

Rainer H. Straub

Understanding Aging, Fatigue, and Inflammation

When the Immune System
and Brain Compete for Energy
in the Body



Springer

Understanding Aging, Fatigue, and Inflammation

Rainer H. Straub

Understanding Aging, Fatigue, and Inflammation

When the Immune System and Brain Compete for Energy in the
Body

Rainer H. Straub
Department of Internal Medicine
University Hospital Regensburg
Regensburg, Germany

ISBN 978-3-662-68903-5 ISBN 978-3-662-68904-2 (eBook)
<https://doi.org/10.1007/978-3-662-68904-2>

Translation from the German language edition: “Altern, Müdigkeit und Entzündungen verstehen” by Rainer H. Straub, © Springer-Verlag GmbH Deutschland 2018. Published by Springer Berlin Heidelberg. All Rights Reserved.

This book is a translation of the original German edition “Altern, Müdigkeit und Entzündungen verstehen” by Rainer H. Straub, published by Springer-Verlag GmbH, DE in 2018. The translation was done with the help of an artificial intelligence machine translation tool. A subsequent human revision was done primarily in terms of content, so that the book will read stylistically differently from a conventional translation. Springer Nature works continuously to further the development of tools for the production of books and on the related technologies to support the authors.

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer-Verlag GmbH, DE, part of Springer Nature 2024.

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Photo credits cover: Reicher/Stock.adobe.com

This Springer imprint is published by the registered company Springer-Verlag GmbH, DE, part of Springer Nature.

The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

Paper in this product is recyclable.

The misfortune of the creature is the unwanted energy expenditure that prevents desired energy expenditures for physical and mental efforts.

For Jürgen Schölmerich,
a friend and supporter of lateral thinking

Foreword

The digitized world brings with it the fact that via Facebook, WhatsApp, blog pages, and many other variants, writing activity on even the most irrational topics is constantly increasing and is omnipresent. A significant disadvantage of this is that while an unmanageable amount of short communication messages and comments flow through the air or the earth cables, a meaningful context to overarching topics is rarely discernible. Sustainability is also usually not recognizable in this, although there might possibly be some clever ideas behind it if one were to think them through to the end and also put them into words.

Exactly this path has been taken by one of the most innovative minds of our time, my long-time colleague and friend, Rainer H. Straub—once again—by summarizing and channeling ubiquitous questions and unsolved mysteries, thus opening a new perspective for the inclined readers.

In this book, the brain and immune system compete, allowing us to sense how much contradiction operates within our body and how much these two “egoists” depend on each other. This problem can be understood especially in conversations with patients with systemic-inflammatory immunological diseases every day, as hardly any of these patients report that they are fully mentally and physically capable despite their disease being inactive under therapy, even though “all” (laboratory) parameters show no activity of their inflammatory disease. This reflects the “concept of the two realms” also contemplated and newly formulated by the author, guided by egotists (brain and immune system) who assist each other in energetic emergencies, but still compete for the limited resources in the body in the long term.

The imbalance of the energy balance and the resulting problems are therefore also the central intersection of this book, and it is very interesting to trace how the author transforms this wealth of information into sometimes deliberately humorous, but easily understandable streams of thought and reading.

For those who are not only interested in the basic culture of conflict between the two egoists (brain and immune system), but also in practical examples and many explanations of individual symptoms and disease states, the third part of the book is intended, in which the individual problems of this energetic imbalance are explained in detail. A special feature is that the author, although he is not yet to be classified in this age group, provides an outlook on the egoistic-energetic processes with increasing age and explains comprehensibly why due to these processes physical youthfulness cannot always be maintained. However, since this only applies to a limited extent to the brain, every interested person is advised to read this work. The mental performance of the reader, even in old age, will certainly be sustainably supported by reading this book.

With special thanks to Rainer H. Straub and his not insignificant efforts to write this work.

Ulf Müller-Ladner

Bad Nauheim/Gießen
im Herbst 2017

Preface

With the description of the genetic material (DNA) in the 1950s, we experienced an unprecedented **molecular revolution**. True to the motto “Everything is molecule and molecule is everything”, many scientists lose themselves in details. Since then, biomedical science has increasingly focused on tiny individual parts of the cell machinery, and the view of the whole is often lost. The patient laments this.

