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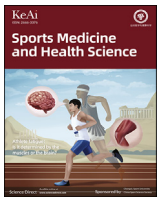

Review

Why Pheidippides could not believe in the 'Central Governor Model': Popper's philosophy applied to choose between two exercise physiology theories

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ABSTRACT

An important epistemological problem has been faced by Exercise Physiologists. On one hand, one theory explains the fatigue through a ceiling effect of oxygen uptake. On the other hand, the new theory proposes that an encephalon mechanism would stop the effort before a catastrophic homeostasis failure. Many physiologists have looked for evidence to support their favourite theory even though the induction logic problem does not allow to prove whether truth is discovered; however, it is possible to prove that it does not occur. When some researchers fail to test their hypotheses, they use relativism to bring up their theories again. Noakes and his colleagues have based their theory on relativism, because it is impossible to refute by empirical observation. It also doesn't explain all phenomena that the oldest Hill's theory is able to explain. Noakes's theory isn't more accurate in its previsions. Noakes did not check whether the oxygen uptake plateau occurs in suitable tests to measure on the mouth what happens in the muscles. Finally, it doesn't propose new tests for the encephalon role during maximal effort, as that is expected in scientific work. For all of these reasons, it is possible to conclude there are no advantages in switching to the "Central Governor" theory.

Historical context for the epistemological problem

An intense and endless epistemological debate has been occurring in the Exercise Physiology academic field. This debate started in 1996, when Professor Timothy D. Noakes gave his controversial lecture at the Annual Meeting of American College of Sports Medicine. His presentation was given at the Joseph B. Wolfe Memorial Lecture, which is an honorific session of this meeting.[1] But the answer to Noakes' ideas came soon when Bassett and Howley in 1997 with their answer paper concluded that:

> "[…] Noakes' views are not supported by strong scientific evidence, and they raise numerous paradoxes and unresolved dilemmas".[2]

Furthermore, Noakes' polemical lecture was published 2 years later in the Medicine and Science in Sports and Exercise journal, which has a strong impact on Exercise Physiology. Also, at the end of the last century, Professor Noakes published his theory in the Scandinavian Journal of Medicine and Science in Sports.[3] Therefore, Prof. Noakes could vastly spread his ideas throughout coaches and other sports professionals.

Noakes' theory was also refused by many eminent exercise physiologists, such as Elin Ekblom Bak, Per-Olof Astrand, David R. Bassett, Edward T. Howley, and Roy Shephard.[4–6] However, at that time, many people already believed in Noakes' ideas, in particular after Pires had published his paper in 2013. In this last paper, Pires uttered that the choice against Noakes ideas could be explained through Thomas Kuhn's structure of scientific revolutions (note 1). In this way, this argument turned from Exercise Physiology to Philosophy of Science.[7]

In 2017, Professor Robert A. Robergs answered Pires' paper by applying Popper's Science demarcation criterion which classifies Noakes' theory as a pseudoscience.[8] In his paper, professor Robergs could show that Noakes had proposed several *ad hoc* hypotheses which changed the definition of the Central Governor Model (CGM) many times since its first publication in 1998. Thus, Noakes' theory is a pseudoscience because it is not a refutable hypothesis.[9] Of course Pires and Noakes answered Robergs through Kuhn's relativism.[10–12] On the other hand, Pompeu, in a short paper published as Editorial of BMJ Open Sports and Exercise Medicine in 2018,[13] pointed out some philosophical problems in both Pires' and Robergs' papers.[7,8] Not only because Robergs mixed up Kuhn's and Popper's vocabularies, but also because Pires proposed to apply Kuhn's sceptical philosophy, which could not solve this problem.

