Fig 1 The author during one of the measured activities - work with a wooden hoe. ■

Problems of Measuring Physical Performance in Experimental Archaeology

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• The article summarises the results of dissertation work, the aim of which was to study the physical requirements of activities presumed to have occurred in prehistory, their impact on human physiology and to create a scale for single activities organised according to their relative energy expenditure.

1 Introduction

Physical performance has been and is a part of all human activities. Its effort importance is dependent on many variables in any action. We can gain some information on physical performance in prehistory from archaeological research, finds of features and artefacts. Every subsurface feature (ditch, clay pit, grubenhaus, posthole, grave), every building (roundel, fortification, house or megalithic building) and all artefacts represent the physical performance of our ancestors. In the vast majority of cases, the performance is of an unknown size and intensity.

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Such feats may have but need not to be the result of teamwork. In some cases, the work could be made easier by use of the basic principles of physics (lever, water transport, use of a sleigh or later a wheel). The proportion of the use of these 'helpers' in single activities is mostly unknown, together with exact technological procedures. In this situation, it is better therefore to focus on a single person. To divide a complicated action, making or building, into simple operations that were probably the foundation stones of a majority of prehistoric activities. These could at least be roughly described and evaluated. Do we have conclusive evidence of concrete activities by prehistoric people? There are finds of simple tools, which indicate what way they may have been used. For example digging sticks, hoes, axe handles, polished stone tools etc. Archaeological research also uncovers many artefacts, which offer us only many uncertainties about their function. It is therefore necessary to admit that our hypotheses about their use are based on modern experience and knowledge. Here experimental archaeology proves its usefulness in the testing of hypotheses of possible uses of single tools, as the other sources of information are restricted.

Experimenters who record human input are recording their own prejudices, how efficient or inefficient they are, therefore they test in first place their performance. Similarly, those who record their feelings or emotions are recording modern and minor irrelevancies. (*Reynolds 2001*) The recording of feelings is certainly insignificant. However, for example measuring the impact the use of replica has on a human physiology, which is (approximately) the same as that of the ancient people, is an experiment independent on modern attitudes (*Tichý 2002*). I am of the same opinion as Radomír Tichý and disagree with a total rejection of research on physical requirements in experimental archaeology, as long as it involves exact research based on archaeological sources. This article and my dissertation are concerned with the studying of physical performance within experimental archaeology. The gained measured values and knowledge will always be related to modern humans of the end of the 20th, beginning of the 21st centuries, in no case it is possible to use them as absolute values corresponding to those in prehistory. We do not know how close we can get to the real levels of prehistoric human work output. It is just a step on the way to learn about our past, although from a view from the present, as any other archaeological research of prehistory. So why give it up?

2 Aims

The article aims to study the physical requirements of activities presumed to have occurred in prehistory, their impact on human physiology and to create a scale of single activities organised according to relative energy expenditure. The research took place between the years 1998 and 2003, mostly at the grounds of the Centre of Experimental Archaeology in Všestary. The main investigated group contained one person – me. It would be very difficult to organise regular participation in the project of more people and I decided to favour integrity over diffusing the issue. One or two persons more would not have improved the situation. In future, I intend to widen the project to a team of experimenters.

I participated in various activities which are presumed for the Neolithic (since 6000 BC) up to the Early Iron Age (to 400 BC). To estimate the intensity of the work my heart frequency was measured with a Sport tester S610itm and the reaction of segments of my body to various working conditions and activities was recorded. The originally planned measuring of oxygen uptake did not take place for technical reasons (the restricted number of portable apparatus in the Czech Republic).

3 Method

The amount of work output of any physical performance can be expressed in several ways provided by medicine, anthropomotorics and kinanthropology (see *Štěpán 2004*).

Intensity of the work: Expresses the quality of working or movement activity. It expresses the effort with which a concrete person executes an activity in relation to an absolutely or pre-determined value (*Placheta 2001*). The evaluation proceeds from different viewpoints.

Quality evaluation: (low, middle, sub maximum, maximum intensity). According to indicators of tiredness, tables, speed of movement and so on. It is subjective and imprecise.

Quantity evaluation: Based on measured (respectively calculated) functional values, respectively quantified subjective feelings. Among them belongs:

- Absolute values of function indicators (watts, heart rate, VO_2, lactate)
- Relative values of function indicators (w/kg, w/m^2, % of maximum heart rate, % of VO_2 max etc)
- Energy requirements (J, MET, kcal) (adjusted according to *Placheta 2001*, 132)

Generally, the determining of energy expenditure is counted as the most conclusive evaluation of physical work. There are several approaches; I used a method used by the Czech Hygienic Service and sports medicine. **Table 1** shows 3 levels (I, II, III) of accuracy where each level contains at least one method of estimation of energy expenditure for working and movement activities.

Method A of the 1st level presents a classification according to the type of activity. It is the first and most fundamental method that I used. Method B presents classifications according to profession (this of course was not used). Both methods give a rough estimate and have great margins for errors.

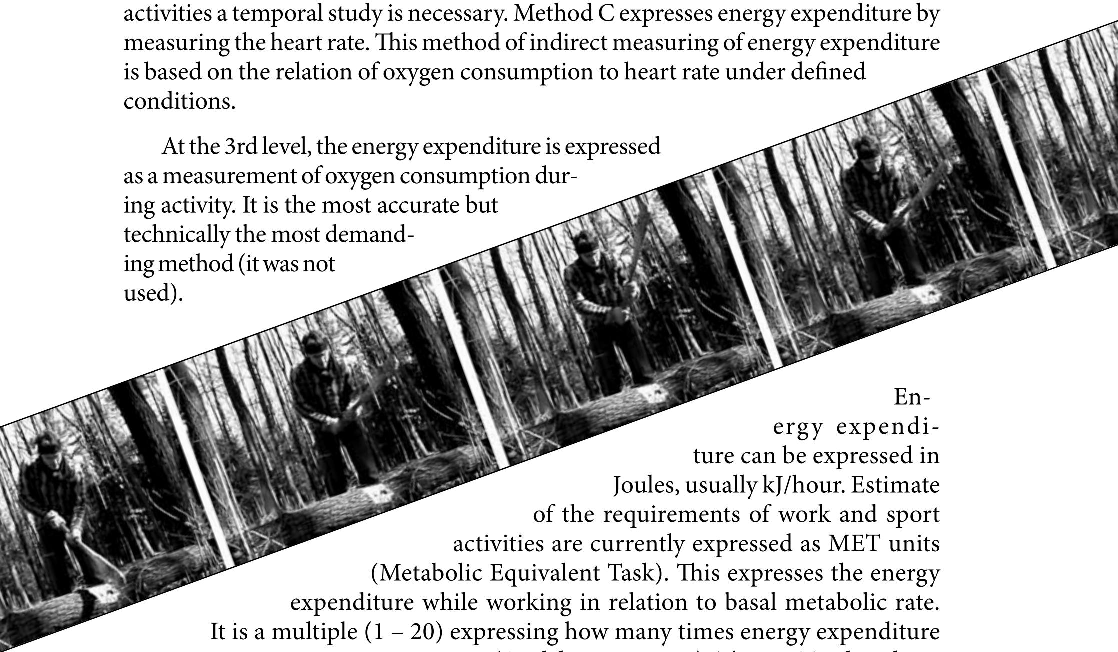
In the 2nd level method A expresses the energy expenditure as a sum of the basal metabolic rate, energy expenditure for the body position, energy expenditure for a given activity and energy expenditure for the body movement independent of the work rate, all according to the tables ČSN EN 28996, 1996. Method B expresses the energy expenditure using the table values of different activities. The margin for error is high. To estimate energy expenditure of work composed from various

Level	Method	Accuracy	Inspection of the workplace
I A	classification by type of activity	rough information with very large margin for error	not necessary
I B	classification by modern profession (not used)	rough information with very large margin for error	information on equipment and organisation of work
II A	use of tables for elements of activity	large margin for error, accuracy ±15 %	time study necessary
II B	use of tables estimating single activities (not used)	large margin for error, accuracy ±15 %	not necessary
II C	use of recorded heart rate (under defined conditions)	large margin for error, accuracy ±15 %	not necessary
III	direct measurement of oxygen consumption during activity	accuracy ± 5 %	time study necessary

Table 1 Levels of accuracy for the determining of energy expenditure (Adopted according to ČSN EN 28996, 5). ■

activities a temporal study is necessary. Method C expresses energy expenditure by measuring the heart rate. This method of indirect measuring of energy expenditure is based on the relation of oxygen consumption to heart rate under defined conditions.