Clinically active, researching physicians, who actually always consider the entire human being and not just a single cell, adhere to this **detail-oriented thinking**. Therefore, research projects often have a single molecule at their center. Even epidemiologically oriented physicians (human geneticists) focus on a tiny genetic detail in order to relate it to diseases in population-based studies using mathematical methods. This focus on detail leads to the problem of a clear description of the transition from cellular events to the problem for the entire human being, the symptom. The patient experiences or feels a symptom, and from there it is a long way to the interior of a cell and to the molecule.

Thus, there are **symptoms** such as depressive mood, fatigue, sleep disorders, loss of appetite and the associated malnutrition and undernutrition, muscle atrophy, bone loss, weight gain and weight loss, dwindling libido and reduced fertility, high blood pressure, increased blood clotting, back pain and much more. Of course, cellular and molecular processes are behind this, but describing the transitions from the intracellular to the whole is extremely difficult. This is probably because we have so far hardly developed a scientific method for assessing and describing the whole. However, in the last two decades, physicians, psychologists, and natural scientists have made important progress by relating various research areas to each other (this began in Germany in the early 1990s).

On the one hand, this is the field of **Psycho-Neuro-Endocrino-Immunology**, where the linking factors between the brain and body—namely nerve fibers (Neuro), hormonal glands (Endocrino) and immune cells (Immuno)—are considered. In doing so, these researchers draw on molecular insights from the individual sub-disciplines, focus on the linking paths between the organ systems, and thus consider the whole. In the USA, this field is often referred to as Mind-Body Medicine today.

Furthermore, in the last two decades, the field of **Evolutionary Medicine** has emerged, adopting the concepts of evolutionary biology for medicine. Evolutionary medicine provides an extraordinarily valuable perspective on the whole. It explains relationships by asserting that they must have a benefit in the context of reproduction (English: “fitness”). If a benefit arises for the individual, genes and the pathways dependent on them are conserved in the gene pool of the offspring. Over many generations, this phylogenetic development leads to traits that exist today (including genes and molecules in us humans), which have a measurable benefit in the context of reproduction. The individual molecule, the gene, or entire signaling pathways, which we usually consider in the context of a disease, probably have entirely different roles in the context of reproduction, for which they were positively selected. Evolutionary medicine sharpens this view, thus creating a new approach to the whole.

Then there is the field of **energy regulation**, which deals more closely with the body's energy supply. Hardly any process in our body takes place without energy, which is why energy-rich substrates must be constantly supplied. However, energy is also constantly lost for heat production and many other functions. Energy-rich substrates are glucose, fatty acids, and proteins, from which cellular energy is obtained. Thus, energy intake and energy expenditure take place at the level of a single cell, but also at the level of the entire body. The energy consumption and energy intake of the human body can be determined exactly using scientifically flawless methods, so that we get a wonderful view of the whole with these procedures.

Within psycho-neuro-endocrino-immunology, many pathways can be explained by the fact that they serve the **energy regulation of the entire body** and reproduction. Starting from the physical role of energy, the first part of the book deals with energy regulation of the entire body. Furthermore, evolutionary medicine is presented, which provides valuable insights throughout the book. The second part of the book presents energy expenditures for various aspects such as immune defense, pain, psychological stress, sleep disorders, anxiety, and others in more detail. With this information, a connection between energy regulation, evolutionary medicine, and the above-mentioned symptoms is made in the third part of the book. The fourth part summarizes everything. Following the text, there is an appendix with a glossary that explains important terms in detail. In addition, there is an extensive keyword index attached.

The author worked for many years in the field of Psycho-Neuro-Endocrino-Immunology (specifically in relation to chronic inflammatory diseases), to then integrate the two elements of evolutionary medicine and energy regulation. This book was created with the desire to represent a transition between molecular and holistic medicine. The content should remain as simple as possible. This may not always have been successful, although a lot of help flowed in from outside.

Such a book is never created entirely on its own, and therefore here too a few very helpful people have given good advice for the German version of the book. The book was critically read and significantly improved, making it more generally understandable. We scientists live in an ivory tower, and we are so blinkered that we urgently need this help. In this sense, the book was read by Dr. Anne Asmacher, Dr. Hubert Stangl, Verena Straub and Gabriele Konanz. Valuable help also came from the Springer publishing house from Dr. Christine Lerche and Claudia Bauer. If inclined readers provide further tips, the author is grateful, because improvements are collected and then added in a further edition.

