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Effect of the "Xco-Trainer" on Heart Rate, Oxygen Intake and Energy Expenditure in Comparison to Solid Weights while Walking and Running

Background and Goals

In the past a number of attempts have been made to increase the effectiveness of walking and running exercise by utilizing training devices aimed at integrating the upper body musculature to a larger extent into the exercise mode. The Xco-Trainer, a hand-held aluminum tube filled with a granulate, which intensifies arm activity during walking and running, constitutes a new training device, which is supposed to increase cardiovascular metabolic activity by integrating additional muscle groups into the exercise. In a pilot study we noted significant increases in heart rate, oxygen intake and calorie expenditure by utilizing the Xco-Trainer in a walking- and running stress test as compared to equivalent tests without the device. In the study at hand we now compare the use of the Xco-Trainer, which is characterized by its "loose" or "shifting" mass inside a solid tube, to equivalent weights with a "solid mass". Based on a physical model one can expect that the required energy expenditure for a "loose" mass is higher than for a "solid" mass. The Xco-Trainer therefore would require a higher degree of muscular activity than when using a solid mass of equal weight. This study examines the effects of the Xco-Trainer as compared to the effects of identical weights with a "solid mass" on metabolic and cardiovascular response parameters based on heightened muscular activity during walking and running.

Material and Methods

The study was conducted at the Institute of Medical Physics of the Friedrich-Alexander University of Erlangen-Nuremberg.

Test Subjects

After solicitation by the Institute of Sport Science and Sports of the Friedrich-Alexander University of Erlangen-Nuremberg, 12 male and 12 female subjects were selected (all students or university employees). Their ages ranged from 20 -38 years. All participants gave their written consent in advance.

Study Design

The study represents a controlled cross-sectional, randomized model of crossover design[1]. To ensure the best possible objectivity amongst the participants, an Xco-Trainer of identical appearance and equal weight but containing a solid mass was utilized. Each subject completed three trials under three different conditions (without a tool; Xco-Trainer with shifting mass; Xco-Trainer with solid mass). Therefore, 24 trials were completed for each condition, which were compared to one another on the basis of the described parameters. The order of tests with tools ("shifting" vs. "solid mass") was randomized. The total number of completed spiroergometric performance tests was 72 in all.

Diagnostic Performance Protocols

The spiroergometric performance tests were conducted on a treadmill (Maxxus T1, Gross-Gerau, Germany) using a step test with 5-minute intervals. Beginning with 5.5 km/hr, the speed was increased every 5 minutes by increments of 1.5 km/hr up to the individual's maximal stress level. The subjects were asked to walk in the first two segments (5.5 and 7.0 km/hr) and to start running at speeds of 8.5 km/hr and faster. The participants completed three performance tests each, ending at the individual's subjective maximal stress level. A rest period of at least 2 days was used to ensure sufficient regeneration between tests. The first test in every case was a control- or base test without any added tool. Prior to the base test a 5 minute standardized indoctrination session with the Xco-Trainer was conducted. During this session we first asked for swinging arm motions in a resting position followed by a brief introduction in the use of the device while walking and running. The participants were then instructed that in the upcoming trials of the following days of testing with tools, weights (Xco-Trainer with solid weights) and the Xco-Trainer were to be respectively utilized to affect an active engagement of the arms. During the walking phase of the control test, active dynamic swinging of the arms – with the elbows at 90 degree angles -- was practiced. During the following two trials with tools, half of the participants were randomly selected to perform the first test with the Xco-Trainer (Xco Walking and Running (Xco-V, 630 g), Flexi-Sport Co., Munich, Germany) and the other half with the modified Xco ("solid" weight, 630 g). The second test was then performed with the other tool. The instructions for all tests were standardized and always in identical form.

[1] i.e. each participant completed three tests, each under different conditions

End Points

Pulse Diagnostic

The heart rate was monitored via a chest transmitter (Polar T 61, Buettelborn, Germany) and relayed telemetrically to the spirometric system (Oxycon mobile, Viasys, Conshohocken, PA, USA) for continual monitoring. Average rates were generated for each stress level.

Lactate Diagnostic

Following each 5-minute interval, blood was taken from the fingertip to measure the corresponding lactate value (Lactate Scout, EKF diagnostic sales GmbH, Barleben, Germany). The blood sample was taken during a 30-second exercise break.

