ANALYSES OF PHYSICAL WORKING CAPACITY AND METABOLIC PROCESSES FOR PROFESSIONAL SPORTSMEN AND PARTICIPANTS OF PUBLIC SPORTS

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Abstract

Complex cardiopulmonary exercise testing of sportsmen is an integral part of professional sport now. It allows the simultaneously study of the responses of the cardiovascular and pulmonary systems to a known physical load stress.

The aim of research is assess the difference and correlation of basic parameters of the physical work capacity during the increase physical load between professional sportsmen and participants of public sports and work out proposals of Calorimetry putting into sports practice.

There is direct correlation between the physical work capacity and the functional ability of the body. The increase of heart rate and oxygen uptake has direct correlation with increased physical load. The performance of muscular work requires the physiological responses of the cardiovascular and pulmonary systems to be coupled to increase metabolic rate. Person's health condition, fitness level and training regime have an influence on substrates utilization way and proportions. Professional sportsmen as a source of energy more effectively use fat reserves of the body and provide glycogen saving. Participants of public sport as a source of energy less effectively use fat reserves of the body and intensively start to use carbohydrates which demand less oxygen uptake.

Calorimetry is a practical and useful method for the planning of sportsmen diet into sports practice. It allows estimating: rest energy expenditure and amount energy expenditure for lifestyle; the chosen diet adequacy, the proportions of substrates which avoid conditions of the energy deficit during the physical load and the optimal physical load for decreasing fat reserve in the body.

Keywords: *Cardiopulmonary test, heart rate, oxygen uptake, Calorimetry, metabolism, energy expenditure*

Introduction

Complex cardiopulmonary exercise testing is now the 'gold standard' for evaluation of the function of cardiovascular and breathing systems, the physical work capacity of the body (Figure 1.). It is well suited for evaluating athletes (health condition, physical work capacity) and assessing methods of improvement. This type of testing is utilized by professionals and Olympic athletic teams in different kinds of sport.

Sports achievements depend on 3 major body systems which the limit possibility to do or continue physical load. These systems have to work together simultaneously and effectively:

1. the cardiovascular system – provides blood supply and oxygen transport
2. the breathing system – provides oxygen uptaking and carbon dioxide elimination out of the body
3. the body muscles which are involved in physical work with muscle weakness, pain, energy reserve and the activity of ferments systems

The physical work capacity and the functional abilities of the body are dependant on the functional possibilities of the cardiovascular and breathing systems, kind, intensity of the physical load, experience, the quantity and variety of energy reserves, psychological conditions, genetic factors, age and body composition.

Figure 1. Complex cardiopulmonary exercise testing and Calorimetry testing - load phase

The energy to support live processes and its changing levels of physical activities are obtained from the oxidation of metabolic substrate. The aerobic oxidation of carbohydrate and fatty acids provides the major source of adenosine triphosphate (ATP) regeneration. Each kind of substrates give fixed amount of energy. The most important thing is to provide the balance between the food intake and the energy expenditure which consists of Basal metabolism, Metabolism induced by lifestyle and Metabolism induced by physical activities. The daily energy expenditure depends on the intensity of physical activities, involving amount of muscles, emotional stress, psychological conditions, age and body composition.

Calorimetry is equally efficient and accurate metabolism analysis method which measures the energy expenditure and proportion of substrates (carbohydrate, fat) during the rest and increase physical load. Different metabolic pathways have different signatures on gas exchange. It is possible for a cardiopulmonary system study to identify aerobic metabolism, anaerobic metabolism and indeed the intracellular response to load. Gas exchange kinetics differs in response to physical load depending on whether work is performed above or below anaerobic threshold.

The aim of the research is assess the difference and correlation of basic parameters of the physical work capacity during the increase physical load between professional sportsmen and participants of public sports and work out proposals of Calorimetry putting into sports practice. The assignments of the research are define and analyze the index of Physical work capacity (W/kg), the changes of heart rate, oxygen uptake, energy expenditure and proportions of substrates utilization during the rest, increased physical load and recovery.

