The effect of different bike tires to the energy expenditure of the organism

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Abstract
Based on the research of accessible data resources we mention information about the influence of different bike tires to the energy expenditure of the body. The aim of the study is to determine the difference in energy expenditure (EE) of the body when using different types of bike tires. The analysis proved that there is a scarcity in systematic research of bike tires´ resistance. We found out that there is a significant difference in EE when using road type tires and fat bike tires, and trekking tires and Fat Bike tires as well. The results of the study will be used for other studies, and as a support in bike tires selection. The data can serve as a basis for development of bike tires or as an interesting sign for cyclists´ trainings.

Key words:
Mountain bike, rolling resistance, spiroergometry, calorimetry

Souhrn
Na základě rešerše dostupných informačních zdrojů uvádíme informace o vlivu rozdílných plášťů jízdního kola na energetický výdej organismu. Cílem studie je stanovení rozdílu v energetickém výdeji (EV) organismu při použití různých typů plášťů kola. Analýza prokázala nedostatky v oblasti systematického zkoumání odporu plášťů kola. Shledali jsme významný rozdíl v EV mezi jízdou se silničními plášti a jízdou s plášti pro Fat Bike, dále také mezi jízdou s trekingovými plášti a jízdou s plášti pro Fat Bike. Výsledky budou využity pro další studie a jako pomoc při výběru plášťů jízdního kola. Data mohou sloužit jako podklad pro další vývoj plášťů nebo jako zajímavé ukazatele pro trénink cyklistů.

Klíčová slova:
MTB, valivý odpor, spiroergometrie, nepřímá kalorimetrie

Introduction

Hulking bike tires with wide track and rough pattern, or tread pattern are the characteristics of mountain bike, also known as MTB, as we recognize it currently. The bike tires fulfil many functions. Beside the fact, that they carry the weight of the cyclist and his equipment, they are responsible for transmission of driving and braking force (as well as all the forces needed for leading the bike). Other important function is the damping of vibrations and bumps. As successfully selected tire can be considered the one, which has the minimal rolling resistance, ideal grip properties and excellent adhesion to the selected terrain. Last but not least, from this tire it is required minimal weight and ability to lead the bike (especially on the front wheel). Furthermore, long life cycle and traffic safety, which are given by the resistance to the abrasions and puncturing (Hrubíšek, 1994).

From the point of view of understanding the technical parameters and a proper choice in regard to the usage, the tires are one of the trickiest parts of the bike. In case that we choose the right tread pattern of the tires for selected terrain, we still have to choose between many types of tires, sizes and rubber mixtures (Mountain Bike Action, 2013).

The tires filled with compressed air can be doubtlessly indicated as a revolutionary invention in the history of cycling. The fact that the popularity of biking would reach the same scale, in case the tire was not invented, is highly unlikely. Indeed, tires are the part of bike which supplies us with comfort and allows us to make for almost any terrain. All this has

