

REVIEW ARTICLE

BRAIN ENERGETIC DEMANDS DURING COGNITIVE ACTIVITIES IN RELATION TO AEROBIC LOAD

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Summary

Fatigue is common clinical issue, where previous effort, whether physical or mental leads to a reduction in the ability to perform activities. Fatigue severely affects human performance and error rate. Recently, in addition to researching physical fatigue, great emphasis has been placed on research into mental fatigue. The relationship between the two types of fatigue is intensively investigated. Exploration of fatigue and its impact on job performance in high-risk military occupations aims to reduce error rates and eliminate potentially large damage, injuries and loss of life. In this review are described the basic theses of fatigue, physiological mechanisms of fatigue and the methods of fatigue research.

Key words: Energetic policy; cognitive fatigue; aerobic load

Introduction

Fatigue is a reduction in the ability to perform an activity that results from previous exertion. According to last taxonomy fatigue is diversified into two branches – physical fatigue and mental fatigue (1).

Both mental and physical fatigue is manifested in two different forms – acute and chronic. Assessing the fatigue extent is the main problem. There is not available any simple, measurable and conclusive indicator of fatigue extent (1,2). Fatigue is multifactorial quantity with various causes and manifestations (2). Even when standardized procedures are used, an individual approach for assessing the fatigue extent is often the only solution.

Acute metabolic fatigue is defined as a decrease in maximal force or power production in response to contractile activity and accumulation of metabolites; it is highly reliable on subjects will exertion and thus on brain activity (27). Amann and Dempsey (3) stated that "...exhausted muscles, accepted as muscles unable to work any further, are able to reach supramaximal performance after minimal rest...".

Mental – cognitive fatigue influences human performance both in physical and psychical tasks. Its impact on subsequent aerobic performance was proved in several studies (4, 5). Decrease of physical performance, higher flaw score in computer test with extreme cognitive demands were proved (6, 7, 8). Lactate levels and/or glycemic index were not influenced, though (6, 7, 8)

The purpose of this review is to compare different approaches in estimating energetic demands of human body both in physical and psychical tasks.

Neurophysiologic background of cognitive fatigue

The extent of cognitive fatigue assessing is always subjective, based on personal feelings and perception of their manifestation. Concentration issues, decreased vigilance, lowered ability of visual perception, decreased ability to reaction, increase of flaws in cognitive demanding tasks or sleepiness is observed (4, 9-11)

Glucose is the main source of energy for brain activities (11). According to current theories, decrease in glucose transport speed is theoretical reason of slowing down the cell metabolic processes (4). Another impact might be caused by increased sarcolemma polarization which might be connected with decreased $\text{Na}^+ - \text{K}^+$ ATP pump activity. It leads to slower nerve excitement and probably implies deregulation of excitation and inhibition of CNS processes. (13, 14).

Utilization of the energy sources in brain is dependent on a number of active neurons, their activity and individual energy consumption. Brain energetic demands during cognitive tasks are important for complete distribution and utilization of energy during motoric tasks. Cortex plays a key role in cognitive functions of the brain (12, 15).

1. Grey matter specifics

Even when many scientific approaches and philosophies try to find the very fundamentals of brain processes, there is still much to uncover (16).

The principles of information coding, transfer and evaluation (cognitive input, perception, etc. in our case) are not clarified yet (6, 16). Moreover, amount and number of active neurons working during information transfer and evaluation in human was not set. Functional magnetic resonance imagining (fMRI) uses blood-oxygenation-level dependent (BOLD) signal, fluorescent molecules or enzyme-substrate pairs for functional mapping of brain structures (17-19). Energetic demands during cognitive tasks can be counted though. Basic human brain statistics are presented in Table 1.

Table 1. Basic statistics of human neocortex (6)

sProperty	Value
Surface area (mm ²)	190,000
Thickness (mm)	2.5
Glucose Consumption (μmol/g/min)	0.40
Glia/mm ³	38,000
Neurons/mm ³	40,000
Synapses/mm ³	7×10^8
Axon Length m/mm ³	4,000
Average Axon Diameter	0.3
Dendrite Length	400
Average Dendrite Diameter (μm)	0.9

Clinical studies on human brain are ethically and technically problematic, therefore, human brain is compared through a researches led at rat neocortex (6, 12) or other species (16). Brain processes in rodents are simpler or can be easier determined, evaluating results is also more convenient. Identical parameters in brain proportionality are seen in basic structure and brain organization (16); size of neuron is nearly the same, ca. 15 μm in diameter and similar is also characteristics of single synapses. Different features in its proportionality are higher amount

of synapses in human brain; thickness of human brain cortex is bigger; neuron density is lower in proportionate to brain of rat and axon and dendrite volume corresponds with a thickness of cortex. Due to the same diameter of neurons, the length of axon and dendrites increases (6, 28-30)

