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Energy expenditure and physiological responses during walking on a treadmill and moving on the Torqway vehicle

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Purpose: One of the new products which can be used to increase physical activity and energy expenditure is the Torqway vehicle, powered by the upper limbs. The aim of this study was to (1) assess the usefulness and repeatability of the Torqway vehicle for physical exercise, (2) compare energy expenditure and physiological responses during walking on a treadmill and during physical effort while moving on the Torqway at a constant speed. *Methods*: The participants (11 men, aged 20.2 ± 1.3) performed the incremental test and submaximal exercises (walking on the treadmill and moving on the Torqway vehicle at the same speed). *Results*: Energy expenditure during the exercise on the Torqway was significantly higher ($p = 0.001$) than during the walking performed at the same speed. The intensity of the exercise performed on the Torqway expressed as $\%VO_2max$ and %HRmax was significantly ($p < 0.001$) higher than during walking (respectively: 35.0 ± 6.0 vs. 29.4 ± 7.4 $\%VO_2max$ and 65.1 ± 7.3 vs. 47.2 ± 7.4 %HRmax). *Conclusions*: Exercise on the Torqway vehicle allows for the intensification of the exercise at a low movement speed, comparable to walking. Moving on the Torqway vehicle could be an effective alternative activity for physical fitness and exercise rehabilitation programs.

Key words: *oxygen consumption, physical fitness, health, exercise machine, exercise*

1. Introduction

Regular physical activity improves cardiovascular and respiratory function [2]. One of the main benefits of regular exercise is improvement in maximal oxygen uptake, decreased pulmonary ventilation, heart rate and blood pressure during submaximal exercise or increase in exercise threshold for accumulation of lactate in the blood. Moreover, physical activity reduces cardiovascular risk factors as well as morbidity and mortality [2]. There is also a correlation between physical activity and health status: an increase in physical activity and fitness leads to improvement in health status [24].

Today's lifestyle and advanced technologies cause people to spend most of the day in a seated position or on non-exercise physical activity. In epidemiological studies, sitting time and non-exercise activities have been linked to rates of metabolic syndrome, type 2 diabetes, obesity and cardiovascular disease [24]. There is a need to seek various forms of exercise encouraging physically inactive people to take up physical activity. Furthermore, this physical activity should be in accordance with guidelines regarding the duration and intensity of physical activity required to maintain or improve

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health [2], [14], [20], [21], [23]. To encourage people to exercise, physical activity aimed at increasing energy expenditure and improving health should be as diverse as possible. For this purpose, physiological response and energy expenditure during various physical activities such as walking or jogging [10], [26], cycling and rowing [11], exercise to music [6], playing active video games [22], and Nordic walking [13], and many others, were evaluated. One of the new products which can be used to increase physical activity and energy expenditure is the Torqway vehicle (Torqway, Poland), powered by the upper limbs. This vehicle is an innovative device with wide application in recreation, sport or rehabilitation. Recently, it has become a multiple award-winning innovation at fairs, among others, it was awarded the title of "Best Invention of Europe" in 2014 in Pittsburgh (USA).

Visually, the Torqway resembles the Segway electric vehicle. However, the Torqway is a vehicle powered solely by the muscular power of its user, mainly by the muscles of the upper limbs and shoulder girdle. The exercise is carried out in a standing position. The vehicle consists of two independently powered large front wheels, a set of torsional smaller rear wheels, two handles (lever arms) and a low suspended lightweight platform allowing the user to occupy an upright position. The platform is divided into two parts, a larger front and smaller rear equipped with two small wheels, which are responsible for turning the vehicle. Turning the vehicle is done via manoeuvring the rear part of the platform using the heels. Each front wheel is equipped with an internal mechanism which converts the swinging movement of the lever to unidirectional rotation of the wheel axle: every movement of the user's upper limbs – forward and backward – is productive and powers the vehicle. Movement speed of the vehicle depends on the user's arm movement frequency, power put into pulling the lever and lever length. The speed of the vehicle is dependent on the type of shifting. Assuming that the user utilizes the vehicle for leisure purposes, it is possible to move with a speed of up to approx. 10–15 km·h^{-1}. The vehicle weighs about 15 kg (mass comparable to average bicycle weight). Stopping the vehicle requires deflection of the lever arms to the outside. Figure 1 presents the subject on the Torqway vehicle during the stress test on a treadmill.

