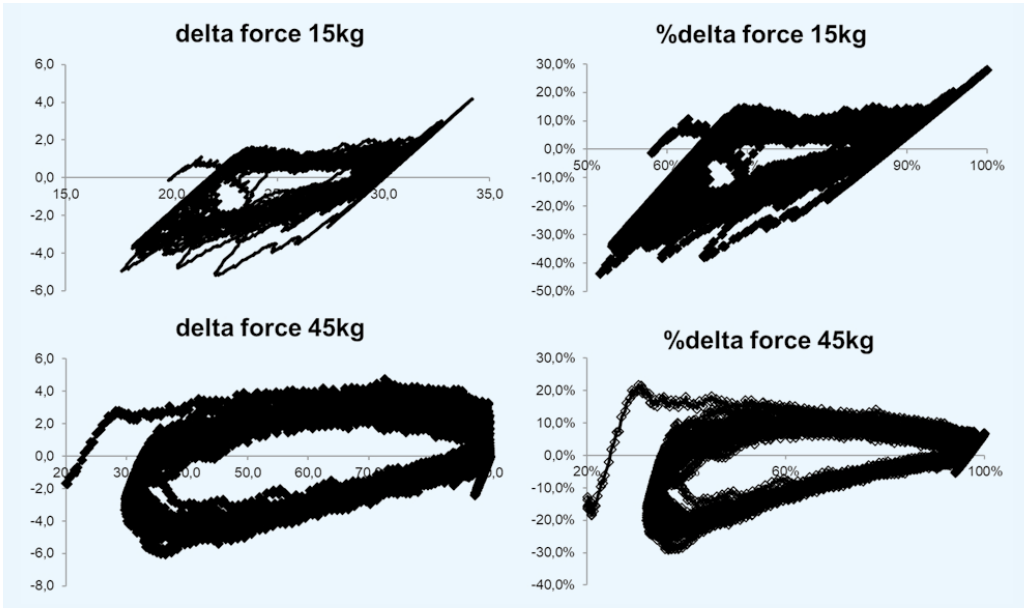

Figure 5

The error of coordination calculated as difference delta (y-axis) absolute values left and in percent right between the given power by the program and the effectively performed power (x-axis) for the left leg with 15kg (the two upper graphs) respectively the left leg with 45kg (the two lower graphs) for a well coordinating participant. It can be detected, that with increasing force the delta in eccentric movement asymptomatically converges to the x-axis. The handle shaped on the left side is due to the start and end period of the program, the thin lines in the 15 kg program are due to a not proper production of force with the hydraulic mechanism.

To mention, the performance was relatively low due to the slow cyclic-eccentric movements. Furthermore, the small sample and the fact that four participants only partly absolved the highest intensity have to be considered (Tab. 1). The initially stated hypothesis, that BORG-Scale values in concentric versus eccentric muscle activity are the same can be partly falsifizied, yet the postulated equation (heart rate=10 x BORG-value) differs for eccentric exercise compared to concentric exercise (Fig. 3).

Newer studies show, that depending on time of exercising different answers in perceived exertion result. Longer muscle contraction (6 seconds) had negative effects on explosive force, while short contractions yielded to increased lactate values, which would be in line with answers of different signal cascades (23, 24). A different perception and motor activation might be found in eccentric movements compared to concentric movements. The further conducted movement analyze of eccentric muscle activity shows with increasing load a tendency towards an asymptotic solution to equality of force determined by program and effective force (Fig. 5). This pattern seems to be less true for concentric movements where mistake was relatively constant over the whole load range. This allows to ›

Table 1

Intensity levels with load in kg 15/25/35/45. Mean (M) and Standard deviation (SD) of BORG-Scale concerning the reported totale exertion and regression weight (ß), intercept (α) and coefficient of determination (R2) of the linear regression between average heart rate of the four intensity levels. (n=12) Marked with * are characterized through participants not finishing all intensity levels reducing sample size (n=8).

HEART RATE								
LAST (KG)	1 MIN (M±SD)	2 MIN (M±SD)	3 MIN (M±SD)	4 MIN (M±SD)	5 MIN (M±SD)	β	α	R2
15 kg	87.8±18.7	81.3±17.5	80.2±19.2	79.4±16.1	79.7±16.5	-0.367	33.00	0.664
25 kg	86.5±14	86.4±14.7	87.2±16.2	90.2±16.3	89.3±16.8	0.784	-65.9	0.741
35 kg	94.8±14.1	100.5±12.7	103.6±17.3	104.5±15.6	106.4±17.1	0.329	-30.5	0,9
45 kg	99.5±19.4	107.1±16.9	111.8±38.7	112±51.7	115±18.2	0.244	-23.6	0.879
BORG (6-20)								
LAST (KG)	1 MIN (M±SD)	2 MIN (M±SD)	3 MIN (M±SD)	4 MIN (M±SD)	5 MIN (M±SD)	β	α	R2
15 kg	8.7±1.5	9±1.5	9.3±1.7	9.5±1.4	9.5±1.5	0.209	8.6	0.907
25 kg	12.1±1.2	12.6±1.4	13.2±1.5	13.8±1.9	14±2	0.5	11.6	0,99
35 kg	15.7±1.9	16.5±1.9	17.3±2	18±2.2	18.5±1.9	0.718	15.1	0.963
45 kg	17.4±1.5	18.3±1.5	18.4±1.5 *	18.6±1.4 *	18.7±1.5 *	0.3	17.4	0.789

suggest, that the complex interaction of perception with motor activation while concentric movements is different compared to eccentric movements.

To sum up the results the small sample of 12 healthy participants has to be considered, as a consequence only first hints can be made and no general recommendations. Furthermore, for patients of cardiac rehabilitation probably other implications would result. All participants were healthy persons without any cardiac morbidity. To analyze and to make secure recommendations studies with especially hamodynamic measurement might give further hints. Larger samples with simultan measurement of haemodynmaic parameters, oxygen consumption, EMG could reveal mechanism and would allow coming to a better understanding what factors determine rate of perceived exertion (4).

Concerning recommendations coaches should be aware that eccentric muscle activity yields to smaller cardiac requirements compared to concentric movements. Eccentric muscle work seems to be especially well suited for patients from cardiac rehabilitation while having a high stimulation of skeletal muscle but only partly using cardiovascular system, despite the fact, that probably high BORG values are reported. This allows to conduct an efficient strength training allowing for example to improve seniors their skills to walk down stairs or as potential prophylaxis for falls. It has to be kept in mind, that the intensity of a strength training measured with BORG-Scale is difficult, the postulated relationship BORG – value multiplied by 10 is heart rate, can not be applied for eccentric training. The estimation of heart rate should therefore be done with heart rote clock in order to observe cardiovascular requirements.

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Conflict of Interest

There are no conflict especially no financial support of interst between the producer of the Softroboters or owners of gym halls with eccentric gear.

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