Rainer H. Straub

Regensburg
im Herbst 2017

Contents

I Energy, Evolution and Medicine

1	Energy and Body	3
1.1	The Pfühlbach and the Dispute.....	5
1.2	Of Reservoirs and Bicycle Dynamos.....	6
1.3	Stories of Thermos Flasks.....	7
1.4	What is Vital Force?.....	7
1.5	The Human Body—An Open System	9
1.6	CAEN (“Controllable Amount of Energy”) or How Much Energy Does the Body Need?	12
1.7	The Big Three	15
1.8	Why We Store Energy—Fever, Tour de France and Newborns	15
1.9	How Much Energy Do We and Our Ancestor Australopithecus Store?.....	18
1.10	Sweet Tooth—Brain, Muscles, and Immune System	21
1.11	Food Search Prior to Energy Storage	22
1.12	Neuronal Factors and Hormones of Energy Storage	23
1.13	A Little Lesson on Stress Hormones	26
1.14	A Brief Lesson on Immune Messengers	27
1.15	Stress Hormones and Cytokines Release Energy.....	27
1.16	A New Look at the CAEN (“Controllable Amount of Energy”).....	31
	References	33
2	Evolutionary Medicine	35
2.1	Darwin, Wallace & Co.—Simultaneity of a Discovery.....	36
2.2	Darwinian Evolution—Species and Selection.....	37
2.3	Darwinian Evolution—Modern Additions	38
2.4	Chickens from Behind	39
2.5	Founder Effect in Canada, Lactose Intolerance and Fat Babies	42
2.6	The Selfish Brain.....	44
2.7	The Selfish Immune System	46
2.8	When Two Fight	47
	References	49
3	Brain and Immune System—Two Competing Realms	51
3.1	Energy Release—Competing Role of Brain and Immune System.....	52
3.2	Energy Release—Mutual Immediate Assistance	54
3.3	Energy Storage—Memory Function of Brain and Immune System.....	55
	References	60

II Energy Expenditure in the Spotlight

4	Inflammation and Energy	63
4.1	Historical Definition of Inflammation	64
4.2	Inflammation Strength: Rose Thorn, Rheumatism, and Sepsis	65

4.3	Inflammation Causes Increased Energy Expenditure.....	67
	References	72
5	Pain and Energy	73
5.1	The Pain Receptors and Pain Stabilization	74
5.2	Inflammation Causes Pain—The Sixth Sense	75
5.3	When the Muscle Becomes Acidic, It Hurts	76
5.4	Heat, Cold, and Pepper—Where Does It Reach the Brain?	76
5.5	Acute and Chronic Pain	77
5.6	Electric Shock, Pain, and Energy Expenditure	78
5.7	Heat, Cold and Energy Expenditure	79
	References	80
6	Psychological Stress and Energy	83
6.1	What is Stress?	84
6.2	Acute Stress—Sport as a Model	84
6.3	Chronic Stress is Unhealthy	85
6.4	Chronic Stress at Work	86
6.5	Stressful Double Hits	87
6.6	Psychological Stress Causes Increased Energy Expenditure.....	87
6.7	Dementia and Heart Disease Increase Energy Expenditure	88
	References	89
7	Other Energy-Consuming Situations	91
7.1	Sleep Problems—Sleep Apnea	92
7.2	Chronic Smoldering Infections	92
7.3	Fear and Anxiety	94
7.4	6 Cigarettes per Day.....	95
	References	96
8	What Does Increased Energy Expenditure Mean for the Body?	99
8.1	Energy Expenditure in Aging	101
8.2	Energy Expenditure is Hereditary.....	103
8.3	Energy Situation During Aging with Additional Energy Expenditures.....	104
	References	107

III From Energy and Evolution to Symptom

9	Daytime Fatigue and Depression	111
9.1	Sickness Behavior in Chronic Inflammatory Disease	112
9.2	Daytime Fatigue and Depression in Old Age	114
	References	115
10	Sleep Disorders and Circadian Symptoms	117
10.1	How can Sleep be Studied?.....	118
10.2	Sleep and Circadian Rhythms in Chronic Inflammatory Diseases.....	119
10.3	Circadian Rhythm of Inflammation	120
10.4	Sleep Problems in Old Age	123
	References	124