The aim of this study was to (1) assess the usefulness and repeatability of the Torqway vehicle for physical exercise, (2) compare energy expenditure and physiological responses during walking on a treadmill and during physical exercise while moving on the Torqway at a constant speed.

Fig. 1. Participant moving on Torqway during stress test

2. Materials and methods

The male participants were familiarized with the purpose and methods of research and gave their written consent to take part in the study, which was carried out in accordance with the Declaration of Helsinki. The project was approved by the Bioethics Commission at the Local Medical Chamber.

The present studies included: a familiarization session, anthropometric measurements, an incremental test, assessment of the repeatability of physiological responses while moving on the Torqway at a speed of 4.8 km·h^{-1} (test and retest) and comparison of energy expenditure and physiological response while walking on a treadmill and moving on the Torqway at the same speed.

During the tests, a constant length of the Torqway lever arm (90 cm) was established for all subjects: when holding the Torqway handle arm, the angle of the elbow joint was approximately 90°. The subjects independently decided on the frequency of arm movements and thus, the force used to pull the lever as well.

All stress tests were carried out in an air-conditioned laboratory, under similar conditions. The tests were conducted on a mechanical treadmill (h/p Cosmos, Saturn, Germany), at the surface inclination angle of 0%. Breathing indicators were measured using the breath to breath method, with the Metylzer 3B ergospirometry (Cortex, Germany) and heart rate was measured using a heart rate monitor (S610, Finland). The metabolic card was calibrated according to the manufacturer's requirements before each test (volume and gas calibration).

Participants

The study involved 11 healthy men, aged 20.2 ± 1.3 years, none of whom trained sport professionally. The participants were physically active men and declared performing physical activity at low or moderate intensity, no more than 3 times a week. The average levels of somatic indicators among the participants were as follows: body height 180.6 ± 5.4 cm, body mass 73.3 ± 7.0 kg, body fat percentage 14.2 ± 4.0% and body mass index 22.5 ± 2.1.

Familiarization session

During the first visit to the laboratory, the male subjects were acquainted with the instruments used in the tests (mechanical treadmill, ergospirometer and Torqway vehicle). The purpose of this stage of the research was to familiarize the subjects with the technique of moving on the Torqway, as well as the conditions in the laboratory. For this purpose, two training sessions lasting 30 minutes were scheduled. During the first session, the subjects learnt techniques of moving on the Torqway on a flat, smooth surface, trying to maintain a constant speed and move without changing direction. During the second practice session, the men practiced moving on the Torqway on a mechanical treadmill, maintaining a constant speed (4.8 $km{\cdot}h^{-1}$) and direction (avoiding turning).

Anthropometric measurements

For the males tested, body height measurements were taken using a stadiometer (Seca, Germany) with an accuracy of 1 mm. Using the body composition analyzer which employs the bioelectrical impedance method (Jawon IOI 353, Korea), the following indicators were determined: body mass and percentage of body fat. For each subject, body mass index was calculated.

Incremental test

The purpose of the test was to determine each participant's maximal oxygen uptake and maximal heart rate. All participants performed an incremental treadmill test to volitional failure. The test was performed on a treadmill. During the test, oxygen uptake (VO_2), carbon dioxide production (VCO_2) and respiratory exchange ratio (RER) were measured.

The test began with a 4-minute warm-up at a speed of 7 $km{\cdot}h^{-1}$. Then, the running speed was increased by 1.2 $km{\cdot}h^{-1}$ every two minutes until the participant reported extreme exhaustion and refused to continue the test. The criteria to determine VO_2max were as follows: a plateau in oxygen consumption, a RER of >1.15, and attainment of a heart rate within 10 beats per minute of age-predicted maximum. However, in situations where no plateau was observed, VO_2peak was taken as the VO_2max [16]. The participants were encouraged by the researcher to give their maximum effort throughout the test.