Materials and methods:

Names of the groups	**Professional sportsmen**	**Participants of public sports**
Number of participants	19	19
Description of the group	Professional cyclists do the cycling as a basic occupation to increase sportsmanship. During the training process the main factor is to take part in competitions for winning	They do the cycling for health and fitness, irregularly take part in public sports competitions for self improvement, but not for winning

Age	21 +/- 1 year	26 +/- 1 year
Weight	76,2 +/- 1,7 kg	78,8 +/- 1,6 kg
Height	185,4 +/- 1,5 cm	181,8 +/- 1,7 cm
Body mass index	22,1 +/- 0,2	24,8 +/- 0,5
Training regime	Regularly, 6 days per week, 2-3 hours 1-2 times per day	Regularly, 2-3 days per week 1-1,5 hours 1 time per day

- Analysis of special literature
- Anthropometric methods: weight, height, BMI (Body Mass Index)
- Complex load test on Cardiopulmonary system Master screen CPX, ISO certified in "Sports laboratory" - a physical health, sports medicine and rehabilitation centre
- Indirect calorimetry
- Statistical analysis methods

Results

1. Physical work capacity

The sports achievement and endurance directly depend on Physical work capacity and the level of body adaptation processes to physical load. Regular physical load increases the functional ability of the body and physical work capacity (Brēmanis, 1991). There is direct correlation between physical work capacity and the functional ability of the body. During the different testing phases the index of Physical work capacity (W/kg) has great difference between the groups (Table 1.).

Table 1.

The index of Physical work capacity during the different testing phases

Groups	Rest	Aerobic threshold		Anaerobic threshold		Maximal load
		W/kg	%	W/kg	%	
Professional sportsmen	0	3.1±0.1	61	4.4±0.1	86	5.1 ± 0.1
Participants of public sport	0	1.5±0.1	43	2.5±0.1	71	3.5 ± 0.1
The difference of average values is statistically confident (P=0,95; α=0,05)						

Physical work capacity is relevantly higher about 69% for professional sportsmen than participants of public sport. During the aerobic threshold professional sportsmen reach 61%, but during the anaerobic threshold - 86% from relative maximal load; comparing with participants of public sports who have reached only 43% during the aerobic threshold, but during the anaerobic threshold - 71% from relative maximal load. It means professional endurance sportsmen have better aerobic abilities but it will be analyzed later.

2. Heart rate changes during the rest, increased physical load and recovery

The regular endurance load causes one of the adaptation changes of cardiovascular system with decreasing of heart rate during the rest and load (Wasserman, 2005).

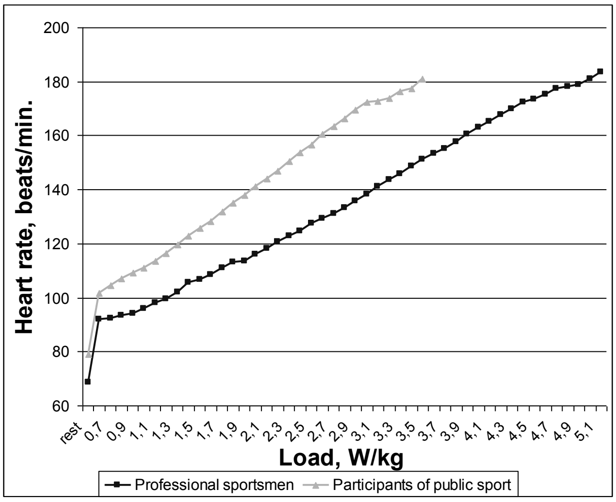

Figure 2. Heart rate changes during the increase physical load

It depends on increased tonus of parasympatic nerve system; decreased request of arterial blood flow of engaged muscles; higher oxygen supply for muscles and improve the biochemical processes in the muscles (Wasserman, 2005., Aberberga-Augškalne, 2002., Brēmanis, 1991).

Professional cyclists have lower heart rate during the rest than participants of public sport (Table 2.). Heart rate increases linearly to quantity of physical load (Figure 2.). During the physical load reduced increase of heart rate for professional cyclists compensate with the increase of cardiac output. It induces longer and stronger heart contraction (Aberberga - Augškalne, 2002).

There is statistical difference between the heart rate of aerobic and anaerobic thresholds. Aerobic and anaerobic thresholds increase in regular endurance trainings. Both groups have reached the same maximal heart rate 186±2; 185±2 bpm, but at the different maximal load (Table 2.). In the literature there is mentioned heart rate response of world elite cyclists with maximal values 188 bpm and anaerobic threshold 169 bpm, elite cyclists of Latvia have anaerobic threshold 173±2 bpm.