11	Loss of Appetite, Malnutrition, and Undernutrition	125
11.1	Appetite and Chronic Inflammation	126
11.2	Anorexia of Aging	127
	References	128
12	Muscle Loss	129
12.1	Muscle Loss and Chronic Inflammation	130
12.2	Detour: Nutrition and Chronic Inflammation	132
12.3	Muscle Mass Decreases with Age	132
	References	135
13	Bone Loss—Osteoporosis	137
13.1	Bone Loss and Chronic Inflammation	138
13.2	Bone Loss in Old Age	140
	References	141
14	Weight Changes (Increase and Decrease)	143
14.1	Weight and Chronic Inflammation	144
14.2	Weight During Aging	144
	References	154
15	The Storage Hormone Insulin Doesn't Work—Insulin Resistance	157
15.1	Antoin Sulin in Resistance	158
15.2	Storage in Chronic Inflammation—Role of Insulin	158
15.3	Insulin Resistance in Aging	159
	References	161
16	Decreasing Libido, Lower Fertility	163
16.1	Sex and Chronic Inflammation	164
16.2	Of Antechinus, Sea Elephants, and Macaques	165
16.3	Estrogens and Chronic Inflammation	166
16.4	Hormones in Old Age	167
	References	168
17	Sympathetic Nervous System Fires and Causes High Blood Pressure	169
17.1	Cortisol and Inflammation	170
17.2	Cooperation of Stress Hormones and Consequence in Chronic Inflammation	171
17.3	Sympathetic Nervous System and Aging	173
17.4	Low Activity of the Parasympathetic Nervous System	173
	References	175
18	Increased Blood Clotting—Thrombosis/Embolism	177
18.1	Coagulation Explained: Lampreys, Sea Squirts, Fugu, and Humans	178
18.2	Coagulation and Inflammation	180
18.3	Increased Coagulation in Chronic Inflammation	181
18.4	Acceleration of Coagulation in Old Age	182
	References	182
19	Stress Worsens Inflammation, and Inflammation Alters Stress Tolerance	185
19.1	Stress and Factor X Constitute a Double Hit	186
19.2	Anti-Stress Therapies	187

19.3	Stress in the Elderly	188
	References	190

IV The Big Summary

20	The Synthesis	195
20.1	Addition of Energy Forms and Unwanted Energy Expenditure.	196
20.2	What are Telomeres?	198
20.3	Inflammation, Cell Turnover and Telomere Length	199
20.4	Chronic Inflammation and Telomere Length	199
20.5	Pain, Stress and Telomere Length	200
20.6	Anxiety, Smoking, and Telomere Length	201
20.7	Conclusion	202
	References	202