a positive effect on driving experience and it allows us to undergo more extreme experiences.
Monitoring of the EE of the body during biking and its affection in regard to surrounding environment is very discussed issue. The EE of the body during biking is affected by many variables. The most often monitored parameters are the resistance of the environment (aerodynamics, rolling resistance) and the weight of the bike, at the same time. In this study From the bike tire it is expected ideal behaviour and safety in selected terrain. This ideal behaviour can be also named as riding qualities, among which are e.g. rate of rolling resistance, good rolling capabilities and adhesion (Konopka, 2007).
The grip as well as rolling resistance are types of friction, i.e. they develop a frictional force, which counteracts the force shunting the element onward the ground. This implies that to achieve the movement it is necessary to overcome the frictional force, or in case of adhesive friction to change it into another. The adhesive friction between the wheel and the ground is a crucial precondition for transmission of circumferential force (i.e. propulsive or braking) and sideway conducting force. This allows rolling of the element, which generates rolling friction (Gscheidle, 2007).
In the context of cycling, these physical laws work in the following manner. When the tire is rolling it flattens in the place of contact with the ground. At the same time, the tread pattern and tread area are constantly being deformed and abraded by the surface of the ground to equilibrate uneven terrain. This external and internal friction along with inelastic deformation of the tread pattern form the ability of the tire to grip, which supports rolling of the tire, in which the rolling resistance arises. But that means the loss of energy, which is necessary to be overcome (Burke, 2003).
Paradoxicaly, from the tire we require excellent adhesion, but minimal rolling resistance, although with higher adhesion the rolling resistance increases.
Each frictional force is a product of normal force and the coefficient of friction (Gscheidle, 2007). Also the rate of rolling resistance is given by normal force and the coefficient of friction. Namely the size of rolling resistance depends on the surface of the terrain, construction of the tread area and its tread pattern, construction of the inner tube, the materials used, inflation of the tire, size of the gravity force, a diameter of the cross section of the tire, wheel diameter, speed, temperature of the tire, torque and the angle of the steering axis (i.e. angle of the 'head tube' axis). The most important of these factors is the character of the terrain, material and the construction of the tire, pressure of the tire and its load (Burke, 2003). The higher the rolling resistance, the greater power the cyclist has to develop to overcome the resistance (Imexpo, 2015). This increased effort is reflected by increased work metabolism, or increased EE (Bartůňková, 2013).
Rolling resistance and the grip are therefore very important issues, which are closely related with our research, the aim of which is discovery of the size of the EE while using different types of tires. Furthermore we focus on the factors, which influence mainly the rolling resistance and the grip of the tire. We focus mainly on rolling resistance while using different types of bike tires.

The factors affecting riding qualities of tire

Weight
The lowest rolling resistance tires are characterized by its thinner walls. This reduction of rolling resistance is given by lower amount of used material, therefore lower weight of the tire.
Beside the amount of used material there is also important the type of the material used. For the production of tire rim, it is the most effective to use thin silk, nylon or Kevlar fibres, not only because of lower weight, but also thanks to lower losses of the energy due to internal friction of the material (Burke, 2003).

Thickness of the material
There is another reason why, apart from lower weight, use of lower amount of the material influences riding qualities. It also means that less material is to be deformed less and therefore loose energy (Imexpo, 2015).

Width
Although it seems paradoxical, it is true that the tires with smaller diameter are, when correspondingly inflated, designated with higher rolling resistance. This is explained by greater deformation of the tire, i.e. its greater flattening, thus its greater grid and rolling resistance (Haymann, 2009).

Flexibility
With higher flexibility of the material (especially rubber mixture) the amount of energy lost when balancing the deformation decrease, thus there is lower rolling resistance (Imexpo, 2015).

Tread pattern and tread area

The tread pattern of the tread area influences the rolling resistance too. Regarding the abrasiveness, the tires with fine pattern have lower rolling resistance than the rougher ones. The lowest rolling resistance has so-called slicks. The primary task of the tread pattern is to improve grip of the tire and not to reduce rolling resistance (Burke, 2003). When riding on a smooth road the type of the tread pattern is not so important, because in this kind of terrain we are able to provide the grip just by galling of the rubber mixture by the roadway. In contrast, in rugged terrain, the role of the tread pattern in terms of traction is essential. Rough tread pattern is unlikely the fine one able to tie in the road and thereby mediate the transmission of propulsive, driving and braking force (Imexpo, 2015). So it is true that, the higher and sparse the blocks of tread pattern are distributed, the better is its ability to grip in dissected or wet terrain. Reversely, thick and fine pattern is suitable to be used on dry road and solid terrain (Makeš, 2002). There is also a compromise construction of road and cross country tread pattern at the same time, i.e. semislick. The tire with this tread pattern is, when underinflated, able to fairly roll in the terrain and reversely, when more inflated, it is able to roll in rigidified terrain (Hrubíšek, 1992). It is not possible to choose the only best type of tread pattern, because each type of the terrain requires its specific pattern; it is also not possible to create all-purpose tire, which could reach the same results as the tires for road use solely (Makeš, 2002).

Rubber mixture

As it was mentioned before, the type of the rubber mixture is one of the factors, which affects weight and flexibility of the tire.