At the 3rd level, the energy expenditure is expressed as a measurement of oxygen consumption during activity. It is the most accurate but technically the most demanding method (it was not used).



Energy expenditure can be expressed in Joules, usually kJ/hour. Estimate of the requirements of work and sport activities are currently expressed as MET units (Metabolic Equivalent Task). This expresses the energy expenditure while working in relation to basal metabolic rate. It is a multiple (1 – 20) expressing how many times energy expenditure increases in comparison to resting (*Soulek 1995*, 18-21). The MET values have the advantage that they are derived from an individual basal metabolic rate, they are more descriptive and easier to compare. They do not work with absolute but relative energy values.

The third possibility is to express the energy expenditure as an output in watts. This method is used in the Czech Norm for Ergonometry – Determination of Thermal Production of Organism – ČSN EN 28996. To individualise it the watts are calculated by the mass of a person (w/kg) or by surface area of the body (w/m^2) (*Štěpán 2004*).

3.1 Classification of the amount of energy expenditure according to types of activity

This classification is in ČSN EN 28996 classified as a 1st degree of accuracy (see **table 1**) and has a large margin of error. Energy expenditure for a given activity is sorted into one of five classes (rest, low, middle, high and very high-energy expenditure). Single activities assessed during our work at CEA Všestary were arranged (see **table 2**) according to table analogues with the norm ČSN EN 28996.

Class / Examples	MET	W/m²	W
rest value / resting	**1 - 1.9**	**65**	**115**
1 - low energy expenditure / light work using hands and arms in sitting, kneeling, standing position: sewing with a bone needle, pottery making, finishing stone artefacts, making of bone artefacts, spinning, cleaning corn, making of small wooden artefacts; standing: cooking, dough preparation; walking up to 3 km/hour	**2 – 2.9**	**100**	**180**
2 - middle energy expenditure / continuous work using hands and arms: knapping, corn grinding; work using arms and body: daubing walls, picking fruit and vegetables, scraping skins, work with chisel, fastening construction, polishing slate, bronze casting, work with small hammer, cutting cereal ears at thigh height, weaving on a loom,	**3 - 5**	**165**	**295**
3 - high energy expenditure / intensive work using arms and body: cutting reed, work with small axe at slow rate, butchering meat, hammering, harvesting cereals with straw, intensive grinding of stone (standing), shovelling with wooden shovel at 25 throw/min, paddling at 6.5 km/hour, hoeing already loosen soil; walking at 5.5 - 7 km/hour	**5 - 7**	**230**	**415**
4 - very high energy expenditure / very intensive work at fast pace: splitting trunks with wedges, ploughing with ard, work with digging stick, daub preparation, deturfing, work with iron axe, digging deep with hoe, carrying heavy loads, working with polished stone axe; walking faster than 7 km/hour, run	**7 – 9 and more**	**290**	**520**

Table 2 Classification of energy expenditure according to the type of activity (Adjusted according to ČSN EN 28996, 15; Soulek 1995, 291-292; Máček – Vávra 1988). ■

3.2 Tables for estimate of energy expenditure according to the components of activity

The energy expenditure for a working person can be estimated as the sum of various components of the expenditure. This process is classified to the second level of accuracy (see **table 1**). It is much more precise than the two previous methods. The energy expenditure is expressed analytically as a sum of values of following components:

a) Basal metabolic rate

b) Energy expenditure for the body position

c) Energy expenditure for the type of work

d) Energy expenditure for body movement related to the speed of work

To allow a comparison of values from different sources these values are recalculated for a standard person – a modern man defined by the values:

- Body height (m) 1.7
- Body weight (kg) 70.0
- Body surface (m^2) 1.8
- Age (years) 35
- Basal metabolic rate (w/m^2) 44
  (adjusted according to ČSN EN 28996, 18-20)

Table 3 contains the approximate values of energy expenditure for the body position, **table 4** values of energy expenditure for various types of work and **table 5** an example of the calculation of a final value approximate energy expenditure according to activity components (ČSN EN 28996, 18-20)

Type of work	Energy expenditure (W/m^2):	middle value	range
work with hands	light	15	≤ 20
	average	30	20 - 35
	hard	40	≥ 35
work with one arm	light	35	≤ 45
	average	55	45 - 65
	hard	75	≥ 65
work with both arms	light	35	≤ 75
	average	85	75 - 95
	hard	105	≥ 95
body work	light	125	≤ 155
	average	190	155 - 230
	hard	280	230 - 330
	very hard	390	≥ 330

Table 4 Energy expenditure according to type of work. ■

Body position	Energy expenditure (W/m²)
sitting	10
kneeling	20
squatting	20
standing	25
standing bending forward	30

Table 3 Energy expenditure according to body position. ■

Activity Digging field (deturfing) with wooden hoe; damp soil, weight of hoe 3.5 kg (position standing bending forward, heavy body work)	
Basal metabolic rate (men) - BMR	44
Position of body - PB	30
Type of work - TW	390
Body movement - BM	0
Sum W/m²	**464**

Table 5 Example of the estimation of energy expenditure with the help of tables for single components of activities. Energy expenditure in W/m² (Adjusted according to ČSN EN 28996, 18-19). ■

The principle of calculation described above was applied to single working activities tested and evaluated by the experimenters from CEA Všestary. Movement activities are arranged by value from those with the lowest energy requirements to the most demanding. The basal metabolic rate is always expressed on a male table value; this arrangement does not deal with the question of gender division in work.

Sewing with a bone needle – Work in a sitting position; the holding of the needle statically exerts hand and forearm muscles over short periods; it is not a problem to rest the hand, we know of the changing of hands from analogues. Holes are prepared with an awl for sowing together hard skins.

BMR	44	PB	10	TW	20	BM	0	**Sum:**	**74**

Retouching knapped industry – Work in a sitting position; middle intensity work with hands. Static exertion of hand muscles by holding the tool and worked material.

BMR	44	PB	10	TW	30	BM	0	**Sum:**	**84**

Hand production of pottery – Work in a sitting or kneeling position; the work is done by small muscle groups of the hand and forearm; possibility of local exhaustion of working muscles; danger from non-physiological kneeling position (see later).

BMR	44	PB	10	TW	30	BM	0	**Sum:**	**84**

Work with whorl – Sitting position (standing position or while walking - not taken into account). The work is done with the muscles of the hand, forearm and one arm.

BMR	44	PB	10	TW	40	BM	0	**Sum:**	**94**

Sharpening the edge of polished industry and metal tools – Work in a sitting position; hard work with both hands; static exertion of the hand and forearm muscles by holding worked material; possibility of local muscle exhaustion.

BMR	44	PB	10	TW	40	BM	0	**Sum:**	**94**

Cleaning grain - Work in a sitting position; use of hand and arm muscles.

BMR	44	PB	10	TW	65	BM	0	**Sum:**	**119**

Making of bone artefacts – Work in a sitting or kneeling position; middle work with one arm or both hands. We presume use of a hammer stone of 1 kg weight for breaking the bones.

BMR	44	PB	10	TW	65	BM	0	**Sum:**	**119**

Beating metal (work with small hammer or mallet of 0.65 – 1 kg weight) – Sitting position; hard work with one arm; local exhaustion of the working arm, biceps and forearm muscles; static exertion of hand and forearm muscles (holding tool).

BMR	44	PB	10	TW	70	BM	0	**Sum:**	**125**

Work with a bronze chisel (and mallet or hammer of 0.65 to 1 kg weight) – Sitting position; middle work with both arms; static exertion of hand and forearm muscles of both arms – holding tools; relation to the hardness of wood.

BMR	44	PB	10	TW	85	BM	0	**Sum:**	**139**

Making of knapped artefacts – Sitting position; middle work with both arms; static exertion of hand and forearm muscles of both hands – holding the hammer stone and worked material.