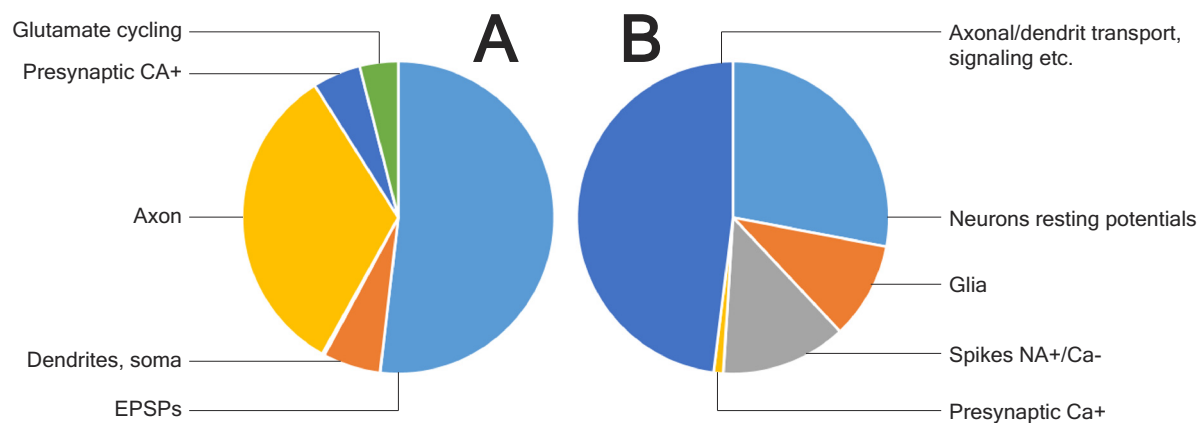
Energetic consumption of pyramidal neuron was thus estimated on basis of differences and identical features with previous work (12). Number of active neurons, their synapses and a volume of active brain cortex was counted to get a complete consumption of human brain.

2. Energetic demands of grey matter

Energetic demands of grey matter are estimated by comparing human and rodent brain (6,12). ATP as molecule of energy carrier representing 7kcal/mole (28, 32, 33). There are a few areas, which can be seen separately when calculating energy consumption: A) Postsynaptic potential counts with $1,2 \times 10^9$ ATP per single signal, calculating with 50% probability of malfunction (20), B) Signal transfer counts $9,2 \times 10^8$ ATP per single signal, calculating with 2,5x longer axons in human than rats (12) C) Release and recycle of neurotransmitters counts with $2,3 \times 10^4$ ATP, $2,1 \times 10^3$ ATP for re-use, respectively and D) The number of activated neurons and the resting potential value must be also counted into the complete energetic demand of neural activity (6).

The picture No. 1 illustrates the proportionality of energetic demands of neural activity.

Complete consumption of human brain is set as $3,4 \times 10^{21}$ ATP/min, counting its average weight as 475g (6).



Picture 1. Energetic demands of neural activity in human cortex (6)

(A) How the cost of a single spike in human pyramidal cell arises in different processes. A spike consumes 2.4×10^9 molecules of ATP. The principal cost (52%) is EPSPs evoked at postsynaptic sites. Propagation in dendrites and soma account for 6% and 0.25%, respectively. Propagation along axon accounts for 33%. Mechanisms of transmitter release and recycling consume 5% and 4%, respectively.

(B) Fractions of total energy expenditure in neocortex that are attributable to different functions. Maintaining resting potentials in neurons and glia accounts for 28% and 10%, respectively. Reversing Na⁺ and K⁺ fluxes from spikes accounts for an additional 13%. Calcium movements associated with transmitter release and transmitter recycling each account for less than 1%. Functions unrelated to neural signaling account for the remainder. Segments that represent costs associated with spiking are pulled out from the chart.