Supplementary Information

Appendix	206
-----------------------	-----

List of Figures

Fig. 1.1	Examples of forms of energy in an isolated system	8
Fig. 1.2	Structure of a dextrose molecule (called glucose)	10
Fig. 1.3	Breakdown of the main energy-rich substrates in food within a cell	11
Fig. 1.4	Comparison of energy expenditures per day in healthy humans at various activities (4,1868 kJ = 1 kcal)	13
Fig. 1.5	Energy stores in the human body.	20
Fig. 1.6	Messenger substances in the human body—short and long-distance effects	22
Fig. 1.7	Significance of the vagus nerve and insulin for body weight.	23
Fig. 1.8	Regulation of energy storage in the human body	25
Fig. 1.9	Regulation of energy release in the human body.	30
Fig. 2.1	Systematics in the animal kingdom with a special focus on the species “Homo sapiens”	38
Fig. 2.2	Distribution of milk tolerance around the world	43
Fig. 3.1	The two realms of acute energy provision (upper half) in contrast to the long-term program of energy storage (lower half)	53
Fig. 3.2	a, b Spatial structure of tetanus toxin (a foreign antigen) and insulin (b autoantigen)	57
Fig. 4.1	a, b Typical changes in severe joint inflammation named rheumatoid arthritis. a Joint deformation. b Redness and swelling as well as nodules along the extensor tendons of muscles that move the fingers (rheumatoid nodules)	65
Fig. 4.2	Serum levels of Interleukin-6 in different states	67
Fig. 4.3	Increase in Interleukin-6 levels increases energy expenditure per day.	68
Fig. 4.4	Correlation between the blood levels of C-reactive protein and the energy expenditure per day in patients with rheumatoid arthritis.	71
Fig. 5.1	Pain receptor at the end of a pain nerve fiber	74
Fig. 5.2	Representation of the various body areas in the cerebral cortex	77
Fig. 8.1	Energy expenditure under various conditions.	100
Fig. 8.2	Energy expenditure during the aging process. (Data from Speakman and Westerterp 2010)	102
Fig. 8.3	Energy expenditure during the aging process with simultaneous additional unwanted energy expenditure.	105
Fig. 9.1	a, b Energy saving through sleep. a Total energy expenditure, b Glucose consumption by the brain. (Data from Ravussin et al. 1986; Boyle et al. 1994)	113
Fig. 10.1	a–c Circadian rhythm of joint stiffness, pain, and physical dysfunctions in rheumatoid arthritis. (Data from Straub and Cutolo 2007)	119
Fig. 10.2	Circadian rhythm of Interleukin-6 in patients with rheumatoid arthritis and healthy normal individuals. (Data from Straub and Cutolo 2007)	121
Fig. 10.3	Circadian rhythm of cortisol and adrenaline/noradrenaline.	122
Fig. 10.4	Increasing sleep problems in old age. (Data from Roberts et al. 2000)	123
Fig. 12.1	Causes of muscle loss.	134
Fig. 13.1	Causes of inflammation-related bone loss.	140

Fig. 14.1	Percentage of people over the age of 15 with obesity. (Data from the Organisation for Economic Co-operation and Development—OECD 2014)	146
Fig. 14.2	Vicious cycle of weight gain.	152
Fig. 15.1	Factors that can lead to insulin resistance and hyperinsulinemia	161
Fig. 16.1	Influence of the inflammation factor interleukin-6 on the serum levels of testosterone. (Data from Tsigos et al. 1999)	164
Fig. 18.1	Blood coagulation in the human body.	179
Fig. 19.1	Significance of Factor X in stress and inflammation.	188
Fig. 19.2	Double hit of mutual reinforcement of inflammation and psychological stress	189
Fig. 20.1	Optimal relationship between lifetime and well-being/health	197
Fig. 20.2	Telomere and Telomerase.	198

List of Tables

Table 1.1	Total energy expenditure in various situations and energy expenditure of organs and organ systems in a human during a day (180 cm and 85 kg)	16
Table 1.2	Energy storage and emaciation time in our ancestors, in modern humans, in the domestic pig, and in the chicken	19
Table 1.3	Regulation of energy storage and energy release in the human body	31
Table 2.1	Distance between humans and the last common ancestors of the mentioned species in years	41
Table 6.1	What is addition and what is synergism?	87
Table 14.1	Characteristics of chronically stressed individuals who gain or lose weight	149
Table 20.1	Unwanted energy expenditures as a percentage of total energy expenditure.	201

Energy, Evolution and Medicine

The book aims to provide a comprehensible explanation of typical problems associated with aging and chronic inflammation. These problems were mentioned in the preface, and fatigue is such a critical and central symptom that it made it into the title of the book. However, before we can reach the level of understanding these elements in Parts II and III of the book, we need to acquire the necessary tools in Part I.

► Chapter 1 begins with the physical consideration of energy. It describes the energy-rich substrates important to us humans (glucose, fatty acids, and proteins), the energy expenditure of the human body, and the body's own regulation of energy storage and energy release. It becomes clear that the brain and the immune system are the main consumers of energy. The 1st chapter of Part I is challenging, and perhaps one might need to read it twice, but it is the important platform for the rest of the book.

► Chapter 2 summarizes—starting from the two discoverers Darwin and Wallace—the contents of the modern theory of evolution and the significance of evolutionary biology for medicine. Evolutionary biological examples are presented that are relevant to today's human medicine. From the special roles of the brain and immune system, the energy egoism of these two organ systems is derived. And it becomes clear that the brain and the immune system dominate the energy regulation.

► Chapter 3 demonstrates the special roles of the brain and immune system and explains the memory function of both in the context of the energy question. It presents the competition between the two organ systems, but also the mutual immediate assistance in energy regulation.