BMR	44	PB	10	TW	95	BM	0	**Sum:**	**149**

Weaving on a Neolithic vertical loom – Position standing bent forward; middle work with both arms.

BMR	44	PB	30	TW	80	BM	0	**Sum:**	**154**

Daubing walls – Changing working positions: standing, squatting; middle work with both arms.

BMR	44	PB	25	TW	90	BM	0	**Sum:**	**159**

Grinding corn with quern stone – Kneeling position; hard work with both arms; nonphysiological position with effect on knee joints.

BMR	44	PB	20	TW	105	BM	0	**Sum:**	**169**

Scraping skins (cleaning off the remains of meat) – Kneeling position; hard work with both arms.

BMR	44	PB	20	TW	105	BM	0	**Sum:**	**169**

Harvesting fruit (picking from a tree, collecting from ground) – Standing position; light work of both arms; body movement – slow walk (about 0.3 km/hour).

BMR	44	PB	25	TW	65	BM	40	**Sum:**	**174**

Bronze casting (ignoring the dissipation of heat) – Standing position bent forward; hard work with both arms.

BMR	44	PB	30	TW	105	BM	0	**Sum:**	**179**

Grinding slate (slow removal of mass) – Kneeling position; light body work; static exertion of hand and forearm muscles – holding of worked material in exact position.

BMR	44	PB	20	TW	125	BM	0	**Sum:**	**189**

Fastening of construction with straps – Standing position; middle body work.

BMR	44	PB	25	TW	125	BM	0	**Sum:**	**194**

Cutting cereal ears at thigh height with a bronze sickle – Standing position bent forward; middle work with both arms; walking at 0.5 km/hour.

BMR	44	PB	30	TW	65	BM	60	**Sum:**	**199**

Weaving of fence – Standing position bent forward; light body work; related to type of wood used.

BMR	44	PB	30	TW	125	BM	0	**Sum:**	**199**

Blowing with simple bellows – Sitting position; light body work.

BMR	44	PB	10	TW	150	BM	0	**Sum:**	**204**

Work with a small iron axe (1 kg) – Standing position bent forward; light body work.

BMR	44	PB	30	TW	140	BM	0	**Sum:**	**214**

Butchering meat – Metal tools; a standing position; middle body work.

BMR	44	PB	25	TW	165	BM	0	**Sum:**	**234**

Intensive grinding of polished artefacts, removal of large amounts of mass – Standing position bent forward; middle body work; static exertion of hand and forearm muscles (holding of worked object).

BMR	44	PB	30	TW	160	BM	0	**Sum:**	**234**

Cutting reed – Iron sickle; a standing position bent forward; hard work with one arm; walking at 2km/hour.

BMR	44	PB	30	TW	70	BM	100	**Sum:**	**244**

Harvesting cereals and straw (cutting 10-15 cm above ground, iron sickle) - Standing position bending forward; light work with both arms; walking at 2 km/hour.

BMR	44	PB	30	TW	70	BM	100	**Sum:**	**244**

Transport of a load on back (backpack type Ötzi) – 30 kg. Standing position; walking with load at 4 km/hour on flat.

BMR	44	PB	25	TW	0	BM	185	**Sum:**	**250**

Building of a house skeleton (lifting logs, holding, placing) – Standing position; middle body work.

BMR	44	PB	25	TW	190	BM	0	**Sum:**	**259**

Hammering (2 kg hammer) – Standing position bent forward; middle body work.

BMR	44	PB	30	TW	190	BM	0	**Sum:**	**264**

Ploughing with simple wooden ard pulled by oxen – Standing position bent forward; middle body work; walking at 2km/hour.

BMR	44	PB	30	TW	155	BM	110	**Sum:**	**339**

Work with digging stick (digging post holes) – Standing position; hard body work; considerable static exertion of finger, hand and forearm muscles.

BMR	44	PB	25	TW	280	BM	0	**Sum:**	**354**

Paddling in a log boat (aerobic regime) – Sitting position; hard body work; considerable effect of the rate and external conditions (waves, current, wind).

BMR	44	PB	10	TW	330	BM	0	**Sum:**	**384**

Digging (quarrying) with a pick in a restricted space (mine, tunnel etc) - Squatting, kneeling position; hard body work; static exertion of hand and forearm muscles; destructive effect of the environment on the whole organism.

BMR	44	PB	20	TW	320	BM	0	**Sum:**	**384**

Hoeing soft soil with a wooden hoe (of 3kg weight) – Standing position bent forward; hard body work; walking backwards at 0.2 km/hour; considerable static exertion of finger, hand and forearm muscles; nonphysiological working position; damage to arm by rebounds.

BMR	44	PB	30	TW	280	BM	50	**Sum:**	**404**

Cutting wood with an iron axe (of 1.5 kg weight) – Standing position bent forward; very hard body work; considerable exertion of finger and forearm muscles; destructive effect of rebound.

BMR	44	PB	30	TW	360	BM	0	**Sum:**	**434**

Running, 9 km/hour - Standing position; light work of both arms.

BMR	44	PB	25	TW	65	BM	301	**Sum:**	**435**

Mixing daub with a wooden spade (of 2 kg weight) – Standing position; bent forward; very hard body work.

BMR	44	PB	30	TW	380	BM	0	**Sum:**	**454**

Digging deep with a wooden hoe – Clay pit, grubenhaus etc. Standing position bent forward; very hard body work; considerable static exertion of hand and forearm muscles; destructive effect of rebound; related to the hardness of soil.

BMR	44	PB	30	TW	382	BM	0	**Sum:**	**456**

Cutting wood with a polished stone axe (of 2 kg weight) – Standing position bent forward; very hard body work; intensive static exertion of hand and forearm muscles; rebound effect; axe was BRACCIANO type.

BMR	44	PB	30	TW	385	BM	0	**Sum:**	**459**

Digging deep of a narrow ditch (or in other restricted space) with a wooden hoe - Standing position bent forward; very hard body work; considerable static exertion of hand and forearm muscles; destructive rebound effect; related to the hardness of soil.

BMR	44	PB	30	TW	385	BM	0	**Sum:**	**459**

Cutting down trees using an iron axe with eye (of 1.5 kg weight) - 33 blows per minute. Standing position bent forward; very hard body work; considerable static exertion of finger, hand and forearm muscles; rebound effect.

BMR	44	PB	30	TW	386	BM	0	**Sum:**	**460**

Cutting down trees using a polished stone axe (of 2 kg weight) –30 blows per minute. Standing position bent forward; very hard body work; considerable static exertion of finger, hand and forearm muscles; rebound effect.

BMR	44	PB	30	TW	390	BM	0	**Sum:**	**464**

Transport of load in front of one's body – For example, daub on a tarpaulin (30 kg), wooden logs. Standing position; hard body work; walking at 3 km/hour.

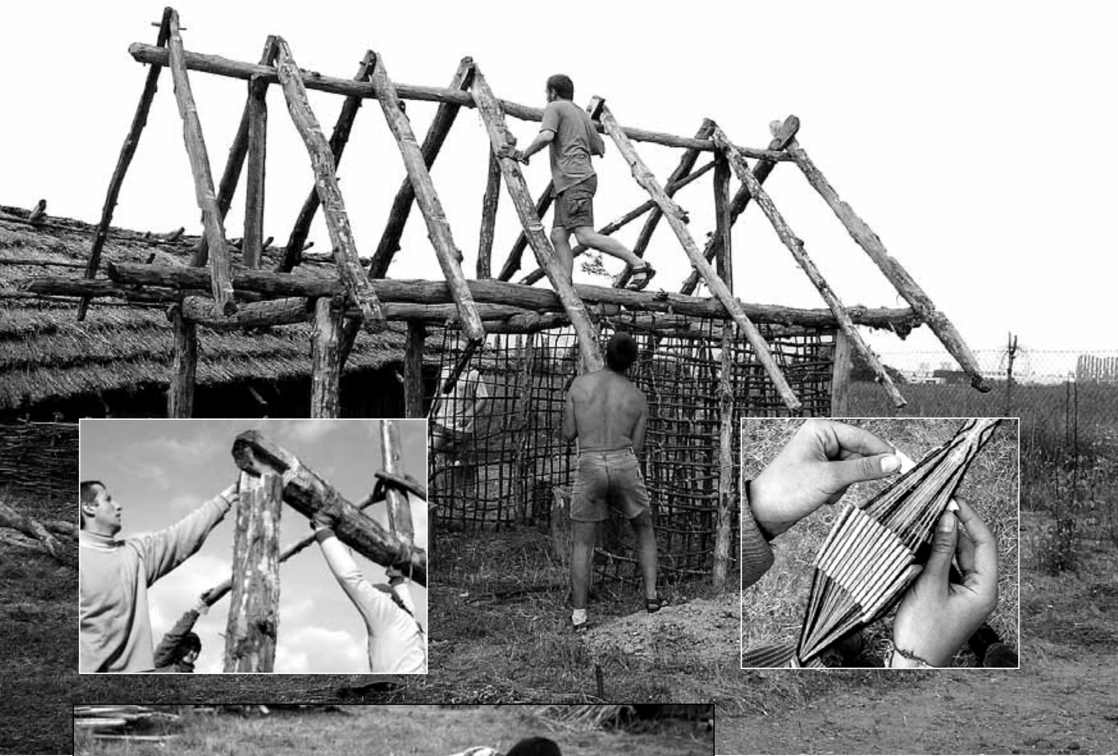
BMR	44	PB	25	TW	290	BM	110	**Sum:**	**469**