In this way, this author's paper intends to go deeper into Popper's doctrine (note 2) to confront the old and the new Exercise Physiology theories. In addition, as a secondary goal, it will be discussed why it is not

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List of abbreviations

α	Statistical significance level
ad hoc	for further verification
ES	Statistical Effect of Size
CGM	Central Governor Model, which is Noakes' theory about the brain integration to stop the effort and avoid a Catastrophic Homeostasis Damage
CNS	Central Nervous System
CtF	The theory part which is false
CtV	The theory part which is true
NIRS	Near to Infra-red Spectroscopy is the exam which measures the absorption of the light near to infra-red wave band length
PO_2	Oxygen Partial Pressure in mmHg
r^2	Statistical determination coefficient
$\dot{V}O_2$ plateau	Oxygen uptake levelling off near the maximum workload during a progressive effort test
$\dot{V}O_{2max}$	Maximal oxygen uptake measured in L/min or mL/kg/min
VS	The theory content which appears like the truth

a good idea to employ Kuhn's doctrine [note 3] to solve this problem.

Criterion of science demarcation

The border between science and metaphysics, according to Sir Karl Popper, is in the possibility of the hypothesis' refutation through empirical tests.[14] The most important thing is not the process of building theories, but the process of testing these theories in rigorous experiments. The idea of positive science, through which the scientist tries to 'prove' his/her hypothesis, is a naive conception.[9]

On the other hand, in Thomas Kuhn's relativism, if the ultimate truth is not possible to be reached, then science should be made of a net of agreements and conceptual assumptions, which scientists share, considering a specific time and place [note 1].[12]

Conceptions, as those above described, have deep consequences in several aspects of human life.[15] Inasmuch as liberal ideas, or the belief in fundamental human rights, free society, egalitarian justice, and law rule will not survive with a sceptical conviction about objective facts. Thus, this optimistic epistemological view, which means believing in objective truth, creates a strong link among Science, liberal ideas, and civil rights [note 3].[16–18]

Moreover, when people believe in epistemological optimism, they also believe that the truth does not need to be explained since it is an evident reality. Therein, the truth always shows itself. If the truth cannot be seen, then it was hidden by someone, because of human evil and/or private interests. Thus, if we are feeling very sure about the evident truth, then this can lead us to a conspiracy theory. This feeling can predispose us to fanaticism and intolerance, even if this epistemological view made the human being think freely, and made him/her become free from political masters and mystical guides.[19] Also, this world view causes the non-conformism, a belief in human dignity, and mutual responsibility among the individuals in their society [note 4].[20] Unfortunately, nowadays, different branches of a pessimistic view about the truth are spread by relativism and other philosophies [note 5]. Sceptical beliefs are grounded on the perception that it is possible to save a theory with the addition of *ad hoc* hypotheses.[21]

It is believed that the above problem would be avoided if scientists were free from their tendencies during the data analyses and/or result interpretations. On one hand, Francis Bacon recommended avoiding bias by using the senses (*empiricism*). On the other hand, René Descartes believed that bias can only be avoided by rationality (*rationalism*).[19] Both philosophers hoped that scientists put aside their prejudice and metaphysical ideas to conduct their analyses, but unfortunately this is not possible. Each one of our interpretations is mingled with our life experiences, beliefs, prejudice, and other idiosyncrasies, even though we strongly want to avoid it. In Popper's words:[22]

> "[…] the process of obtaining knowledge, of grasping the world, the mind is, so to speak, actively digesting all that material which enters it by senses. […] it impresses on it its own intrinsic forms or laws - the forms or laws of our thought." (p. 437).

Moreover, the philosophical tendency is necessary in the background to interpret the world or to propose theories. These tendencies could be Determinism, Irrationalism, Idealism, Voluntarism, and Nihilism.[23] All these tendencies are metaphysical ideas and, consequently, no refutable or testable beliefs. Even though we can refute scientific theories through logical analysis and experimental observations, these theories have lots of metaphysical ideas. These metaphysical assumptions link one scientific postulate to another. Therefore, the scientific theoretical gaps inside the theories cannot be refuted. Another problem is about the big number of metaphysical concepts inside the language which is used to express these theories.[19]