Table 2.

Heart rate during the different testing phases

Groups	**Rest**		**Aerobic threshold**		**Anaerobic threshold**		**Maximal load**	**Recovery 6. min**
	bpm	%	bpm	%	bpm	%	bpm	bpm
Professional sportsmen	69±2	37	139±2	75	173±2	93	186±2	110±2
Participants of public sport	79±3	43	127±2	69	159±3	86	185±2	114±2
The difference of average values is statistically (P=0,95; α=0,05)	confident		confident		confident		not confident	not confident

The duration of testing load and the appearance of complains depend on health condition, functional ability and fitness level of the person's body (Wassermans, 2005., Schabort, Hawley, Hopkins, 1997). For healthy people the reasons of interruption of Complex load testing are reached maximal heart rate, local fatigue of engaged muscles because of lactic acidosis, general fatigue of the body and shortness of breath.

The difference is not great in changes of heart rate during the recovery after the physical load between the groups (Table 2). It could explain with the difference in reaching maximal load and intensity of training regime between groups.

3. The changes of oxygen uptake during the rest and increased physical load

Determining aerobic and anaerobic ability is equally important for estimation functional abilities of the body. During the all testing phases for professional sportsmen oxygen uptake is higher than participants of public sport (Table 3.).

During the physical load the oxygen uptake increases gradually and linearly (Chart 2.). The increase of oxygen uptake has direct correlation with increased physical load. The body clearly has an upper limit for oxygen uptake at present health condition, fitness level of the body and person's training regime. During the physical load the slow increase of oxygen uptake contribute: reduced muscular efficiency during the heavy physical load by recruiting more low-efficiency fast-twitch muscle fibers; increase in oxygen uptake to satisfy the increased work of the respiration muscles, the heart at high ventilatory and cardiac output responses; call in to play additional muscles; progressive stock up of metabolism end products (Wasserman, 2005).

Table 3.

Oxygen uptake during the different testing phases (ml/kg/min)

Groups	**Rest**		**Aerobic threshold**		**Anaerobic threshold**		**Maximal load**
	ml/kg/min	%	ml/kg/min	%	ml/kg/min	%	ml/kg/min
Professional sportsmen	4.5±0.1	8	37.7±1.3	65	51.9±1.3	92	56.7±1.0
Participants of public sport	3.8±0.1	10	21.3±1.1	55	30.2±1.6	77	39.0±0.9
The difference of average values is statistically confident (P=0,95; α=0,05)							

Oxygen uptake during the aerobic ATP resynthesis is adequate to supply oxygen needed of engaged muscles (Wasserman, 2005). There is statistical difference between oxygen uptake of aerobic and anaerobic threshold in each group. During the aerobic threshold professional cyclists reach 37.7±1.3 ml/kg/min but participants of public sport 21.3±1.1 ml/kg/min. If oxygen uptake is not adequate there started processes of anaerobic ATP resynthesis and gradually developed metabolic lactic acidosis. During the anaerobic threshold professional cyclists reach 51.9±1.3 ml/kg/min but participants of public sport reach - 30.2±1.6 ml/kg/min (Figure 3.).