By replacing or change of the ratio of different components of the rubber mixture it is possible to create two tires, which seem to look the same at the first sight, but they have completely different riding qualities. Except that, one of the tires can compose of several different types of rubber mixtures. Maximum amount of used mixtures used for one tire varies according to the producer. For example, the company Maxxis offers single, dual or triple compound technology, i.e. they use one to three types of rubber mixtures for production of one tire (Maxxis, 2016).

Temperature

Along with higher temperature of the rubber, the viscosity decreases, thereby the internal friction of the material decreases too. Increasing temperature leads to air expansion, thus the pressure in tires increases. This means that heated tires better roll than the cold ones (Burke, 2003).

Pressure

The pressure in the tire, along with the diameter of the tire, partake in determination of the size of the tire interface with the ground, whereas higher interface causes greater grip and rolling resistance (Burke, 2003). Concerning the pressure, in case of riding in smooth terrain we choose the pressure which is reaching the maximum. Thanks to that the tire is fewer deformed even burdened identically. In rough terrain, however the opposite is true, i.e. it is better to use inflation with lower pressure. The tire then better adapt to the disparities, it will not bounce that much and thus will not be so much braked by them. Thereby the rolling resistance will decrease. Not always high pressure means low rolling resistance (Imexpo, 2015). It is necessary to avoid congestion as well as underinflation. The first case will lead to loss of grip, thus loss of safety, and it will be uncomfortable in addition. In the second case, the rolling resistance as well as the risk of perforation of the tire will increase (Hrubíšek, 1992). To eliminate affection of the EE, there are all tires in this study inflated to the exact inflation range recommended by the producer.

Tire diameter

Although the greater diameter of the tire is characterized by greater interface with the ground, its rolling resistance is lower. This is caused by the angle, under which the wheel approaches the roughness on the road, in combination with greater grip surface. Wheels with greater diameter which approach disparity roll on under smaller angle, than those wheels with lower diameter. Thus they are less hampered. The disadvantage remains in higher weight and e.g. 29 inch wheels cannot be used in all types of frame geometry due to its size (Imexpo, 2015).

Methodology

The research set was formed from a group of five men aged 26.4 ± 2.2 years, with body height of 186 ± 7.6 cm and body weight of 87 ± 12.6 kg. All tested are active cyclists, especially they focus on following disciplines: Freestyle BMX, Dirt Jumping and Downhill. In selection these probands there was

an emphasis on comparable riding experiences and abilities.
Laboratory testing was performed under following conditions: temperature of ambient environment 24.6 ± 0.8°C, humidity 33.3 ± 1.9 %.
Each of tested undertook three rides on cyclists´ training circuit, during which for each ride there were different types of tires used. Measuring of energy expenditure was done by the method of spiroergometry via analyser of exhaled gases MetaMax 3B (Cortex), and sporttester.
Individual heat up and warm-up of the probands was prior the testing itself. Then there was trial ride with assistance and a trial ride without assistance. It was discovered that it is not possible to objectively measure energy expenditure without assistance because of the loss of balance, therefore it was necessary to perform all test rides with assistance.
After this, all group members completed the first ride using one of three types of tested tires.
Each tested men wore sporttester and a vest with analyser of exhaled gases. Then, there was time delay which was caused by necessary reconfiguration of the analyser. Before each man rides, the height of the bike seat was individually adjusted to fit his body height. After all adjustments, each of tested men got a rubber embouchure into his mouth and the testing ride started. The length of the testing ride was not established. For relevant results it was necessary to measure minimum 4 minutes rides, during which the values of VO2 did not excessively fluctuate (standard deviation could reach a maximum of 0.45 l/min). Each probands, with regard to their diverse bodies and thus also performance parameters, reached this stabile level of oxygen consumption in individual time. Average time of one ride was 4:55 ± 1:50 min. Reversely, the pace, i.e. cadence of treading, bas exactly assigned to 80 turns per minute. The riders followed the metronome, which was visible during entire ride.
Other two rides were conducted in the same way. Before the second and third circles it was necessary to change the tires to other tested type of tire.