Running – 12 km/hour – Standing position; light work of both arms; intensive work of lower limbs.

BMR	44	PB	25	TW	65	BM	350	**Sum:**	**484**

Running – 15 km/hour – Standing position; hard work with both arms, and very intensive work of lower limbs.

BMR	44	PB	25	TW	75	BM	406	**Sum:**	**550**



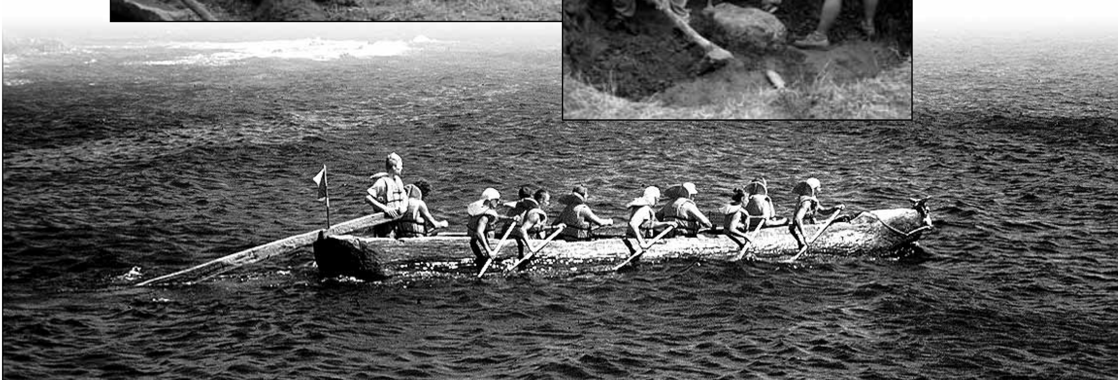












The list of working activities given above is not fully exhaustive, many activities are missing for various reasons. For example working activities which are difficult to evaluate or so specific that we have only uncertain notions of them in relation to prehistory. Despite this, I consider the list as sufficient, covering the basic working activities and movements presumed in prehistory in any given period.

A great number of external variables affects the above list of energy expenditure and influences the variability of the value interval.

1. Outside temperature, strength of wind, rain – weather.
2. Differences in working object – effectiveness of tools – knapped industry, polished industry, copper, bronze, iron.
3. Hardness of worked material – e.g. wood – depends on species, method and time of cutting (drying).
4. Hardness of soil – dry soil is compact and resistant to digging, on the other hand damp soil is easy to work and hoe.
5. Technique, experience, dexterity.
6. Intensity pace of work.
7. Mental component – stress, fear, anger, motivation.

3.3 Estimation of energy expenditure according to relation between heart rate and oxygen uptake (linear interpolation method)

As we could not measure oxygen consumption directly due to the of inaccessibility of the necessary apparatus for this method it was the most accurate available to us. In ČSN EN 28996 it is classified as on the second level of accuracy (see **table 1**). For physiological reasons, it is necessary to respect certain restrictions limiting this method. The relation between heart rate and oxygen uptake is linear only if we are considering dynamic muscle work of the large muscle groups in neutral thermal conditions in relation to the energy expenditure.

A considerable dissipation of heat, static muscle work, and the dynamic work of small muscles or mental exertion can change the direction and shape of the relation of heart rate to oxygen uptake and energy expenditure. Generally an interval between 120 beats/minute and heart rate (maximum – 10) is considered as acceptable (ČSN EN 28996, 13).

The overall heart rate (HR) can be considered as the sum of several components.

$$HR = HR_0 + \Delta HR_M + \Delta HR_T + \Delta HR_N + \Delta HR_E$$

where

HR_0 heart rate, in beats per minute of a person resting in a recumbent position in neutral thermal conditions;

ΔHR_M increase of heart rate, in beats per minute, caused by dynamic muscle exertion in neutral thermal conditions

ΔHR_S increase of heart rate, in beats per minute, caused by static muscle work
ΔHR_T increase of heart rate, in beats per minute, caused by thermal exertion
ΔHR_N increase of heart rate, in beats per minute, caused by mental exertion
ΔHR_E residual component of heart rate, in beats per minute, on basis of, for example influence of breathing.

(adjusted according to *Soulek 1995* and *ČSN EN 28996,* 13)

An example of determining MET from the relation of HR to VO_2:

Digging with a hoe - time of measurement 14:25 min

- measured average HR 128 beats/hour
- from physiological curve on the basis of average HR we determine with linear extrapolation VO_2 1.55 l = 1 550 ml of uptake oxygen
- we calculate uptake of O_2 on 1 kg of the workers mass: VO_2/kg = 1550/77 = 20 ml/kg
- MET = VO_2 (ml/kg) : VO_2 (ml) rest, 20 : 3.5 = 5.7 MET

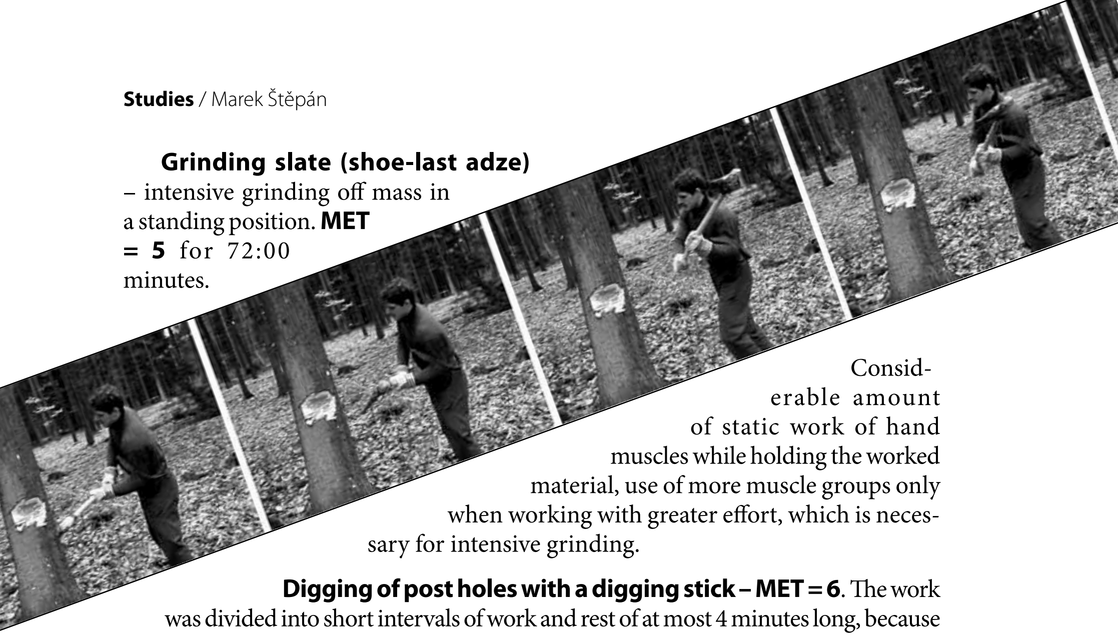
(adjusted *Soulek 1995, Máček - Vávra 1988, Placheta 2001*)