Part I summarizes the mechanisms of energy regulation dominated by the brain and immune system.



Energy and Body

Contents

- 1.1 The Pfühlbach and the Dispute – 5
- 1.2 Of Reservoirs and Bicycle Dynamos – 6
- 1.3 Stories of Thermos Flasks – 7
- 1.4 What is Vital Force? – 7
- 1.5 The Human Body—An Open System – 9
- 1.6 CAEN (“Controllable Amount of Energy”) or How Much Energy Does the Body Need? – 12
- 1.7 The Big Three – 15
- 1.8 Why We Store Energy—Fever, Tour de France and Newborns – 15
- 1.9 How Much Energy Do We and Our Ancestor Australopithecus Store? – 18
- 1.10 Sweet Tooth—Brain, Muscles, and Immune System – 21
- 1.11 Food Search Prior to Energy Storage – 22
- 1.12 Neuronal Factors and Hormones of Energy Storage – 23
- 1.13 A Little Lesson on Stress Hormones – 26
- 1.14 A Brief Lesson on Immune Messengers – 27

1.15 Stress Hormones and Cytokines Release Energy – 27

1.16 A New Look at the CAEN (“Controllable Amount
of Energy”) – 31

References – 33

1.1 The Pfühlbach and the Dispute

The ten-year-old son of a pharmacist, Robert, played at the Pfühlbach, a small river near Heilbronn that flows into the river Neckar. He passionately built simple water mills, dreaming of inventing a *perpetual motion machine*. A perpetual motion machine is a utopian machine that performs work indefinitely without an energy supply. It would have been something if Robert had invented such a machine. He conducted many experiments, only to have to admit with a heavy heart that a *perpetual motion machine* could not be built. These experiments never left Robert. Many mill wheels ran hot and left a lasting memory in him: “Mechanical work and the associated heat cannot be created out of nothing.”

The interest of Julius Robert Mayer (1814–1877) did not come out of nowhere, as his father instilled in him a love for science. Mayer Senior filled the house to the brim with various chemical and physical instruments, botanical and mineralogical collections, medicinal plants, and many books. Robert often accompanied his father on excursions, and gradually began to conduct chemical and physical experiments on his own.

Nevertheless, Robert Mayer did not choose a natural science subject, but instead studied medicine, which he completed in March 1839. After a one-year adventure as a ship’s doctor aboard the *Java* in the East Indian Ocean, Mayer began to ponder important questions of physics from 1840 onwards. Analogous to the indestructibility of matter, he was fascinated by the topic of the indestructibility of physical forces, and he summarized these considerations in a first publication in June 1841 at the age of 27. Indestructibility meant for him that a force (cause) produces an effect (result), so that this effect generates a new force that produces a next effect, and so on. Everything should be traceable back to a primal force. Energy or work in the modern physical sense was not yet spoken of at that time.

This first attempt at publication in the *Annalen der Physik und Chemie*, the most important German publication organ in the natural sciences of his time, was unsuccessful, as the editor Johann Christian Poggendorf never responded despite receiving three letters from Mayer. The following year, Mayer published the slightly modified text in the *Annalen der Chemie* under the editorship of Justus Liebig. In principle, this early work already discusses energy conservation and energy transfer—for example, from mechanical processes to heat.

Through elegant analogies and thought experiments, Mayer succeeded in establishing a correct relationship between the mechanical work of lifting a weight and the work of heating a quantity of gas. He calculated that a 1 gram body would have to be lifted and dropped 367 meters (mechanical work) to heat one cubic centimeter of air from an initial temperature of 0 degrees Celsius to 1 degree. Work and heat were thus closely related, and he had correctly recognized this. He himself always referred to this relationship as “the mechanical equivalent of heat.” One can easily imagine how complicated wooden constructions of mill wheels in the Pfühlbach slowly heated up or even smoked. This must have deeply imprinted itself on him.

Mayer himself never used the terms work or energy, which were only later introduced by other physicists such as Rudolf Clausius, James Joule, William Thomson (Lord Kelvin), William Rankine, and others. Nevertheless, he succeeded in describing the principle of energy conservation and “the mechanical equivalent of heat” for the first time. From 1848, he argued with James Joule for several years over the