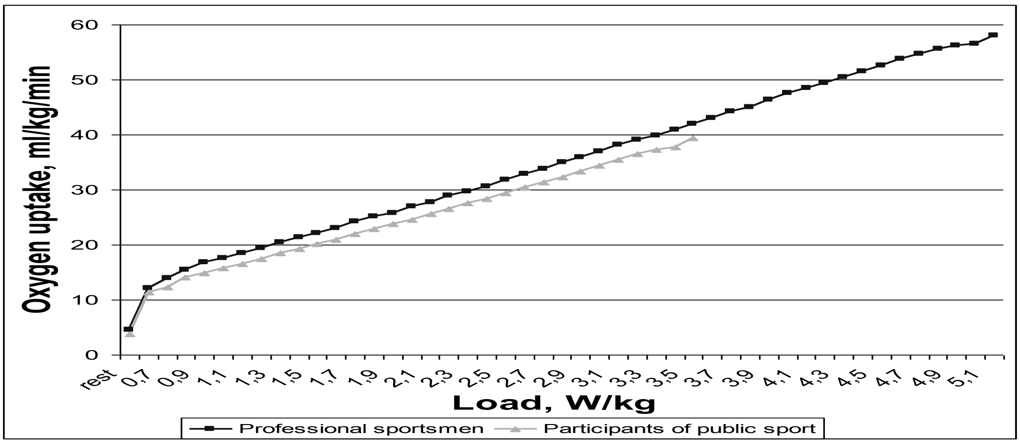

Figure 3. The changes of oxygen uptake during the rest, increase physical load

The aerobic threshold and the anaerobic threshold increase in regular endurance trainings. Professional sportsmen with high aerobic work capacity often do not reached anaerobic zone of ATP resynthesis because kinetic processes of oxygen are more intensive and the fatigue takes place in local engaged muscles (Wasserman, 2005).

Maximal oxygen uptake is relevantly higher about 69% for professional sportsmen than participants of public sport. Maximal oxygen uptake is limited by maximal cardiac output, oxygen saturation of arterial blood, cardiac output factional distribution of engaged muscles and oxygen utilization of muscle cells. During the maximal load Latvian elite cyclists reach 56.7±1.0 ml/kg/min but participants of public sport - 39.0±0.9 ml/kg/min (Chart 4.). During the anaerobic threshold for world elite cyclists oxygen uptake has been reported in the literature to be in the range of approximately 4.9-5.09 l/min, 56-76 ml/kg/min or 80% of maximal oxygen uptake values (Wassermans, 2005., Schabort, Hawley, Hopkins, 1997, Smith, Dangelmaier, Hill, 1999). In research elite cyclists of Latvia reach 91.5% of maximal oxygen uptake but participants of public sport reach 77.4% of maximal oxygen uptake during the anaerobic threshold.

4. The energy expenditure during the rest and increased aerobic physical load

The performance of muscular work requires the physiological responses of the cardiovascular and breathing systems to be coupled to increase metabolic rate. Energy system is limited and supported by substrate and oxygen availability. Physical load requires immediate breakdown of intracellular ATP as a source of high energy phosphate. The source of ATP is aerobic oxidation of mainly glycogen and fatty acids. Aerobic metabolism supplies the majority of ATP up to the anaerobic threshold. If aerobic metabolism is unable to support the requirement of ATP, anaerobic metabolism of glucose via pyruvate and lactic acid will provide some ATP but in much smaller amounts. Anaerobic metabolism merely supplements aerobic production of ATP as the work rate increases.

Table 4.

Total energy expenditure during the different testing phases (kcal/24h)

Groups	Rest	Aerobic threshold	Anaerobic threshold
Professional sportsmen	2386 ± 75	20585 ± 556	28431 ± 722
Participants of public sport	2063 ± 80	11635 ± 644	16581 ± 906
Difference between groups	14 %	44 %	42 %
The difference of average values is statistically confident (P=0,95; α=0,05)			

Person's total body metabolism depends on health condition, physical load intensity, duration and metabolism intensity (amount of oxygen uptake and produced carbon dioxide). Person's fitness level, health condition and training regime have an influence on substrates utilization way and proportions. During the rest total energy expenditure is higher for professional sportsmen 2386±75 kcal/24h compare with participants of public sport 2063±80 kcal/24h.

During the physical load total energy expenditure increases gradually and linearly (Figure 4). The increase of total energy expenditure has direct correlation with increased physical load. During the increased physical aerobic load for professional sportsmen total energy expenditure increases for 12 times, but for participants of public sport total energy expenditure increase only for 8 times.