A conclusion could be that the evident truth must be seen as a regulatory goal. In this conception, truth is something that we can bring closer and closer, but that will never be completely achieved. It makes intellectual modesty necessary, which compels us to fight against intolerance. Otherwise, fanaticism will block the pluralism expression and conceal our mistakes.[24,25]

Science development is caused by the strain between empiricism and rationalism. Experiments compel scientists to refute or correct their theories. In this way, a new rationalisation is built-in consequence of a new way to understand the phenomenon.[21] These theories' partial corrections or total replacement are traditionally made by what Edgar Morin called 'closed rationalisation' [note 6].[26]

Pluralism is necessary for knowledge to be still in progress. Thus, scientists need to protect the digression, to stimulate how to think in a different way. However, students have not been receiving encouragement for being pensive or critical. In the end, the students believe in their master's theories just like sect members believe in their religious dogmas.[19]

The scientific theories

As we can see in the section above, theories are conjectures which are proposed by someone to explain a phenomenon or reality.[note 7] A theory can be refuted by a logical analysis of its premises and/or by empirical observations.[9] A scientific theory can be characterised through its precise prediction of a future observation. Therefore, this theory must be universal and refutable. This means that scientific theory must completely comprise the whole phenomenon, and it can be also rejected because of mistakes in its previsions. Therefore, the demarcation criterion between science and pseudoscience is that a scientific theory can be refuted by observations[note 8].[27] However, there are non-scientific theoretical systems that can be successfully applied to the real world. That means these non-scientific theoretical systems cannot be refuted by experimentation, such as psychoanalysis.[21]

In order to continue knowledge progress, an old scientific theory should be totally replaced by a better one, or this old theory should be improved by correcting its wrong parts. In a scientific revolution, an old theory is completely replaced by another one with more precise previsions and/or more information.[24] It is important to take into account that a scientific theory should explain a phenomenon by its causes. It happens when the scientist deduces a descriptive statement from one or more universal laws of nature.[28] For example, it is possible to theorise that:

> It is necessary to increase the oxygen uptake rate, to run long and middle distances, in consequence of the aerobic metabolism rate increase. (Universal Statement)
>
> My oxygen uptake rate increased from 0.250 L/min, at rest level, to 4.05 L/min while I was running the distance of 1,600 m. (Specific Statement)

The experiment result, or the specific statement, shows the prevision and describes the effect. In the above statement, the effect is to increase the oxygen uptake rate, which is caused by running 1,600 m, which increased the cellular respiratory rate. Therefore, it is possible to deduce previsions through the principle of causality. But there is always one cause for another cause, and it produces an *ad infinitum* regression.[19] Thus, on one hand, when the hypothesis is a description of the real world, its final cause is in metaphysics. On the other hand, when the statement is a logical analysis, it is a tautological assertion.[25,29] In addition, a scientist can only see a preceding and a consequent phenomenon, that is one event happening before the other. So, the link between cause and effect is only an abstraction.[25]

Scientists should methodologically guide their work to find a universal law through a coherent theoretical system. It means that scientists should look for a numerically universal statement because it can be changed into a finite number of singular statements. Every reference in space and time involves an individual, or specific concept [note 9].[25,30]

A universal statement can be existential (as "there is") and negation ("there is not"). This kind of statement cannot be demonstrated to be true, and it can only be rejected if a space and time region has been limited.[30] An example of an existential statement can be:

The highest maximum oxygen uptake, which is possible to measure in a human being, is 4.0 L/min.

When an existential statement is circumscribed in space and time, it could be called a "pure" or "strict" statement. If we demonstrate the existence of something contrasting the universal statement, then we can only show the falsehood through a strict statement, for instance:[30]

In my laboratory, now, there is a rower who reached 6.15 L/min of maximum oxygen uptake.