Spiroergometrics

The following respiratory parameters were monitored continuously via the spirometric method (see above) and recorded and analyzed every 30 seconds:

- oxygen intake,
- energy expenditure,
- fat expenditure,
- respiratory quotient.

Averages at every stress level were determined for each respective parameter. In addition, metabolic equivalents (METs) are provided to allow for a better understanding of the inferences drawn for the absolute intensity of the body's stress level[2].

Statistical Evaluation

The required statistical frequency was determined via the program G*Power 3.0.3 (University of Kiel, Germany). To statistically substantiate the mean difference of 10 % (±12) between groups (Power 0.8, $p<0.05$), the calculations

[2] 1 MET is equal to the energy use while at rest in a supine position, i.e. roughly the energy-use in calories per kg. of body weight in 1 hour. Activities < 3.0 METs are considered to be light physical activities, those above 6 METs strenuous physical activities.

showed a requirement for 24 participants or test runs respectively. In the following, the measured values are given as mathematical averages with standard deviations. Group differences were analyzed by single factor ANOVA (ad hoc test per Scheffe). All test runs were two-tailed tests whereby the probability of error under 5 % is determined to be significant. The different levels of significance are presented as follows: *$p<0.05$; **$p<0.01$; ***$p<0.001$. The program SPSS 14.0 (SPSS Inc., Chicago, IL) was used for the statistical analysis. For this analysis only those stress levels that were completed by all participants were used (5.5 - 13 km/hr). Aside from the first stress level, the evaluation in each case ignored the first minute of each 5-minute interval since those values are faulty due to the 30-second break (blood drawing).

Results

A total of 72 test runs by 24 subjects were completed (3 runs/subject). Following is a comparative description of the three test conditions with regard to the final criteria to be surveyed ((1) test run without a tool, (2) test run with Xco-Trainer with solid weights, (3) test run with Xco-Trainer).

Heart Rate

Overall higher pulse rates were observed at the test runs with the Xco-Trainer than at the runs without Xco or with solid weights (table 1). The differences were most pronounced at the 3 lower speed levels. It was observed that when walking at 5.5 km/hr with the Xco-Trainer, the mean heart rate was 10 beats higher than without the Xco and 12 beats higher than tests with solid weights. The difference between tests with Xco and those without any tools, as well as the differences between tests with Xco and those with solid weights were statistically significant. When walking at 7.0 km/hr, the pulse rates achieved with the Xco-Trainer and solid weights were significant. The effects diminished when the speed was increased. When running with the Xco-Trainers at 8.5 km/hr, the pulse rate was 7 beats higher, at 10 km/hr 5 beats higher than without a tool, or at 8.5 km/hr higher by 8 beats and at 10 km/hr higher by 5 beats than running with solid weights. These differences, however, no longer reached the level of significance. At the stress levels of 11.5 and 13 km/hr the differences in pulse rate were even smaller. Between running without a device and running with solid weights, no difference in pulse rate was noted.

	Tests without tool Pulse rate [bpm] [ml/min/kg]	**Tests with solid weight Pulse rate [bpm] [ml/min/kg]**	**Tests with Xco-Trainer Pulse rate [bpm] [ml/min/kg]**
Walking 5.5 km/hr	97 ± 12	95 ± 12	$107 \pm 13^{*1**2}$
Walking 7.9 km/hr	113 ± 15	112 ± 14	$123 \pm 14^{*2}$
Running 8.5 km/hr	135 ± 17	134 ± 15	142 ± 14
Running 10 km/hr	149 ± 18	149 ± 15	154 ± 16
Running 11.5 km/hr	162 ± 18	162 ± 15	165 ± 15
Running 13 km/hr	173 ± 16	171 ± 12	174 ± 14

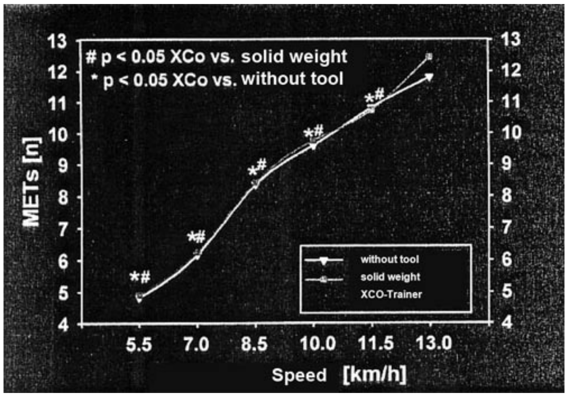
Table 1: Mean values of pulse rates with standard deviations while testing without tools, with solid weights and with Xco-Trainers at different speed levels. Significant group differences are marked by asterisks and numericals (*p<0.05; **p<0.01; ***p<0.001); [1] significant difference compared to tests without tools; [2] significant difference compared to tests with solid weights.