The following list of the working activities is not exhausting, more it is a poor remain, which at least partly fulfils the demanding to those requirements for correct measurement. The activities are sorted from the least demanding top those with the highest MET value (adjusted according to *Štěpán 2004*, 82-93)

Hoeing the ground with a hoe on an already worked field – **MET = 5**. The measurement took place on a square 400 by 400 cm, with a hoe of about 3 kg weight. We progressed backwards so we would not walk on already loosen soil. The work took place in standing position but continuously bent forward. Work was mostly done with both arms, the body in a fixed position. Here it is necessary to stress the clearly nonphysiological position of the body, which could, if this activity repeated often, have a destructive effect on the muscles and skeleton, particularly of the back. The level of the physical exertion is proportional to (among others) the following main factors:

- **Hardness of soil**
- **Effectiveness and condition of the hoe** – condition of the edge, weight
- **Technique of digging** – ability to hold the handle lightly, stretch only above head without straightening the body

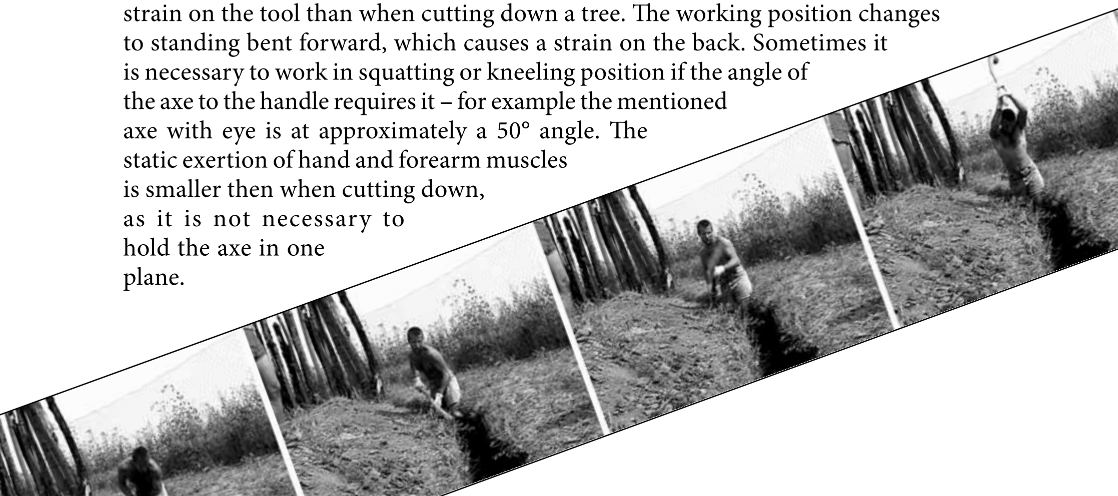
The mentioned square was hoed over at a relaxed pace in 7:54 minutes (**graph1**) with a maximum heart rate of 143 beats/minute. The hoe was held at the tool's centre of gravity, the arm closer to the blade was exerted most, which is the opposite than the case when digging deep.

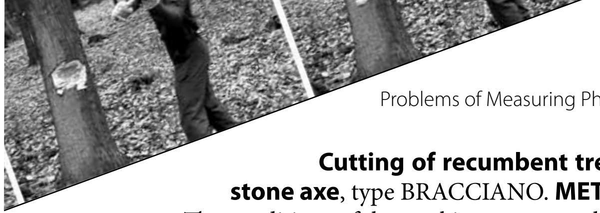


Grinding slate (shoe-last adze) – intensive grinding off mass in a standing position. **MET = 5** for 72:00 minutes. Considerable amount of static work of hand muscles while holding the worked material, use of more muscle groups only when working with greater effort, which is necessary for intensive grinding.

Digging of post holes with a digging stick – MET = 6. The work was divided into short intervals of work and rest of at most 4 minutes long, because of the necessity to remove the loosened soil. The time interval was also dependant on the tiredness of the muscles used to hold the tool. Only the time of digging was evaluated. If the breaks for removing soil were counted in the total, the energy requirements in relation to time decrease as the muscles regenerate during the break. Considerable damaging effect on the 'main arm', which works the tool with more force (the arm at the top). The movement of this arm can be compared to spear throwing with the same health risks. It is the possibility of damaging elbow tendons-lateral and medial epicondylitis (so called tennis and golfer's elbow). The working person can help himself by using the lower limbs (as with spade), this variation was not tested.

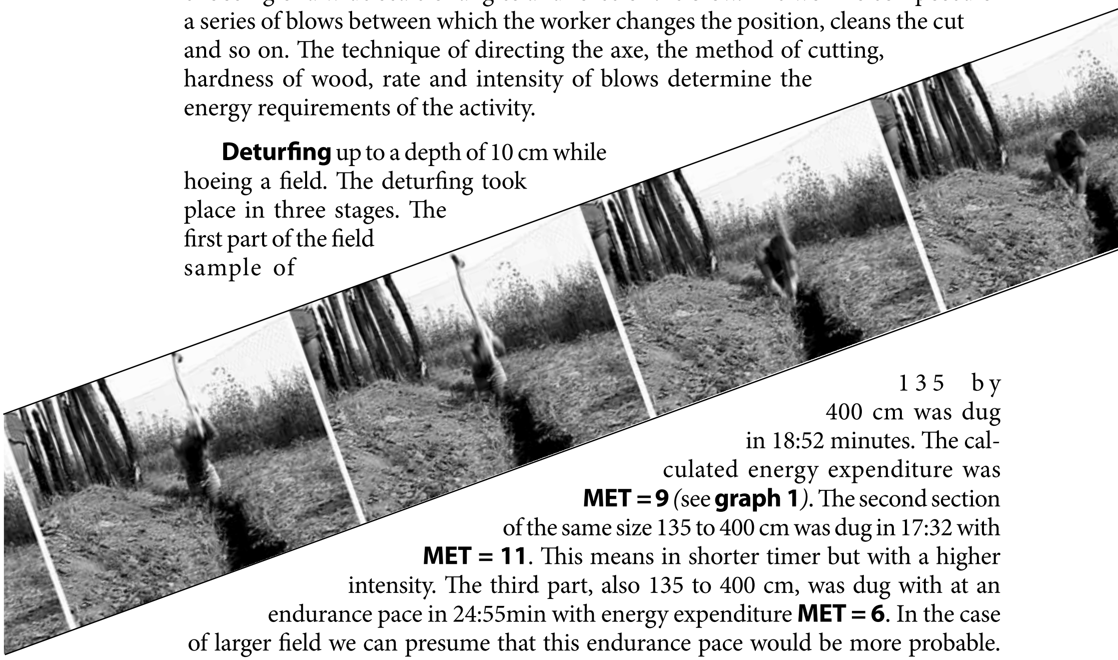
Cutting of recumbent tree trunks with an iron axe with eye, Hallstatt – la Tène, about 1.5 kg weight. **MET = 6.4**, average HR = 136 beats/minute. The activity only seems identical to cutting down the tree itself. In reality, there are many different components. The trunk lies on the ground; in 85% of cases, it is impossible to move it. The working person has to direct the axe blows from a restricted angle and as a result is forced to take off more wood and with bigger strain on the tool than when cutting down a tree. The working position changes to standing bent forward, which causes a strain on the back. Sometimes it is necessary to work in squatting or kneeling position if the angle of the axe to the handle requires it – for example the mentioned axe with eye is at approximately a 50° angle. The static exertion of hand and forearm muscles is smaller then when cutting down, as it is not necessary to hold the axe in one plane.





Cutting of recumbent tree trunks with a Neolithic polished stone axe, type BRACCIANO. **MET = 7.2**, average HR = 140 beats/minute. The conditions of the working space are the same as above. The difference is in the effectiveness of the tool, weight (about 2 kg) and fixing the axe on the handle in such a way that it can take the blows without damage. The choice of the angle of the blow is much more restricted, in fact the direction of the blow must be perfect otherwise, the axe slides off or rebounds. The width of the handle is also a problem and as a result, it is necessary to take off much more of wood then when cutting with narrow metal tools.