2. Energetic demands of motoric activity

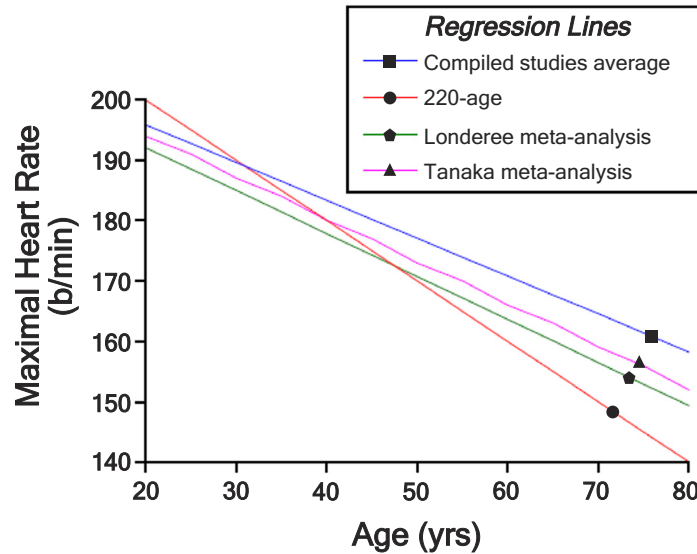
In contrast of estimating energy demands of brain which are complicated, the same procedure in motoric manifestation is much simpler.

Physical fitness is defined as a result of longitudinal process of gradual organism adaptation on motoric tasks. It is posted as long-term advancing adaptation on motoric training led in accordance with physiological rules (21).

2.1. Load intensity, age and heart rate

Heart Rate (HR) is used to prove the basic manifestation of load intensity. Most of the researchers use the calculation $220 - \text{age}$, which is used for setting up the HR_{\max} and then, in comparison with actual HR for energetic zone determination (22, 23)

According to current research (24), the linear relation “Age – HR_{\max} ” does not exist. This fact is depicted in the picture No. 2.



Picture 2. Meta-analysis and ideal dependency comparison (14)

HR indirectly reflects an effort extent (load intensity); a value of HR also reflects the zones of energetic coverage. $\text{HR} > 180$ beats/min. shows to (LA)→(ATP – CP) system of energetic coverage. $\text{HR} 150 - 180$ beats/min or $\text{HR} < 150$ beats/min. show (LA – O₂) and (O₂) system respectively.

2.2. Energetic demands determination

To determine energetic demands of physical activity, researchers use mathematic formulas. The first formula for setting up an assumed energetic demand of specific motoric task uses the coefficient of energy expenditure. Simple walk, crouch, position changing from stand to sit etc. can represent a specific motoric task. The formula of Energy Consumption during motoric task, validated for the Czech population, includes relevant list of “q” (21). EC (energy consumption) is equal to t (time) multiplied by w (weight) and q (coefficient of energy expenditure in kJ/hour). It does not count with age, level of precise motoric skill, economy and effectivity of motoric task solution was not taken under consideration respectively (14, 16, 9, 8).

Also, metabolic equivalent (MET) is widely used for quantifying intensity of motoric tasks. 1 MET = 3,5 ml of O₂ consumption/kg/hour while motoric tasks varies from 1 (sleeping) throu 4 (normal breathing) to 7 (extreme exertion) (25).

For estimating the $\text{VO}_{2\max}$ value, as an indicator of individual aerobic fitness, the nomogram (26) is mostly used.

3. Current research

Energy consumption in humans is very attractive topic mostly in obese (35, 38) or athlete (36) population or in clinical approaches in medicine (37). Measuring the overall energetic demands of human body is often led

thru respiration calorimetry (39) doubly labeled water (31-33) or using different formulas (25) or coefficients (21). The current science focuses on human energy expenditure to find out mechanisms of metabolic needs, fuel utilization and for effects of food, drink or drugs (34).

4. Conclusion

Depleting energy sources cause physiological fatigue or inadequate supply of energy demands for activated tissues respectively. Fatigue manifests in decrease in maximal force or power production and in concentration issues, decreased vigilance, lowered ability of visual perception, decreased reaction ability and many more.

To determine energetic demands of motoric tasks, it is plausible to use Energy Consumption formula or MET equivalent. Determination of motor task energetic demand is impossible without proper “background” of brain activity, which should be taken under consideration when working with fatigued subjects.

Brain is one of the energy, ATP molecules consumers. Its cortex is mostly connected with fulfilling cognitive tasks. Neocortex is responsible for distribution and transfer of all the signals and information, which plays role not only at the motoric tasks (Proprio-function, perception from vestibular apparatus and many more) but also for their processing. Energetic demands of this part of human body cannot be proved for ethical and clinical reasons. Comparing with other researches led on other mammals set human brain energetic demands.

Focusing on energy policy of human body as combination of muscles and CNS might play role in highly demanding tasks (pilots, weapon operators, drivers etc.) and further studies are desired.

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Conflict of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

Adherence to Ethical Standards

This article does not contain any studies involving animals performed by any of the authors.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study.

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