Furthermore, it is important to emphasise that science is inductive reasoning. Therefore, this reasoning goes from a specific truth to a universal truth. In this way, a researcher observes a phenomenon 1, 2, 3 …, 100 … 1,000 … times and pronounces his/her hypothesis as a natural law. But only 1 contrary example will be sufficient to refute this theory. This is known as "problem of induction". The solution for this problem is to replace truth with probability.[21] Nowadays, scientists utter the above hypothesis as follows:

The highest human being's $\dot{V}O_{2max}$ is 4.0 L/min with significance level of $\alpha \leq 0.05$.

The rules of logical reasoning show a valid way of making an inference. When someone gets premises from the facts or the statements, he/she can be led to the conclusion. If the conclusion is corroborated by observation, then it is believed to be true. Therefore, the premises are also true, because it is not possible, in a valid logical inference, for a true conclusion to come from false premises. The observations which are contrary to the conclusion show that these premises are not true, or that these hypotheses are false.[21]

An example of a mistake in using logical rules, or fallacy, in this theoretical discussion, can be what Noakes proposes about why to refute the oxygen uptake plateau. The author believes that $\dot{V}O_2$ plateau must be a consequence of the cardiac output plateau. Thus, it would cause a myocardium's ischaemia.[1] This is not a valid inference because several phenomena are not considered in that hypothesis to link the premise to the conclusion, such as: differences between skeletal and cardiac muscles in size, number, and elasticity of their blood vessels; differences in oxygen diffusion gradient; differences in the mitochondrial density; in chronotropic and inotropic adjustments in response to the cardiac muscle fibre metabolic rate, and others. In other words, the premise cannot be directly linked to the conclusion. Therefore, this mistake is caused by an inductive jump and it makes the premise not true because the conclusion is also not true.

Any new concept could be added to a scientific theory, or it could replace a wrong concept of this theory.[30] Also, this theory must be an axiomatic system. It means that this theory must start from a premise that is accepted as an immediate truth. Moreover, these axioms must not show contradictions among them. These axioms must be independent one from another, that is, 1 axiom cannot be a consequence of another. Also, these axioms must not drive us to superfluous presumptions.[30]

It is possible to demonstrate the falsehood of the whole theory, or of only one of its parts. It depends on which level the axiom is refuted by experiments.[31] But it is not possible to know if this axiomatic system is an empirical or a conventionalist one. The last system is characterised by the addition of a new *ad hoc* hypothesis to save the whole theoretical system, as it is done in astrological previsions. This *ad hoc* hypothesis reduces the scientist's ability to refute his/her theoretical system by empirical experiments.[32] Therefore, the complete theory must be presented from the first moment by its author. This strategy would avoid an individual bias when the scientist tries to save his/her own theory by adding an *ad hoc* hypothesis.[21] Moreover, only axioms after the basic statement can be corrected without overthrowing the whole theory.

If someone wants to propose a new theoretical system, then he/she must ask whether his/her new system will promote scientific knowledge progress. Only the logical analysis of experimental results cannot solve this doubt.[33] The contrast among theory's basic statements could be more useful. Thus, an empirical theory can be demonstrated to be false without ambiguity. Therefore, an empirical system must refute at least one universal event or basic statement.[34] In this way, it is necessary to know all of the basic statements which are incompatible with this theory. Also, it can be useful to raise the basic statements which are compatible with this theory in order to, know the evidence supporting the theory.[23] Many researchers, when they cannot corroborate their theories, excuse their failure by using the relativistic, irrational, and sceptical argument.[35] As we can see in Pires' text below about the Central Governor Theory.[7]

> '[…] What may prove to be a scientific revolution began as a natural consequence of accumulated anomalous findings. In the presence of these inconvenient findings, new ideas created the 'crises' that promoted a scientific revolution in exercise sciences – what Kuhn referred to as a paradigm shift. The CGM (Central Governor Model) may have boosted an increased acceptance of a new interpretation, a centrally regulated effort model, to understand the exercise limits. […]' (p. 722).