Testing bicycle

For testing, it was chosen a brand 'Specialized' bicycle, specifically the model Fuse Comp 6Fattie. In regard to the fact that it is a Fat Bike, the frame of this bike does not have a component of rear shock suspension, i.e. it is a hardtail. The Fat Bike was chosen due to the fact, that one of tested tires was the one made especially for this bike type and it could not be used in other bike types because of its oversize.
It was necessary to use two types of rim, because rims for Fat Bike tires are too wide for road bike tires, which were also one of the tested tires. The rims slightly differed in weight, but this difference does not have essential impact on energy expenditure, thus was not considered.
Based on the highest stability during the trial ride, for the testing it was used the gearing of 1/7, i.e. the lowest gear, the seventh sprocket from above with the sprockets ratio of 30:18. This gear was also the most suitable in regard to cadence of treading.

Tested tires

There were 3 types of tires tested. Road type, trekking and fat bike tires. All used tires were the 'Specialized' brand. The category of road tires was represented by the model of Espoir Sport 700x25C, in the category of trekking tires it was Fast Trak Sport 29x2.0 and the tire for Fat Bike was Ground Control 2Bliss Ready 650Bx3.0 FATTIE. The technical parameters of those tires are mentioned in the following tables.
The tires were inflated to the middle level of pressure range recommended by the producer. In case of Fat Bike it was the value of 1 bar, for the trekking tire it was 3.5 bar and the road tire was inflated for 8.1 bar.

Measuring instrument

The desired values, i.e. oxygen ventilation (VO2), ventilation of carbon dioxide (VCO2), respiratory volume (VT), breathing frequency (BF) and minute

Table 1 – Specification of bicycle Specialized Fuse Comp 6Fattie

Frame	**Specialized M4 Premium Aluminium, Trail 6Fattie geometry**
Frame size	19“
Front suspension	SR Suntour Raidon 650+, air spring
Approximate weight	9.8 kg (without wheels)
Wheels	WTB Scraper i45, 29“

Table 2 – Technical parameters - Ground Control 2Bliss Ready 650Bx3.0 FATTIE

Type of construction	**Without inner tube**
Fabric density	120 TPI
Derailleur hanger	Kevlar, butyl stiffener
Mixture	60a (medium hard compound)
Approximate weight	1045 g
Recommended pressure	min. 0.621 bar, max. 1.379 bar
Width	7.6 cm
Tread	Rough, sparsely distributed massive blocks

Table 3 - Technical parameters - Fast Trak Sport 29x2.0

Type of construction	**Classic**
Fabric density	60 TPI
Derailleur hanger	Wire
Mixture	70a (hard mixture)
Approximate weight	715 g
Recommended pressure	min. 2.413 bar, max. 4.482 bar
Width	5.1 cm
Tread	Semislick

Table 4 - Technical parameters - Espoir Sport 700x25C

Type of construction	**Classic (with anti-defect protection BlackBelt X 2)**
Fabric density	60 TPI
Derailleur hanger	Wire
Mixture	70a (hard mixture)
Approximate weight	370g
Recommended pressure	min. 7.584 bar, max. 8.618 bar
Width	2.5cm
Tread	Slick

ventilation (V), were recorded during entire testing by metabolic analyser of exhaled gases MetMax 3B. The heart frequency (SF) was measured by the sporttester.
The MetaMax 3B device works on the principle of continuous analysis of breathing gases by the breath-by-breath system (Cortex-Medical, 2016).