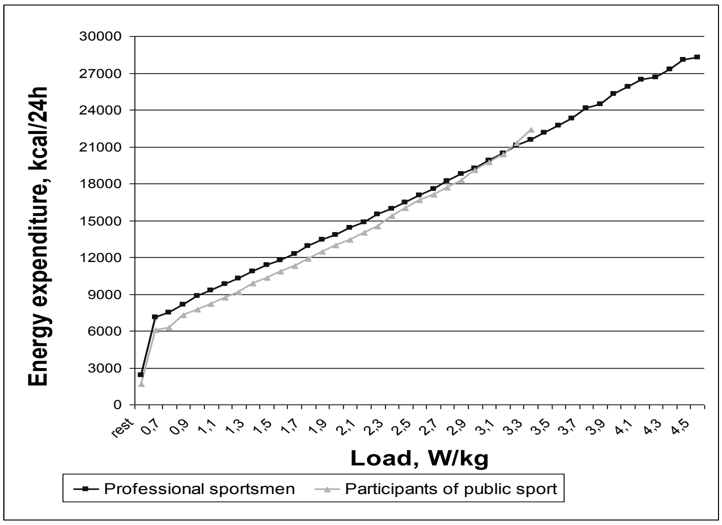

Figure 4. Energy expenditure during the rest and increased physical load

Calorimetry is a practical and useful method for the planning of sportsmen diet into sports practice. It allows estimating energy expenditure, person's energy needs and the proportions of substrates during the physical load.

5. Carbohydrate utilization during the increased aerobic physical load

Physical fitness affects the proportions of substrate utilization. Human skeletal muscle contains, on average to 80–100 mmol (15–18 g) glucose per kilogram of wet white stored as glycogen (Wasserman, 2005). These are total skeletal muscle carbohydrate pool. During the aerobic load carbohydrate utilization is higher for professional sportsmen than participants of public sport (Table 5.).

Table 5.

Carbohydrate utilization during the different testing phases (g/h)

Groups	**Rest**	**Aerobic threshold**	**Anaerobic threshold**
Professional sportsmen	12.6±1.3	116.4±5.1	263.5±7.8
Participants of public sport	9.1±1.3	65.2±3.7	157.9±7.6
Difference between groups	28 %	44 %	40 %
The difference of average values is statistically confident (P=0,95; α=0,05)			

Increased utilization of carbohydrates associated with a reduction in muscle glycogen stores. When muscle glycogen becomes depleted, the exercising subject senses exhaustion. Muscle glycogen stores are important in work tolerance and there is high positive correlation between the tolerable duration of high-intensity work and the muscle glycogen content before load. The way and proportion of carbohydrates and fats utilization depends on physical fitness level, the intensity of physical load and the intensity of metabolism during the load. Respiratory exchange rate shows proportions of carbohydrate and fat utilization in the metabolic process.

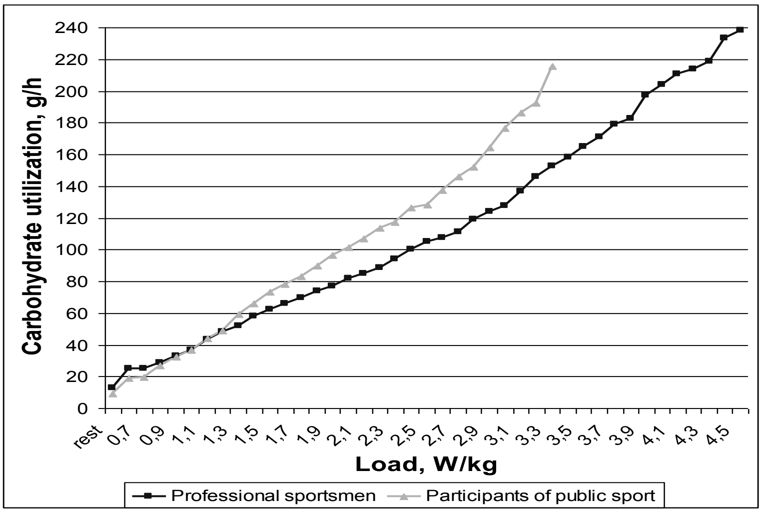

Figure 5. Carbohydrates utilization

The increase of carbohydrate utilization has direct correlation with increased physical load (Figure 5). During the increased physical load till anaerobic threshold for professional carbohydrate utilization increases for 21 times or 95%, but for participants of public sport carbohydrate utilization increases for 17 times or 94%. For saving energy reserves fat is more effective source of energy but its aerobic oxidation increase amount of oxygen uptake of the body, but for economy of the oxygen use more effective source of energy are carbohydrates.

6. Fat reserve utilization during the increased aerobic physical load

Skeletal muscle has access to their own intramuscular store of fat, averaging 20g of triglycerides per kilogram wet white (Wasserman, 2005). This score accounts for a considerable proportion of the total energy required by the muscles depending on the duration and intensity of physical load and the rate of depletion of muscle glycogen. Extra muscular lipid sources are also utilized during the physical load. It comes from adipose tissues where triglycerides undergo hydrolysis. The factor what reduces the rate of adipose tissue lipolysis during the physical load blood lactate is increased (Wasserman, 2005).