Relative to oxygen intake, both running and walking showed higher values for the Xco-Trainer than under the other two conditions (see Table 2). The differences recorded at all stress levels were significant as compared to running without a tool. Compared to solid weights, levels of significance were also reached at every level, with the exception of the 13 km/hr level. In walking the differences were more pronounced than in running. the difference between the Xco-Trainers and no weights in running reached an average of 23%; between Xco-Trainers and solid weights, 21%.

	Tests without tool Oxygen intake [ml/min/kg]	**Tests with solid weight Oxygen intake [ml/min/kg]**	**Tests with Xco-Trainer Oxygen intake [ml/min/kg]**
Walking 5.5 km/hr	16.9 ± 1.6	17.1 ± 2.2	21.6 ± 3.3^{***1***2}
Walking 7.9 km/hr	21.6 ± 2.2	21.8 ± 2.9	25.4 ± 3.0^{***1***2}
Running 8.5 km/hr	29.3 ± 2.5	29.5 ± 3.5	32.2 ± 3.0^{**1**2}
Running 10 km/hr	33.7 ± 2.0	34.0 ± 3.5	36.3 ± 3.4^{*1*2}
Running 11.5 km/hr	37.9 ± 2.2	37.8 ± 3.6	40.3 ± 3.8^{*1*2}
Running 13 km/hr	41.3 ± 3.2	43.4 ± 2.8	44.2 ± 4.2

Table 2: Mean values of oxygen intake with standard deviations while testing without tools, with solid weights and with Xco-Trainers at different speed levels. Significant group differences are marked by asterisks and numericals. (*p<0.05; **p<0.01; ***p< 0.001; ^{1} significant difference compared to tests without tool; ^{2} significant difference compared to tests with solid weights.

In relation to oxygen intake at different stress levels, the differences of metabolic equivalence (METs) in comparison to tests without tools were all significant. Compared to solid weights, all but the 13 km/hr test reached a level of significance of $p < 0.05$.



Illus. 1: Mean values of metabolic equivalents during test without tool, with solid weights and Xco-Trainers, at different rates of speed.

At all stress levels, running with the Xco-Trainer showed the highest energy expenditure (Tab. 3). At the first two levels, the difference between Xco-Trainers and exercising without weights was an average of 23%; between Xco-Trainers and solid weights, 22%. The difference decreased with increasing stress levels, and – contrary to the first two levels – no longer reached levels of significance.

	Tests without tool Energy use [Kcal/hr]	**Tests with solid weight Energy use [Kcal/hr]**	**Tests with Xco-Trainer Energy use [Kcal/hr]**
Walking 5.5 km/hr	338 ± 68	342 ± 76	433 ± 101^{**1**2}
Walking 7.9 km/hr	434 ± 75	439 ± 89	513 ± 106^{*1*2}
Running 8.5 km/hr	597 ± 111	599 ± 122	654 ± 121
Running 10 km/hr	689 ± 124	695 ± 140	740 ± 134
Running 11.5 km/hr	779 ± 139	777 ± 153	828 ± 155
Running 13 km/hr	859 ± 167	919 ± 157	939 ± 163

Tab. 3: Mean values for energy expenditure with standard deviation while testing without tools, with solid weights and with Xco-Trainers at different rates of speed. Significant group differences are marked by asterisks and numericals (*p < 0.05; **p< 0.01; ***p < 0.001; ^{1} significant difference compared to tests without tool; ^{2} significant difference compared to tests with solid weights.

Regarding respiratory quotients and lactate concentration, there were no noticeable differences between tests with the Xco-Trainers, with solid weights or without tools (Tab. 4 and Tab. 5). The higher caloric conversions during tests with Xco-Trainers at equal respiratory quotients results in an absolute higher fat burn-off rate during tests with the Xco-Trainer.