Cutting down trees with an iron axe with eye, Hallstatt – la Tène, 30 blows a minute. The weight of the axe was about 1.5 kg. Work was in a standing position, bending towards the 'weaker' hand holding the axe handle. **MET = 7.4**, average HR = 142 beats/minute. The endurance profile of the activity prevails with a considerable static exertion of the hands holding the axe handle. There was a considerable destructive effect of rebound transferred onto the hands of the working person. There is a danger of health problems because of the long-term strength contraction of the finger, hand and forearm muscles. The quality of the axe allows for the choosing of a wide scale of angles and force of the blow. The work is composed of a series of blows between which the worker changes the position, cleans the cut and so on. The technique of directing the axe, the method of cutting, hardness of wood, rate and intensity of blows determine the energy requirements of the activity.



Deturfing up to a depth of 10 cm while hoeing a field. The deturfing took place in three stages. The first part of the field sample of 135 by 400 cm was dug in 18:52 minutes. The calculated energy expenditure was **MET = 9** *(*see **graph 1***)*. The second section of the same size 135 to 400 cm was dug in 17:32 with **MET = 11**. This means in shorter timer but with a higher intensity. The third part, also 135 to 400 cm, was dug with at an endurance pace in 24:55min with energy expenditure **MET = 6**. In the case of larger field we can presume that this endurance pace would be more probable. Stretching was in all three cases always high above the head. The blow was done with great force with using the body muscles (mostly back), upper and lower limbs. To turn the soil over a considerable pull towards the digger was necessary, also with the use of back and arm muscles. The force of the blow did not vary; the energy expenditure was dependant on the rate of blows. The force of the blow was determined by the hardness of the soil, the condition of the edge and the weight of the hoe. The method of digging is similar to digging to a depth, the hoe is held far from the blade and the centre of its gravity with the main hand on the end of the handle. During the blow, there is transmission of low frequency vibration to the hand of the digger. These could have detrimental effect (possible damage of ligaments, joint cartilage, inflammation and so on).

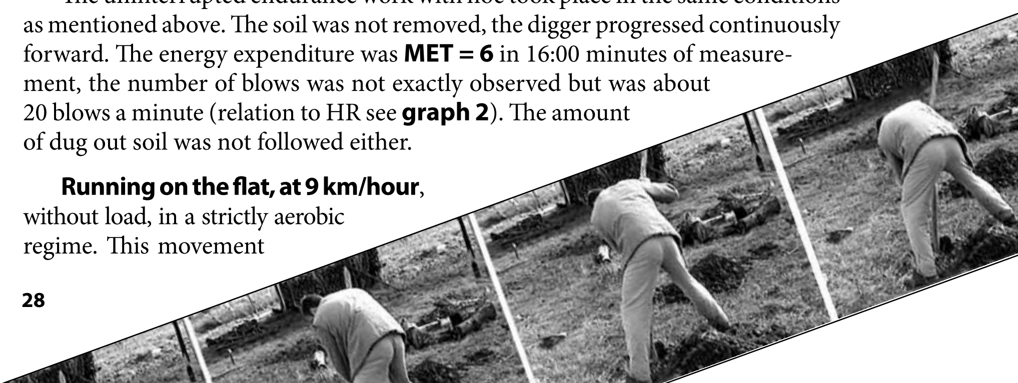
Digging in a clay pit, quarrying of loess. In comparison to the digging of a field, it usually consisted of short work intervals at most 6 minute long, several following each other. The average energy requirement was **MET = 9.3**, at maximum it reached **MET = 10** for 5 minutes. Again, the quality (hardness) of soil affected requirements, together with the edge and weight of the hoe and other variables. The most effective method seems to be 'pulling down steps', when the digger can gain more soil with one blow. The digger progresses around the centre of a hole with a method reminiscent of a drill and the clay pit automatically gains a round shape. Within several minutes of the digger's rest, the dug out soil was removed. Here is space for further consideration. The most effective method seems to be working as a pair, where one person digs with a hoe, the other removes the loosened soil and these two regularly change over. The possibility of single person both digging and removing was calculated as a much more exhausting but also possible.

Digging the foundation ditch for a palisade with a wooden hoe. The ditch was 70 cm deep, the hoe 3 kg. The work is very specific because of the space restriction when it is necessary to increase the proportion of force effect of hands on the hoe handle for total control of the direction of the blow. In addition, the position of the worker is not ideal; there is considerable lack of space for the lower limbs, which causes a higher energy expenditure for keeping the working position. The work took place in repeated intervals of up to 5 minutes of digging and 6 to 10 minutes of soil removal, all by one person. In the case that two people would be working, one digger digging and other removing the soil, the pace of work would increase and the time of digger's rest would shorten but would be more effective. The energy requirements of one working activity done by the same person but with different intensity are different. In the example, a number of blows determine the intensity in a minute, with theoretically identical force of blows:

- 25 blows/minute – **MET = 7**, in 5:30 min, one wheelbarrow of soil
- 35 blows/minute – **MET = 10**, in 4:00 min, 1.5 wheelbarrows of soil

The uninterrupted endurance work with hoe took place in the same conditions as mentioned above. The soil was not removed, the digger progressed continuously forward. The energy expenditure was **MET = 6** in 16:00 minutes of measurement, the number of blows was not exactly observed but was about 20 blows a minute (relation to HR see **graph 2**). The amount of dug out soil was not followed either.

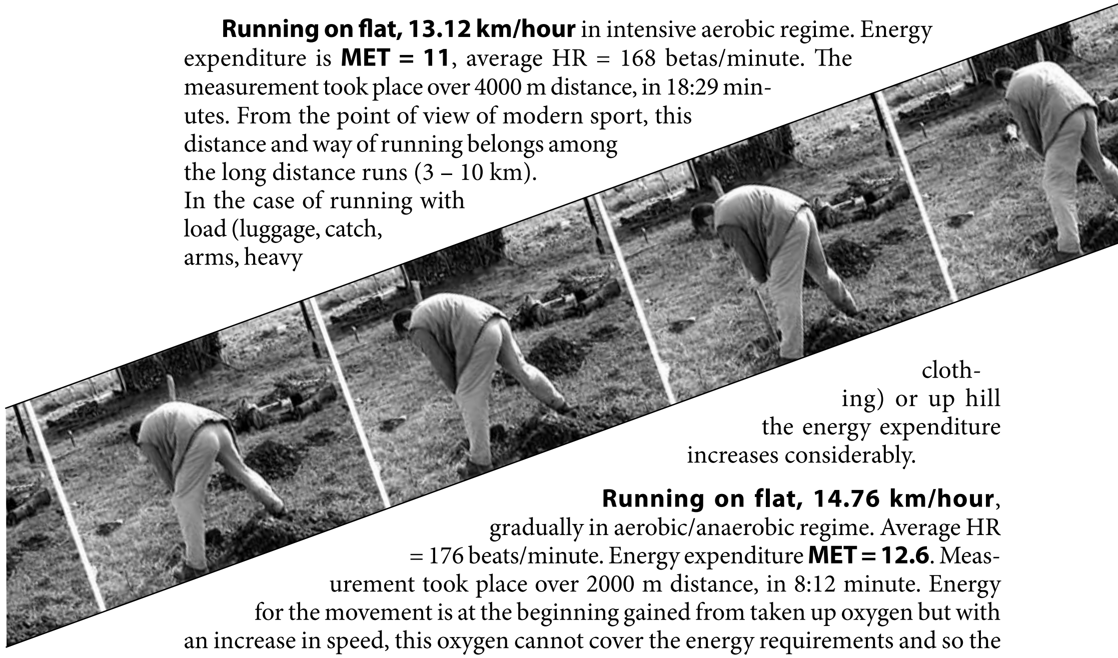
Running on the flat, at 9 km/hour, without load, in a strictly aerobic regime. This movement



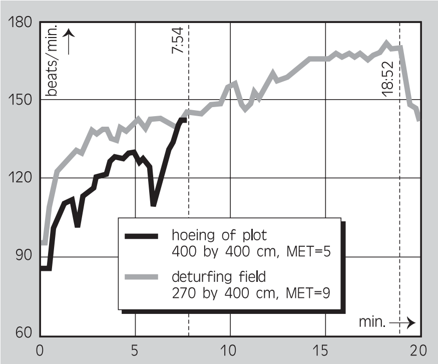
activity is analogous in prehistory to hunting, transport, transferring messages and so on. The locomotion activities are more often presumed for hunter-gatherer groups than for farmers although archaeology does not offer any conclusive evidence of this. **MET = 9**, people are capable of this way of running on long distances of 10 to 20 km and more.