Professional sportsmen as a source of energy more effectively use fat stores of the body (it depends on higher oxygen uptake) and provide glycogen saving. The maximal use of fat stores 34.2±2.9 g/h they reach at load intensity 3,0+/-0,1 W/kg.

Table 6.

At stores utilization (g/h)

Groups	**Rest**	**Maximal use of fat stores** (relative load W/kg)
Professional sportsmen	3.3 ± 0.5	34.2 ± 2.9 (3,0+/-0,1W/kg)
Participants of public sport	3.2 ± 0.5	22.6 ± 2.0 (1,1+/-0,1W/kg)
Difference between the groups	3 %	34 % (63%)
The difference of average values statistically (P=0,95; α=0,05)	Not confident	Confident

Participants of public sport as a source of energy less effectively use fat reserves of the body and intensively start to use carbohydrates which demand less oxygen uptake. The maximal use of fat stores 22.6±2.0 g/h they reach at load 1,1+/-0,1 W/kg. The difference is 76% (Table 6.).

Professional sportsmen use greater proportion of fatty acids for energy than participants of public sport (Figure 6).

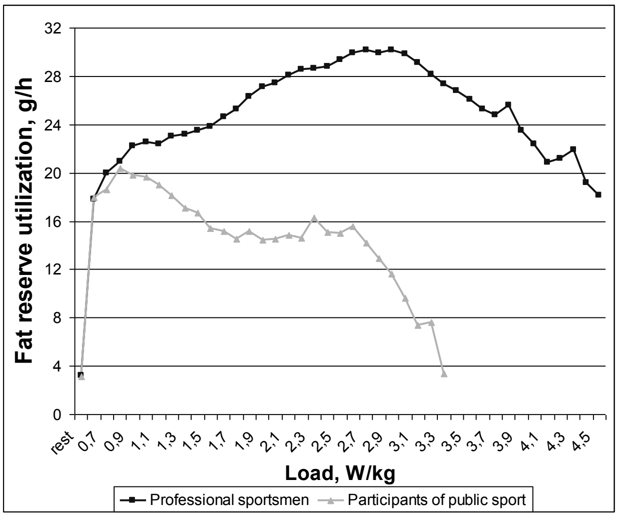

Figure 6. Fat stores utilization during the rest, increase physical load

This mechanism conserves glycogen allowing more work to be performed before glycogen depletion and consequent exhaustion.

Discussion

The performance of muscular work is coupled to increase metabolic rate. Person's health condition, fitness level and training regime have an influence on substrates utilization way and proportions. Muscle glycogen stores are important in work tolerance and there is high positive correlation between the tolerable duration of high-intensity work and the muscle glycogen content before load. These processes studies allow avoid conditions of the hard energy deficit during the physical load. Till now Calorimetry is rarely use method in sports practice. This research allows estimate the Calorimetry as a practical and useful method for the planning of sportsmen diet. In sports practice it would be useful to compare Calorimetry results for different kind of sport sportsmen.

Conclusions

1. Physiological testing of sportsmen is an integral part of professional sport now. There is direct correlation between the physical work capacity and the functional ability of the body.
2. Physical work capacity is relevantly higher for professional sportsmen about 69% than participants of public sport.
3. Maximal oxygen uptake is relevantly higher about 69% for professional sportsmen than participants of public sport. During the anaerobic threshold elite cyclists of Latvia reach 91.5% of maximal oxygen uptake but world elite cyclists reach - 80% of maximal oxygen uptake.
4. The total energy expenditure is higher for professional sportsmen comparing with participants of public sport. Professional sportsmen as a source of energy more effectively use fat reserves of the body and provide glycogen saving. Participants of public sport as a source of energy less

effectively use fat reserves of the body and intensively start to use carbohydrates which demand less oxygen uptake.

5. Calorimetry is a practical and useful method for the planning of sportsmen diet into sports practice. It allows estimating: rest energy expenditure and amount energy expenditure for lifestyle; the chosen diet adequacy, the proportions of substrates which avoid conditions of the energy deficit during the physical load and the optimal physical load for decreasing fat reserve in the body.

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