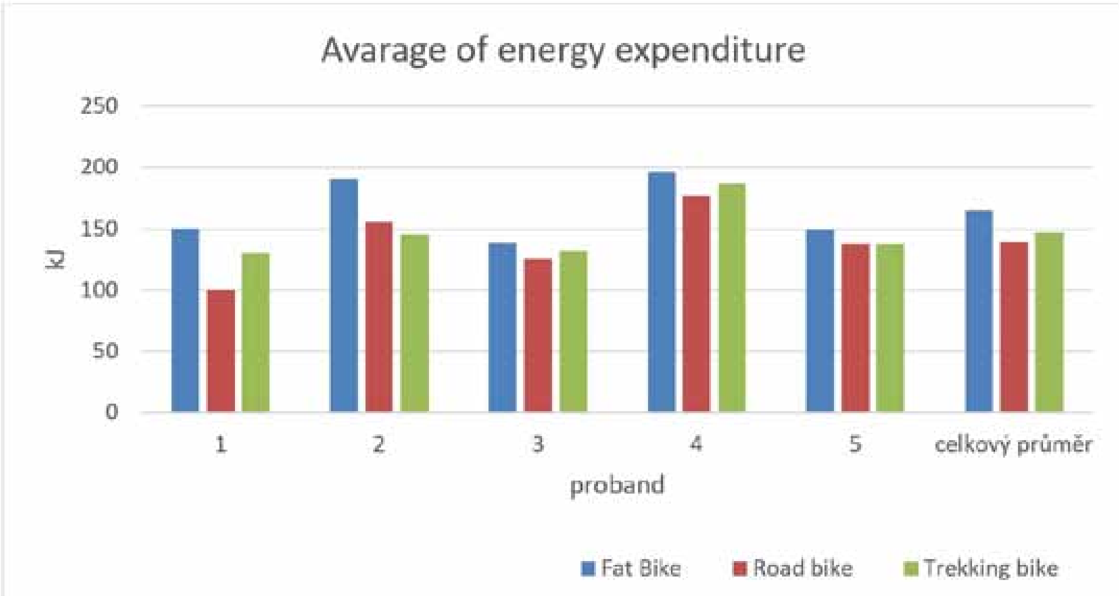
Results evaluation

Measured values of monitored variables were evaluated by basic methods descriptive statistics, i.e. by arithmetic average and relevant deviations. Average values and relevant deviations VO2, and energy expenditure are listed in the tables.
Values of energy expenditure were found by the method of indirect calorimetry. The accuracy of the results could have been affected by two factors. It is a biological and technical factors. Biological error could be caused by the hyperventilation, oxygen debt or by other influences. The technical error of analyser of respiratory gases MetaMax 3B was standard, i.e. maximum 5 %. Due to the factors influencing the accuracy of the measurement, as a significant we consider the difference in energy expenditure which exceeds 10 %.

Table 5 – Average energy expenditure

Proband	Energy Expenditure (kJ)		
	Fat Bike	Road type	Trekking
1	150.6	99.6	130.7
2	191.0	155.7	145.8
3	138.1	125.2	132.0
4	196.0	176.9	187.0
5	149.7	137.6	137.8
Relevant deviation	26.5	29.4	23.3
Total average	165.1	139.0	146.6

Graph 1 – Average energy expenditure



RESULTS

In the following table, there are recorded values of oxygen ventilation and energy expenditure from all three rides of each proband in the interval of 20 seconds. In next tables, the values of average oxygen consumption in millilitres per kilogram of body weight, and an average of energy expenditure within each ride as well as total energy expenditure, are shown.

Discussion

For testing there was used mountain bike type Fat bike, which does not have a rear suspension. In study there was used a bike ‚Specialized' Fuse Comp 6Fattie (frame size 19"). The Fat Bike was chosen because one of the tested bike tires was the Fat Bike tire, which is not suitable for standard size frames due to its size. All tested tires were the same size of 29" to eliminate the influence of its different diameter on the EE. The study of Steyn, J. et al. (2014) aimed to determine the degree of influence of particular variables to rolling resistance; and there was not proved that there is significant influence of the tire diameter or level of suspension on the rolling resistance. Therefore we can assume that the results of our measurements would remain the same even when using wheels with 29" diameter or suspension type 'full suspension'. The tires were inflated to the median value of the optimal range specified by the manufacturer and also for the reason of assumption, that overinflation or underinflation could influence rolling resistance of the tire and consequently also

EE. This presumption was disproved by Ryschon, T. W. et al. (1993) study. The level of tire inflation was one of the observed parameters in the studies of Steyn J. et al. (2014) and Bertucci et al. (2013), who found made the same conclusion as Ryschon T. W. et al. (1993).