Cutting down trees with a Neolithic polished stone axe, type BRACCIANO, 30 blows per minute. Approximate weight of the axe 2 kg. **MET = 9.8**, average HR = 154 beats/minute. Working position standing bent sidewise. The requirements of the work are increased by a considerable static exertion on the hands holding the axe handle. The blow must be directed and kept at a 90 – 45° angle towards the axis of the trunk, any hesitation at the moment of the touching the wood with the edge can cause it to slide or rebound. This effect is more common the harder the wood is. The handle must be large enough to allow the fixing of the axe but that decreases its flexibility and ability to absorb low frequency vibrations that affect the worker's hands. Woodworking with stone tools is generally risky for the fingers and palms holding the tool. The high static exertion of finger and forearm muscles can cause a worsening of blood circulation and a collecting of lactate acid in the working muscles, which speeds local exhaustion. Following the straining of tired muscles there is an increased occurrence of rebound, which can cause an inflammation of ligaments, tendons, joint cartilages or other damage to muscles. Cutting with this type of axe is demanding not only physically but also mentally. The worker has to concentrate continuously on every blow. Practise with this method of cutting shows considerable increase in effectivness.

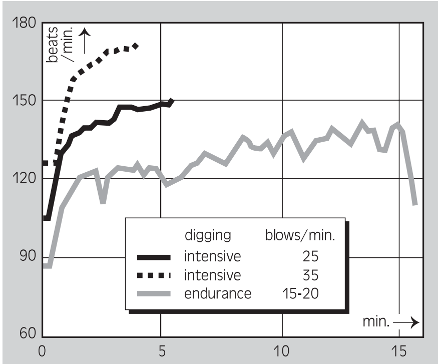
Running on flat, 13.12 km/hour in intensive aerobic regime. Energy expenditure is **MET = 11**, average HR = 168 betas/minute. The measurement took place over 4000 m distance, in 18:29 minutes. From the point of view of modern sport, this distance and way of running belongs among the long distance runs (3 – 10 km). In the case of running with load (luggage, catch, arms, heavy clothing) or up hill the energy expenditure increases considerably.



Running on flat, 14.76 km/hour, gradually in aerobic/anaerobic regime. Average HR = 176 beats/minute. Energy expenditure **MET = 12.6**. Measurement took place over 2000 m distance, in 8:12 minute. Energy for the movement is at the beginning gained from taken up oxygen but with an increase in speed, this oxygen cannot cover the energy requirements and so the



Graph 1 Heart rate - deturfing and hoeing. ■



Graph 2 HR - digging a foundation ditch. ■

organism reaches an 'anaerobic threshold' (see *Štěpán 2004*, 45-48). Running in anaerobic-aerobic regime can last for approximately 800 to 1500 m, that is about 4 to 5 minutes. Running, locomotion activities, including fast walk is evaluated as the most demanding movement activity (adjusted according to *Štěpán 2004*, 82-93).

4 Discussion

4.1 Validity of the research

The first two methods of physical performance using evaluation worked by the assigning of table values according to the norm ČSN EN 28996 were used within their limits (see **table 1**) and I do not have any reservations about them. The method of linear extrapolation has problems, which increased its margin of error. Most of the work activities presumed in prehistory, which I was ready to evaluate, did not fulfil the basic requirements for the validity of the estimation of energy requirements in relation to heart rate. This concerns especially the use of at least 60% of the body muscle groups and a sufficiently high heart rate during the measurement, large share of static muscle work and work in anaerobic regime. This means that most of the measured values of heart rate did not express the total physical performance and in reality, the energy expenditure during the measurements was higher then the resulting values of MET. Despite this, it is a unique and complex overview allowing us to compare the possible activities.

For a better orientation I added the values of MET measured by us in CEA Všestary to the table of values of energy requirements of modern working and recreational activities (**table 6**).

The problem of the accuracy of the results can be resolved only by research with use of an apparatus for measuring of oxygen uptake during the activity. The use of sport tester only is not sufficient.

4.2 Note on the type of performance

Today muscle activity of a static character prevails in the life of modern people. It does not have a necessary stimulating effect on the cardiovascular or the kinetic systems. Some theories presume that in the past the profile of the daily life activities of dynamic or

Modern activities	MET	Evaluated activities	MET
Sleep, rest; Sitting quietly; Standing quietly, eating, hand writing, repair of watch, drawing, typing on a typewriter, driving car	1.0 1.2 1.4 - 1.7	Not evaluated – low heart rate	
Printers, copying, work in laboratory, bookbinding, baking, easy housework (sweeping, cooking), repair of car, light woodwork, sewing	2.0 - 2.5	Not evaluated – low heart rate	
Work of nurses, locksmiths, toolmakers; Driving lorry, harvester, tractor; Work in tree nursery, carpentry, middle housework (making bed, tidying up)	3.0 - 3.7	Not evaluated – low heart rate	
Weeding; Painting, wallpapering, carpentry, raking leaves; Hard housework (carpet beating, washing floor) Mechanized agricultural work	4.0 - 4.5	Not evaluated – low heart rate	
Postman, builder, hand washing car, carpentry, mowing lawn; Digging and rooting garden; Traditional agricultural work	5.0 - 5.6	Grinding slate (intensive grinding while standing) Hoeing soil (digging field in slow pace)	5.0 5.0
Work in deep mine Cutting wood, clearing snow, cutting grass with scythe	6.0 6.5	Digging postholes with digging stick, Deturfing (in a slow pace) Cutting of recumbent trees with iron axe	6.0 6.0 6.4
Steel industry (operating furnaces) Digging ditch Cutting with handsaw Carrying of load 36 kg Cleaning stables	7.0 7.4 7.5	Digging foundation ditch (25 blows/min) Cutting recumbent trunks with Neolithic stone axe Cutting down tree with iron axe	7.0 7.2 7.4
Hard forestry work (cutting trees, debranching trunks, carrying logs)	8.2	Not evaluated	
Clearing furnace	9.9	Deturfing Running on flat at 9 km/h., aerobic regime Quarrying of loess in clay pit Cutting down trees w. Neolithic stone axe	9.0 9.0 9.3 9.8
		Digging foundation ditch with hoe (40 blows/min)	10.0
		Intensive deturfing Run on flat at 13.12 km/hour – intensive aerobic regime	11.0 11.0
		Running on flat at 14.76 km/hour – anaerobic/aerobic regime	12.6

Table 6 Activities (Adjusted according to Soulek 1995; Placheta 2001). ■

prevailingly static character has changed from dynamic to prevailingly static character rather than a total daily energy expenditure (*Máček - Vávra 1988*, 263).

During my measurements and observation, I concluded that the majority of the evaluated activities presumed in these prehistoric periods are of a non-locomotive character. This corresponds with the proportion of craft, building and farming activities in comparison to, for example hunting. Most of the work during the measurement was done with the upper limbs and body , the lower limbs work mostly on basis of static contractions while keeping the working position (clay pit, foundation ditch, grinding stone, woodworking with axes, cutting the logs, partially field work, grinding cereals, making pottery, textile etc) (*Štěpán 2004*).