Reliability of Torqway vehicle

The aim of the study was to determine repeatability of physiological response during moving on the same Torqway vehicle. The test was carried out on a mechanical treadmill (h/p Cosmos, Saturn, Germany) at a speed of 4.8 $km{\cdot}h^{-1}$ and the effort lasted 6 minutes. The test was performed twice with a one-week interval. During the effort, VO_2 and HR were measured. The task of the participant was to maintain the required constant speed and direction (avoiding turning). The subject could individually choose the pace of work of the upper limbs as well as the strength necessary to pull the arm lever. The level of physiological indicators recorded in the steady state conditions was analyzed. It was assumed that the steady state fluctuations in VO_2 should not exceed 0.1 $L{\cdot}min^{-1}$ [9].

Calorimetry, physiological and biochemical measurements

The aim of the test was to compare the physiological and biochemical response during walking on the treadmill and exercise on the Torqway at a constant speed. Energy expenditure (EE) was assessed during both efforts. The energy expenditure was determined using the open-circuit indirect calorimetry method (based on oxygen consumption and the RER respiratory rate). It is assumed that the consumption of one liter of oxygen, depending on the RER, resulted in energy expenditure of 4.66 to 5.02 kcal [8].

The test consisted of two exercises, lasting 6 minutes each, with an interval of 3 minutes. Both efforts were carried out at a speed of 4.8 $km{\cdot}h^{-1}$. During the first exercise, the form of movement was walking on a treadmill, while the second exercise was performed on the Torqway (also on the treadmill). We analyzed the level of physiological indicators recorded in the steady-state. The exercise intensity was expressed as $\%VO_2max$ and %HRmax. To assess the subjective rate of perceived exertion (RPE), the Borg scale was used (scale of 6–20 points, where 6 = very, very light; 20 = very, very heavy exercise) [4].

Prior to the test and directly following each effort (walking on treadmill and moving on Torqway), capillary blood samples were taken for biochemical analysis. Biochemical analyzes included determination of lactate in the blood plasma (La^-) and concentration of hydrogen ions (H^+) in the arterialized blood. The concentration of lactate was determined by spectrophotometry (Evolution 201 UV/Vis Thermo Scientific spectrophotometer, USA) immediately after centrifugation of blood, using Lactate PAP enzymatic assay (BioMerieux, France). Blood was collected into micro-tubes containing anticoagulant and glycolysis inhibitor (NaF). The concentration of H^+ ions was assessed using RapidLab 348 Siemens analyzer (Germany).

Statistical analysis

Data are presented as mean and standard deviation (mean ± SD). Data distribution was verified using the Shapiro–Wilk test. The Intra-Class Correlation Coefficient (ICC) and *t*-test for dependent samples were used to determine the reliability and the repeatability of the measurements (test and retest of the Torqway vehicle) [3], [25]. Additionally, in the test–retest, the confidence interval (CI) was calculated.

The significance of differences in the level of the analyzed variables between the walking on the treadmill and exercise on the Torqway, as well as the change of biochemical parameters (pre–post test) was determined using the *t*-test for dependent samples. In all statistical tests, differences were considered statistically significant when $p < 0.05$. Statistical analysis was performed using Statistica 10 (StatSoft, USA).

3. Results

Reliability of the Torqway vehicle

No significant differences were found between variables in the two tests (test and retest) performed on the Torqway vehicle, and these variables showed significant correlation in the ICC test (Table 1).