	Tests without tool	**Tests with solid weight Respiratory quotient (CO_2/O_2)**	**Tests with Xco-Trainer Respiratory quotient (CO_2/O_2)**
Walking 5.5 km/hr	.81 ± .04	.79 ± .04	.81 ± .05
Walking 7.9 km/hr	.84 ± .05	.83 ± .04	.85 ± .05
Running 8.5 km/hr	.87 ± .05	.86 ± .04	87 ± .05
Running 10 km/hr	.90 ± .04	.88 ± .04	.88 ± .05
Running 11.5 km/hr	.92 ± .04	.91 ± .05	.91 ± .05
Running 13 km/hr	.96 ± .05	.94 ± .05	.94 ± .05

Table 4: Mean values of respiratory quotients with standard deviations at tests without tools, with solid weights and with Xco-Trainers, at different rates of speed.

	Tests without tool Lactate concentration [mmol/l]	Tests with solid weight Lactate concentration [mmol/l]	Tests with Xco-Trainer Lactate concentration [mmol/l]
Walking 5.5 km/hr	1.5 ± .5	1.4 ± .6	1.4 ± .6
Walking 7.9 km/hr	1.4 ± .4	1.3 ± .4	1.4 ± .5
Running 8.5 km/hr	1.6 ± .5	1.6 ± .7	1.7 ± .7
Running 10 km/hr	2.0 ± .9	2.0 ± .8	2.3 ± 1.2
Running 11.5 km/hr	2.9 ± 1.5	3.0 ± 1.5	3.2 ± 1.8
Running 13 km/hr	4.6 ± 2.4	4.4 ± 2.2	4.4 ± 2.2

Table 5: Average lactate concentrations with standard deviations at tests without tools, with solid weights and with Xco-Trainers, at different rates of speed.

Discussion

The goal of the study at hand was to determine the effects of the so-called Xco-Trainers on metabolic and cardiovascular responses during walking and running activity. The study represents a controlled randomized study of cross-over design, whereby each subject completed three tests under different conditions. Two comparisons were made to walking and running with the Xco-Trainer: one without any tool (true base model) and one with solid weights. A “blind” trial was in this case, as in the case of most sports science testing, only of limited value, since the difference between the Xco-Trainers and modified Xco’s (with solid mass) could be immediately felt and heard. By selecting test subjects who had no prior experience with Xco-Trainers, we tried to assure that, by using modified Xco’s (solid mass, identical appearance) and standardized instructions, both Xco varieties were utilized in the same manner. The study at hand, with 72 stress tests, represents a study which should adequately answer the central question with regards to its expected effects.

In this study the Xco-Trainer was proven as a suitable too to increase heart rate, oxygen intake and energy expenditure in comparison to walking without a tool. Even in direct comparison to “solid” weights, we note, for both walking and running, that the use of the Xco-Trainer shows an enhanced effect which favorably impacts the target parameters. Generally, the effects were more pronounced at lower speeds than at higher ones. The reduction of the Xco’s induced effects concurrent with higher rates of speed are due to the fact that at higher rates of speed, the relative contribution of the upper-body musculature engaged by the Xco-Trainers is proportionately less significant in comparison to the increased oxygen or energy demands of the lower extremities of the body at high rates of speed. Because of this, the effects of Xco during walking and running at lower speeds are more pronounced.

Both the lactate concentrations and respiratory quotients were almost identical within all rates of speed without any device, with solid weights and with the Xco-Trainers. Accordingly, the increased cardiovascular and metabolic responses while using the Xco-Trainers must be interpreted as being caused by engaging additional muscle groups in the upper body, i.e., more muscles are being called upon within the same intensity or metabolic range. An increase in heart rate and energy usage via increased activation of more musculature would be considered a desirable effect as regards any health or recreational form of sports activity. Further increasing the intensity of either walking or running with increased speed, however, automatically results in a higher demand on the primary working musculature and thus triggers a metabolic shift towards reduced fat burn-off (recognized through a higher respiratory quotient) and towards higher lactate values.

Altogether, a training program intensified by using additional devices which integrate the upper body musculature more effectively into the exercise, is most relevant in talking exercises. Especially younger health-conscious athletes will often not attain levels of intensity or pulse rates sufficiently high for an effective cardiovascular exercise program simply by walking. Furthermore, the energy expenditure while walking as compared to running is relatively lower, and it cannot be significantly influenced by improving the technique. In this context, any device which promotes higher energy expenditure in a walking program earns a high ranking, especially if it supports the often desired exercise goal of weight loss.