It is possible that people in past carried out more muscle activity of prevailingly dynamic character and locomotion. This can be presumed for hunter-gatherer populations as is known from ethnographic research. This shows that to secure a subsistence living hunter-gatherers move over longer distances than settled farmers do (*Sládek 2002*, 306). The transition to farming has been the centre of interest for a long time. We can presume the beginning of the development that continues today, e.g. increase of muscle work of a static character. The transition to farming was not everywhere analogous to this ideal model. On the contrary, it seems that the adaptation of ancient population in the transition to farming was varied and did not follow one script (*Sládek 2002*, 308). Despite this, it is possible to presume that with an increase in the volume of farming and crafts, locomotion activities of a dynamic character decreased. Experimental measurements showed that the way the Neolithic farmer spent his time between single activities is decisive. How often did they make new polished tools? How often did they hoe their fields, dig in a clay pit? How many times in a week or month did they go hunting? How far and often did they move their herds and respectively move with them? There are many questions. But it is certain that the more often people built constructions like roundels, wells, settlement fences and so on the more work characterised by static muscle activity prevailed. (*Štěpán 2004*).

5 Conclusions

From the point of view of the researched working activities, it is impossible to miss the considerable differences caused by the intensity of the work. Intensity is the key to the question ‘In what time?’ and that goes also the other way round. Unfortunately, archaeology does not hold this key. We can of course suppose that the work intensity used to be, as today, individual (lazy versus hard workers) and also determined by outer conditions (danger, tiredness, peace, prosperity, motivation and so on), if it was necessary to do the work quickly or if on the contrary there was no hurry and the work was done in a slow endurance pace (*Štěpán 2004*).

The total energy expenditure does not change by the variation of work intensity, the time changes. A lower intensity is compensated by a greater volume of work. In the terms of physics, we can express it as follows: ‘Lower output in watts is given over longer time therefore the resulting work in Joules is the same as with higher output over shorter time’.

A system of roughly evaluated and arranged working activities was created. How close it is to the prehistoric reality is a subject for much debate and further research, hopefully with better equipment and results.

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Summary

Comment évaluer les performances physiques en archéologie experimentale?

Cet article ressort de la thèse de ľauteur qui traite les performances physiques de ľhomme sur le plan de ľarchéologie expérimentale. Ľauteur a pratiqué plusieurs travaux supposés pour ľépoque dès le Néolithique (depuis 6000 BC) jusqu'à ľHallstatt (jusqu'à 400 BC).

Ses recherches ont consisté sur la mise en évidence des exigences des activités supposées pour la préhistoire et de leur impact sur la physiologie et le physique de ľhomme et encore sur ľélaboration ďune échelle des différentes activités suivant les dépenses relatives ďénergie. Les travaux ont été effectués en 1998-2003, notamment

dans le Centre d'archéologie expérimentale de Všestary (République tchèque). Une seule personne a été soumise à l'examen - l'auteur même de la thèse pour que l'intégrité des recherches soit garantie.

Généralement on prend la mesure de l'énergie dispensée pour l'évaluation la plus probante de la charge physique. L'auteur a appliqué trois méthodes différentes empruntées dans la médecine sportive. La première, celle la moins précise, classifie les activités selon leur caractère. La deuxième méthode tient compte de l'énergie nécessaire pour le métabolisme basal, le maintien, le propre travail et pour le mouvement du corps indépendant de l'intensité de travail. La méthode la plus précise dont l'auteur disposait, examine les dépenses énergétiques exprimées par la fréquence cardiaque. Cette dernière méthode est fondée sur la relation entre l'oxygénation et le rhytme cardiaque, dans des conditions bien définies. L'expérimentateur mesurait les fréquences au cours du travail avec Sport tester et parallèlement, il examinait et enregistrait les réactions des différents segments du corps. Pour chaque méthode, les activités effectuées et évaluées ont été classifiées à partir des plus faciles jusqu'aux plus exigeantes. Les données prennent en compte plusieurs déterminants qui agissent sur les dépenses d'énergie et donc ils ont de l'influence sur les résultats. Bien que les résultats reflètent les capacités de l'homme du 21e siècle, cette recherche permet de comparer l'exigence relative des différentes activités. La mesure où les résultats rapprochent de la réalité préhistorique est mise en question et se prête à de nouvelles recherches.

Enfin, le recherche met en évidence des différences importantes à propos de l'intensité de travail. On peut supposer que, jadis comme aujourd'hui, l'intensité de travail était individuelle et déterminée par les conditions externes, la nécessité de se dépêcher etc. Ces variations néanmoins peu modifient le total des dépenses d'énergie. C'est en effet le temps qui change. D'habitude, une faible intensité de travail est compenseée par un temps de travail plus impotrtant.

Probleme bei der Messung körperlicher Tätigkeit in der experimentellen Archäologie

Der Artikel basiert auf einer Dissertation, die sich mit der Erforschung körperlicher Tätigkeit in der experimentellen Archäologie befasst. Der Autor nahm dabei an verschiedenen Aktivitäten teil, welche die Zeit vom Neolithikum (ab 6.000 v. Chr.) bis zur Hallstattzeit (um 400 v. Chr.) betrafen.

Das Ziel der Arbeit bestand darin, die körperlichen Anforderungen zu untersuchen, die Arbeiten betreffen, welche in prähistorischer Zeit vermutlich durchgeführt worden sind; außerdem sollte ihr Einfluss auf die menschliche Physiologie festgestellt werden und eine Skala für einzelne, spezifische Tätigkeiten erarbeitet werden, mit welcher der relative Energieaufwand zu messen wäre. Die Untersuchungen wurden zwischen 1998 und 2003 durchgeführt und fanden vorrangig auf dem Gelände des Zentrums für Experimentelle Archäologie in Vsestary in der Tschechischen Republik statt. Die Forschungsgruppe bestand dabei vor allem aus einer Person, dem Autoren selber, um die Zuverlässigkeit der Daten zu gewährleisten. Für die Zukunft ist geplant, das Projekt mit einer Gruppe von Experimentalarchäologen weiter zu führen.

Um die körperliche Tätigkeit zu erfassen, wurde der Energieaufwand als zuverlässigste Datenquelle für physische Arbeit gemessen. Der Autor hat dabei drei verschiedene, unterschiedlich genaue, aus der Sportmedizin entlehnte Methoden angewandt, um den Energieaufwand zu bestimmen. Die erste, am wenigsten genaue Methode war eine Klassifikation, die sich nach der Art der Aktivität richtete. Mit der zweiten Methode wurde der Energieaufwand als die Summe der elementaren Stoffwechselrate, des Energieaufwands für eine bestimmte Körperhaltung, des Energieaufwands für eine bestimmte Aktivität und des Energieaufwands für die Bewegungen des Körpers unabhängig von der Arbeitsbelastung berechnet. Die genaueste zur Verfügung stehende Methode gibt den Energieaufwand anhand der gemessenen Herzfrequenz an. Sie basiert auf dem Verhältnis von Sauerstoffverbrauch zur Herzfrequenz unter bestimmten Bedingungen. Die Herzfrequenz während der Arbeit wurde mit einem Sportmessgerät bestimmt; außerdem wurde gleichzeitig die Reaktion verschiedener Körpersegmente auf unterschiedliche Aktivitäten beobachtet und festgehalten. Die getesteten und ausgewerteten Aktivitäten waren – getrennt nach den erwähnten Methoden – so aufgebaut, dass sie von denjenigen, die den niedrigsten Energieaufwand besaßen, zu denjenigen mit den höchsten Anforderungen durchgeführt wurden. Die Aufzeichnungen erfassten dabei auch diverse Variablen der Arbeitsumgebung, welche den Energieaufwand betrafen und damit das Ergebnis beeinflussten. Obwohl die gemessenen Werte immer auf Menschen am Übergang zum 21. Jahrhundert zu beziehen sind, gibt die Untersuchung aber einen Einblick in das relative Verhältnis von verschiedenen Aktivitäten. Wie nah die Resultate an der prähistorischen Realität liegen, ist ein zu diskutierendes und weiter zu erforschendes Thema.

Die Arbeit betont auch die erheblichen Unterschiede in Blick auf die Intensität der Arbeit. Es ist möglich festzustellen, dass die Intensität der Arbeit – wie auch heutzutage - individuell ist und durch äußere Bedingungen wie z. B. dem Zwang zu einer hohen Arbeitsgeschwindigkeit beeinflusst wird. In jedem Fall ändert sich nicht der totale Energieaufwand mit der Veränderung der Intensität der Arbeit, sondern lediglich die Dauer für die Erledigung einer bestimmten Aufgabe ändert sich. Eine umfangreichere Arbeit wird normalerweise durch eine geringere Intensität ausgeglichen.