The concept of truth might be misunderstood when we believe that to be aware of a fact is the same as knowing the truth. For instance, it would be possible to believe that the truth is everything that we can measure and weigh. Thus, it is a pragmatic view of reality. In this case, we are misunderstanding the concepts of usefulness and truth. Another example would be when the truth is believed to be the same as the consensus among scientists. In this case, the concepts of certainty and truth are being mixed up.[19] Truth can also be accepted by criteria such as: its sources, frequency of success, and even incapacity to think in another way. In general, these ideas about the truth are subjective and rely on the beliefs, or other characteristics, of each person. But an important clue to approach the truth is to look for coherence and consistency. Even though these are actually not criteria for the truth, their absence is a criterion for the falsehood.[36]

This way, scientists should not accept partial and/or individual "truths". But they could understand truth like Bertrand Russell, who defined this concept as:[25]

> "Truth consists in a certain relation between a belief and one or more facts other than the belief. When this relation is absent, the belief is false." (p. 135).

Therefore, a theory must be similar to the truth. This theory's verisimilitude (VS) is given by the theory's part which contains the truth (CtV) and its part which contains the falsehood (CtF). Thus, the quality of a theory can be found by the formula: [VS = CtV - CtF]. In this way, a scientist could improve the quality of his/her theory by increasing the truth content, decreasing the falsehood content, or both.[36] Nowadays, scientists employ probability, or statistical analysis, instead of true information to improve their theories. Therefore, the statistical analysis combines the truth with no information.[27]

Scientists need to create theories similar to the truth (or reality) because these theories teach them to observe a phenomenon and raise pertinent questions. In this way, scientists make experiments to answer these specific questions. Moreover, these theories are built with coherent and consistent statements which describe past observations. Based on this construction, a scientist may make predictions about a new future observation, which is also coherent and compatible with this theory, despite the fact that only the multiple occurrences of a phenomenon in the past does not justify that it will occur again in the future.[21]

Scientists have normally tried to propose a theory with the highest level of probability, instead of the highest verisimilitude.[27] A good corroboration of their hypothesis is the same as a high statistical probability. But they should consider that each one of a theory's statements can be true or false. Therefore, the whole likelihood of a theory is equal to the arithmetic multiplication of every statement probability. It is easy to see that a long theory has a very low probability to occur in a random way.[27]

The scientific revolution of the 'Central Governor Model'

In the exercise physiology field, a debate has occurred about oxygen supply and demand during the maximal effort. The most complete theory was proposed by A.V. Hill from 1921 to 1924.[37–40] This is a construction that has been modified and improved since then.[4,5] The basic idea of Hill's theory is that when the body cannot intake and carry oxygen to supply the muscle metabolic rates, the energetic metabolism is complemented by lactic acid production. Hill called this phenomenon 'oxygen deficit'. Important evidence of corroborating the oxygen deficit is the oxygen uptake plateau during the maximal effort. In this case, even though a person can support a higher workload, because of the anaerobic metabolism, the oxygen uptake cannot be increased.[39,40]

On the other hand, Noakes pointed to a logical conflict in Hill's theory, such as:[1]

(1) The $\dot{V}O_2$ plateau occurrence means that the anaerobic metabolism is happening, while its absence means adequate muscle oxygenation.
(2) Perceiving that $\dot{V}O_2$ plateau does not always occur during the maximal effort,
(3) Either anaerobic metabolism does not restrict the maximal effort in all subjects, or this anaerobic metabolism every time limits the maximal effort, with or without $\dot{V}O_2$ plateau.

Therein, Noakes suggested the 'Central Governor' hypothesis (CGM). It means that the encephalon stops the maximal effort after it has integrated several somatic information, to avoid a 'homeostasis catastrophic damage'.[3]

The question is: Which theory is better? Before answering this question, we need to settle a potential criterion for knowledge progress. For instance, the better theory could be that one with more information. If a scientist is deeply going into this criterion for knowledge progress, he/she should choose the theory with more empirical data.[32]