The empirically obtained results are compatible with calculations obtained via the laws of physics, according to which a “shifting mass” requires a higher expenditure of energy. On this basis of considerations in physics, it is obvious that a “shifting mass” changes the dynamics relative to the force-time-characteristic and the required expenditure of energy. At equal amplitudes (and frequency) of the arm’s movements, the center of gravity of the shifting mass travels a longer distance due to the shifting of the granules. This stipulates a higher velocity and requires a higher rate of acceleration for a greater impact at the point of reversal, thus demanding a greater effort, or higher energy expenditure. An additional expenditure is to be expected due to friction and a longer stroke as a result of the specific displacement of the granules within the shifting mass. Not only the quantity but also the quality of the impact of the shifting mass is of a differing nature. Due to the delayed deceleration of the various masses (tube-granulate-granulate), the impact imparts itself in a flatter, broader manner, thus reducing the peak of the force. As described in the following calculations of differences in energy expenditures, based on the model of a rotating pendulum, indicates that, even when neglecting the influence of friction, the energy expenditure required by an Xco with a shifting mass is up to 26% higher than one with a solid mass:

Moment of inertia: θ = m*l; m = .63 kg; length of swing r = .48m

The cycle time of a rotating pendulum is

$$T = 2\pi * \sqrt{\frac{\Theta}{D_r}}$$ D_r Moment of reversal

potential energy

$$E_{pot} = \frac{1}{2} * D_r * \alpha^2$$ α angle of rotation in radian

Determining the unknown Dr via the cycle time

$$E_{pot} = \frac{1}{2} * \left(\frac{2\pi}{T} * \alpha\right)^2 * \Theta$$

$$E_{pot} = \frac{1}{2} * \left(\frac{2\pi}{T} * \frac{\varphi}{180} * \pi\right)^2 * \Theta$$ φ angle of extension in degrees

$$\Theta = m_{gesamt} * r^2$$

Center of gravity shift from center, when the granulate is on one side:

$$s = \frac{m_{Granulat}}{m_{gesamt}} * \left(\frac{l_{Hantel} - l_{Granulat}}{2}\right) = \frac{0{,}353}{0{,}63} * \left(\frac{0{,}251 - 0{,}145}{2}\right) = 0{,}0297$$

this represents an angle of:

$$\varphi = \arcsin\left(\frac{s}{r}\right) = \arcsin\left(\frac{m_{Granulat}}{m_{gesamt} * r}\right) * \left(\frac{l_{Hantel} - l_{Granulat}}{2}\right) = 3{,}547°$$

energy ratio

$$\frac{E_{pot}^{Granulat}}{E_{pot}^{starr}} = \left(\frac{\varphi_{Granulat}}{\varphi_{starr}}\right)^2 = \left(\frac{(29 + 3{,}547)}{29}\right)^2 = 1{,}26$$

Nevertheless, the empirically determined differences in energy expenditures cannot be explained solely on the basis of a physical model. We presume that the characteristic dynamic properties of the Xco-Trainer, or the motions required to activate the swinging mass, require additional exertion of the arms. Even though we deliberately standardized our instructions, this phenomenon could have led to a relatively increased dynamic force in the swinging of the arms during exercises with the Xco-Trainers. Since we did not conduct any kinematic analyses of the arm motions, this assumption remains speculative. Independent of the cause for a higher energy expenditure, all mechanisms that stimulate increased metabolism could be termed to have a positive effect in any case. Collectively it can be assumed that these dynamic characteristics of the Xco-Trainers benefit both the process and the resulting effects of the training activity. Compared to solid weights, the Xco-Trainer summons a higher degree of effort and assures a consistently intensive work-out of the arms, due to the motions required for the oscillation of the shifting mass, while also constantly receiving feedback of the quality of the movements. The fact that solid weights did not increase heart rate and only had negligible effects on raising oxygen intake levels and energy expenditures was surprising to us. We attribute this to the possibility that in relation to the weight of the arm (about 7-8 kg), the additional weight of the solid weights may not have been enough of a load to make a significant impact above and beyond the exercises with no additional weights at all, during which the subjects also actively moved their arms in a dynamic manner.

Overall, the Xco-Trainer constitutes a training device that in the study at hand proved itself as able to raise the effectiveness of the training, especially of walking, with regards to heightened cardiovascular response and energy expenditure. A solid mass of identical weight, on the other hand, showed no effects on the parameters monitored. Therefore the Xco-Trainer is an appropriate training device – especially for walking – yielding, as a result of a more intensive training mode, increased cardiovascular response and increased calorie burn-off. The results of this study will be submitted for publication in a renowned journal, subject to the customary peer review process.