In our study, the tires had different weight, but due to insignificant difference in EE influence during rotational movement is was not considered.

We assumed the EE rise along with the size of the tire contact area, where we assumed significant differences in EE when comparing road, trekking and Fat Bike tires. The largest contact surface has a tire for Fat Bike in width 7.62 cm, the smallest is the road tire with width 2.5 cm and width of trekking tire is 5.08 cm. This assumption was formulated on the basis of studies cited in theoretical part as well as on Bertucci et al. (2013) study. In Bertucci et al. (2013) study, there was the rolling resistance evaluated and it was discovered that when using narrower tires with smooth tread pattern (Vittoria 'Randonneur', road tire with 4 cm width), the results are lower than when using the wider one with rough pattern (Hutchinson 'Python', classic XC tire with 5 cm width).

Our study proved that there is significant difference in EE when using road tires and tires for Fat Bike; the difference is 18.76 % (26.07 kJ). There was also proved significant difference in use of trekking tires and the Fat Bike tires, the values differed by 12.56 % (18.43 kJ). Conversely, the difference in EE when using road and trekking tires reached 5.5 % (7.65 kJ), so in regard to the value of standard deviation we cannot consider this difference as significant. The results show that the EE increased with increasing interface, because the width of road tire is 2.5 cm and the Fat Bike tire is 7.62 cm.

By the extrapolation of measured values we obtained the estimate of the development of the EE curve in longer time period. This estimate shows linear increase of the values of the EE in time for all rides, thus increase of the differences in EE. The difference in EE within one hour of ride with Fat Bike tires and road tires would, according to our estimate, reach the value of 452.8 kJ. The difference when using road and trekking tires would be 183.5 kJ, when comparing ride with Fat Bike and trekking tires, the difference would be 269.4 kJ.

If we take into consideration the results of the study from Steyn, J. et al. (2014), we can expect that the values of EE which were measured by us on the smooth training circuit would significantly differ in rougher terrain. Steyn, J. et al. (2014) mentions that the character of the terrain surface is the factor which influence the rolling resistance the most. This argument was supported by measuring the rolling resistance when so called cost-down is performed. It means when the bike reaches a particular speed, the cyclist stop treading and stop by inertia, his speed is constantly monitored and the length of the stopway is measured.

Conclusion

Significant difference in energy severity of riding with Fat Bike tire and road tire was proved by this study with regard to standard deviation of the measurement. Furthermore we found significant difference in EE when riding with trekking tires and Fat Bike tires. The difference in riding with road and trekking tires was, with regard to standard deviation of the analyser of breathing gases MetaMax 3B, not significant.

As a critical margin for conclusiveness of the differences in EE, with regard to standard deviation, was set increase over 10 %. This level was during the measurement reached, but not in all cases. It is true, that ride with tires of the smallest interface showed the lowest energy consumption. Conversely the tires with the biggest interface demanded the highest amount of EE: The difference in EE between those two rides was significant.

The average energy consumption, when riding on road tires the training circuit with 4 minutes length, was 139.01 ± 29.40 kJ. In case of trekking tires it was 146.66 ± 23.32 kJ and in case of Fat Bike it was 165.09 ± 26.46 kJ.

The difference between ride on Fat Bike tires and road tires reached the level of 26.07 kJ, what is an equivalent of increase by 18.76 %. The difference between trekking and Fat Bike tire was also significant, it was 18.43 kJ, i.e. increase by 12.56 %. Conversely, the difference when riding on road tires and trekking tires was only by 5.5 %, representing 7.65 kJ, thus it was not significant.

By extrapolation of the results we obtained the trend of EE in time, which shows linear character. Part of this estimation is linear increase of the difference in EE between particular rides. The difference in one hour ride between Fat Bike tires and road tires is estimated at 452.8 kJ, when riding road tires and trekking tires the estimation is 183.5 kJ and the difference between the ride with Fat Bike tires and the trekking ones is estimated to 269.4 kJ. Two hours ride would increase the difference even to 910.8 kJ, 371.7 kJ and 539.0 kJ respectively.

This study is considered as a pilot one.

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