It is possible to notice, in one of Noakes' first papers, that he had not shown empirical data to test or support the CGM.[1] Instead of this, Noakes chose to make a new interpretation of other authors' experiments.[1,3] It has already been discussed earlier that the researcher should propose a hypothesis that has at least one refutable universal statement. Afterwards, this hypothesis must be tested in an experiment especially designed to show that it is false. Using only the literature about early experiments, that were proposed for other goals, and making a new analysis is not enough. Professor Noakes should have raised observations which are not compatible with CGM and tested them.[41]

Moreover, in 2012, Noakes raised the hypothesis that fatigue is an emotion that was created by the brain to protect against damages to homeostasis.[42] In this paper Noakes tried to raise evidence to support his Central Governor hypothesis. He believed that the brain gets hold of the effort through feedback and feedforward neuro drives. He also could not describe clearly the causative mechanical phenomenon which was integrated by the encephalon from sensory and motor drives. He listed many stimuli, such as: nutrition state, sleep deprivation, drug intake, neurotransmitters, immune endocrine signals, and many others in disorganised and disconnected ways to explain his theory. He cannot explain the relative importance of each one of these variables; when they will be working and which kind of effort will be controlled by them.[42]

On the other hand, Hill's former theory has been lasting for 90 years of accumulated evidence of experiments, which have been conducted by independent researchers. Moreover, Hill's theory has empirical information about phenomena, which go from the muscle fibre metabolism to the circulatory and respiratory systems, because the brain is still very difficult to access.[4]

Another criterion that could be applied to choose which theory is better is to prefer that one with more interesting or venturing issues.[36] The conjecture that the brain could stop an effort to protect the body from a breakdown, or a 'catastrophic damage', already exists. In 1923, Hill & Lupton suggested that the Central Nervous System (CNS) might have an important role in setting the effort interruption. They wrote:[38]

> "Different individuals, even those apparently of similar muscular development, differ enormously from one another in the vigour and duration of their maximum efforts. […] The withdrawal of protective nervous inhibitions, the mental and moral factors ('guts'), which make one individual inevitably a better man than another, are clearly of importance: the excitability of the respiratory centre, and of the nervous system as a whole, the size and capacity of lungs and heart, the fitness of various organs to stand the strain of violent effort, have all clearly to be taken into account. […]" (p.145).

So, we can expect that human beings can resist their biological determinants. As in Pheidippides' story, when the 'Central Governor' did not avoid the 'catastrophic damage'. This story tells that Pheidippides died after he ran a very long distance to deliver the message that the Greeks had won the battle against the Persian troops in Marathon.

Noakes has raised the below list of evidence to refute Hill's theory:[1,3,43]

- There is a failure in Hill's theory because only fifty percent of all subjects shows the oxygen uptake plateau during the maximal effort. Noakes has criticised Taylor et al.'s ergometric protocol,[44] since they showed $\dot{V}O_2$ plateau in almost all of their subjects. Noakes believes that the treadmill workload, which increments through the inclination degree, rather than the velocity, had produced a mistake. According to him, this protocol had changed the normal motor pattern, while a subject was running on the field, then it caused the $\dot{V}O_2$ plateau. But this is a fallacious argument, because the researcher should test the $\dot{V}O_2$ plateau phenomenon, instead of testing whether the motor pattern changes while a subject is running on the field or on the treadmill.
- Noakes studied an opioid drug which is an inhibitor of the CNS and it can increase the perception of discomfort during an effort. Therefore, this drug could cause a premature effort interruption. Even though this evidence might be true, it does not refute Hill's theory. The prime

cause of $\dot{V}O_2$ plateau, in physiological conditions, is still the ceiling effect of the oxygen uptake.