Table 1. Reliability of Torqway vehicle

Statistics	VO_2 ($L·min^{-1}$)		$\%VO_2max$		HR ($b·min^{-1}$)		%HRmax		RPE	
	Test	Retest	Test	Retest	Test	Retest	Test	Retest	Test	Retest
Mean	1.32	1.28	34.4	35.0	131	129	66.0	65.1	9.5	10.3
SD	±0.23	±0.26	±4.5	±6.0	±16	±15	±8.4	±7.3	±1.5	±2.5
CI –95%	1.15	1.10	31.3	29.9	120	119	60.3	60.2	8.4	8.5
CI +95%	1.47	1.45	37.4	38.0	142	139	71.6	70.0	10.4	12
ICC	0.75*		0.42		0.98*		0.98*		0.73*	
t-test (*p*-value)	0.68		0.82		0.10		0.22		0.18	

*$p < 0.05$; SD: standard deviation; CI: confidence interval; ICC: Intra-Class Correlation Coefficient; VO_2: oxygen uptake; HR: heart rate; RPE: rate of perceived exertion.

Comparison of energy expenditure and physiological response between walking on the treadmill and moving on the Torqway vehicle

Energy expenditure during the exercise on the Torqway was significantly higher (about 20%) than during the walking performed at the same speed. The average energy expenditure during movement on the Torqway vehicle was 384.5 ± 90.9 $kcal·h^{-1}$ (6.4 ± 1.5 $kcal·min^{-1}$), while during the walking it was 318.8 ± 53.4 $kcal·h^{-1}$ (5.3 ± 0.9 $kcal·min^{-1}$) (Table 2).

The results of the study indicated a significantly ($p < 0.05$) higher metabolic cost of the effort when moving on the Torqway vehicle compared to walking at the same speed (Table 2). During the exercise on the Torqway, the oxygen consumption, pulmonary ventilation and heart rate were significantly ($p < 0.001$) higher compared to the walking. The intensity of the exercise performed on the Torqway expressed as $\%VO_2max$ and %HRmax was significantly ($p < 0.001$) higher than during walking (respectively: 35.0 ± 6.0 vs. 29.4 ± 7.4 $\%VO_2max$ and 65.1 ± 7.3 vs. 47.2 ± 7.4 %HRmax). Also, the rate of perceived exertion was significantly greater during

Table 2. Physiological response to walking on treadmill and during moving on Torqway vehicle at 4.8 km·h^{-1} (mean ± SD)

Variable		Walking	Torqway	*t*-test (*p*-value)
VO_2 (L·min^{-1})		1.10 ± 0.17	1.28 ± 0.26	<0.001
VO_2 (mL·kg^{-1}·min^{-1})		15.10 ± 1.82	17.42 ± 2.74	<0.001
%VO_2max		29.4 ± 7.4	35.0 ± 6.0	<0.001
HR (b·min^{-1})		94 ± 15	129 ± 15	<0.001
%HRmax		47.2 ± 7.4	65.1 ± 7.3	<0.001
VE (L·min^{-1})		24.6 ± 3.9	35.1 ± 7.2	<0.001
EE (kcal·h^{-1})		318.8 ± 53.4	384.5 ± 90.9	0.001
EE (kcal·min^{-1})		5.3 ± 0.9	6.4 ± 1.5	0.001
RPE		7.5 ± 1.7	10.3 ± 2.5	<0.001
La^-(mmol·L^{-1})	before	1.62 ± 0.77	1.69 ± 0.79	0.805
	after	1.69 ± 0.79	2.60 ± 0.97	0.041
	p	0.805	0.041	
H^+ (nmol·L^{-1})	before	38.72 ± 2.21	39.03 ± 2.07	0.548
	after	39.03 ± 2.07	40.14 ± 1.76	0.030
	p	0.545	0.030	

VO_2: oxygen uptake; HR: heart rate; VE: pulmonary ventilation; EE: energy expenditure; RPE: rate of perceived exertion; La^-: lactate concentration; H^+: concentration of hydrogen ions.

exercise performed on the Torqway than during walking. After the exercise on the Torqway, a significant increase in the concentration of lactate and hydrogen ions was noted; no change in the level of La^- and H^+ was observed following the walk (Table 2).

4. Discussion

The main aim of this study was to compare the energy expenditure and physiological response while walking on the treadmill and moving on the Torqway at the same speed (4.8 km·h^{-1}) and thus, to determine the usefulness of the Torqway vehicle in increasing energy expenditure during exercise. Furthermore, we evaluated the reproducibility of physiological responses during exercise performed on the Torqway.

The test showed that standard exercise on the Torqway elicit a similar physiological response: we found no statistically significant differences in the level of analyzed indicators between the two tests (test and retest). Comparing the metabolic cost of walking on a treadmill and moving on the Torqway at the same speed, the study indicated that moving on Torqway is a significantly more intense exercise than walking. The walking economy (expressed as relative oxygen uptake) was about 15.1 ± 1.82 mL·kg^{-1}·min^{-1} (approx. 4.3 METs), and when moving on the Torqway it averaged 17.4 ± 2.74 mL·kg^{-1}·min^{-1} (approx. 5 METs). According to the classification proposed by the ACSM [2], both exercises were of moderate intensity (3–6 METs). Moderate (64–76 %HRmax or 46–64 %VO_2max) to vigorous (76–96 %HRmax or 64–91 %VO_2max) intensity of aerobic exercise is recommended for most adults, and light (57–64 %HRmax or 36–45 %VO_2max) to moderate intensity aerobic exercise can be beneficial to individuals who are de-conditioned [2]. These exercises should be performed 3 to 5 times a week for at least 20–30 minutes [14].

In our study, we evaluated the intensity of the exercise on the Torqway at low speeds, corresponding to the walk. The intensity while moving on the Torqway was lower (35.0 ± 6.0 %VO_2max and 65.1 ± 7.3 %HRmax) than that of the ACSM [2] recommendations, but the intensity of the exercise on the Torqway can be easily and safely increased, e.g., by changing the length of the arm lever or by increasing the moving speed. Furthermore, the total caloric expenditure during moving on the Torqway vehicle was 384.5 ± 90.9 kcal·h^{-1}, which is higher than the ACSM [2] recommendations for weight loss.

Upper body exercise elicits greater cardiorespiratory, metabolic and perceptual responses to arm exercise than leg exercise at the same power output [4], [7], [18] and arm crank is physiologically more stressful than leg cycle exercise at the same oxygen uptake [15]. Results of this study confirm data presented in previous studies [1], [17]. In our study, we noted significantly higher lactate concentration during exercise on the Torqway than while walking. The high arm vs. leg lactate release appears to be associated with differences in regional circulatory adaptation by the exercising limb [17]. Moreover, when exercising, the arm compared to leg muscles working at the same relative intensities utilize more carbohydrates, mainly muscle glycogen resulting in higher lactate release by the exercising extremity [1]. The observed differences in the response might also be related to differences in muscle fibre composition that are known to exist between the upper and lower body musculature: these differences between arm crank and leg cycle exercise are consistent with a greater and/or earlier recruitment of type II muscle fibres during arm crank exercises [19].

While moving on the Torqway, the working upper body muscles performed work necessary to shift a larger weight (body and vehicle weight), however, when walking, the work of the lower limbs served only to shift body mass. The effect of this may be the increased energy expenditure observed in our research during moving on the Torqway vehicle in comparison to walking.

Without a doubt, an important advantage of moving on the Torqway is the standing position during the exercise, and the vehicle can be used by adults as well as children. The power required to move the device is generated by the power of the upper limbs, which causes a slight up and down shift of the center of gravity to take place during moving on the vehicle, and no dynamic overload of the knee joints occurs, such as in the case of running. The vehicle can therefore be used by people having difficulty with movement in the form of walking or running (medical contraindications, people significantly overweight or obese), maintaining an upright position. The manner of powering the vehicle forces the performance of physical activity, and at the same time, allows one to cover long distances in the field. This makes the vehicle an attractive tool for the encouragement of a healthy lifestyle as well as the promotion of a training device for the development of the user's upper muscles and perhaps, improving coordination. The vehicle has wide application, it can be used in physical therapy, in pro-health exercise as well as a tool aiding sports training.

5. Conclusion

In conclusion, exercise on the Torqway vehicle allows for the intensification of the exercise at a low movement speed, comparable to walking. Moving on the Torqway vehicle could be an effective alternative activity for physical fitness and exercise rehabilitation programs.

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