- Noakes concluded that the failure of skeletal muscle oxygenation is not a clear cause of effort interruption. He reached this conclusion because of the 'unquestionable' fact that the muscle cells do not enter anaerobic state. He pointed to the average of oxygen partial pressure (PO_2) inside the muscles as an evidence, which stays above the critical PO_2 inside the mitochondria. The problem is that the average explains very little about a phenomenon without considering its variance size. There is a large variation of these results caused by technological problems in transferring these conclusions from *in vitro,* or *in situ,* to *in vivo* studies, such as: muscle histology, biopsy depth, sample representation for the whole muscle group involved in a specific effort, and a very high oxygen diffusion resistance. Thus, it is not an unquestionable conclusion.
- Another argument in favor of CGM is about encephalon oxygenation during effort. Noakes based his analysis on the Near to Infrared Spectroscopy (NIRS) exam. He pointed out the study in which fifteen runners from the Kalenjin tribe in Kenya, with 28.7 ± 0.4 min of performance in the 10 km race, were submitted to an exhaustive test.[44] These athletes repeatedly ran 1 km bouts on a treadmill with 105% of their best velocity on the 5 km race, with 1% of inclination, 30s-pause between each one of these bouts, until they could not maintain the effort anymore. These researchers collected data through the NIRS at the pre-frontal lobe, on the left side. The authors could see that the cerebral oxygenation was reduced along the bouts ($\alpha \leq 0.01$ and Effect of Size [ES] = 4.59), cerebral oxygenation *versus* velocity showed a negative correlation ($\alpha \leq 0.017$, $r^2 = -0.37$) and there was a reduction difference between athletes who ran 5 or less bouts and those who ran more than 6 bouts (56.0% ± 20.5% *versus* 48.4% ± 20.9%, respectively and $ES = 0.36$). Even though this study did not have a control group and it did not consider the normally large variation of NIRS data, these authors concluded that there is a cerebral oxygenation threshold which can trigger the fatigue. The authors also did not offer an explanation why and how the left pre-frontal cortex could cause the fatigue. Moreover, even though this cerebral oxygen failure could have occurred, it does not refute Hill's theory. Noakes would need to link the cerebral oxygenation deficit with exhaustion when it happens with or without the $\dot{V}O_2$ plateau.
- The lactate paradox has also been employed by Noakes to refute Hill's theory. This paradox states that the blood lactate concentration reduces, in not acclimated subjects, after few days in high altitude environment. It is known that lactate production can occur when epinephrine stimulates the glycogen phosphorylase enzyme, which makes extra-mitochondrial metabolism faster than intra-mitochondrial metabolism.[45] Thereafter, this process produces lactate because of the law of mass action. But it is also true that lactate is produced when an effort is made where blood circulation is blocked; or during iso-volumetric anaemic conditions; or while someone is breathing a mixture with carbon monoxide gas (to produce carboxyhemoglobin); and other handlings to decrease the oxygen delivery.[46,47] Therefore, the lactate paradox does not refute Hill's theory. This phenomenon does not exclude the possibility that the lactate could have been produced by anaerobic metabolism during VO_2 plateau.
- Also, Noakes studied the phenomenon of the decrease in activity of the electromyography, while a subject was making an effort in high altitude. This result was interpreted by Noakes as an evidence of CNS lower activity. However, this evidence might be truly explained both as a central or as a peripheral fatigue, although the central fatigue could not be showed by electromyography.

Based on this list, it seems as if Noakes has been trying to prove his theory by disproving Hill's theory. It is a kind of negative *modus ponens* inference. An analogy for this could be:

(1) If it is snowing, the road is slippery.
(2) It is not snowing.
(3) ∴ The road is not slippery.

Or.

(1) If Hill's theory is correct, the CGM is wrong.
(2) Hill's theory is not correct.
(3) ∴ The CGM is not wrong.

Modus ponens inference can only be valid in positive statements. It is easy to see that the road could be slippery without snow, for several other reasons.

Final considerations and conclusion

We can conclude which theory is the best one by answering the following questions:[36]

I) Has Noakes made more precise previsions through his theory than Hill had?

Answer: No! Noakes proposed the 'Central Governor' model through a new interpretation of data which already existed in the literature. Therefore, the precision cannot be better.

II) Does Noakes' theory take more facts into account than Hill's theory?

Answer: No! Hill's theory is a big construction which involves cellular, biological tissues, and organic systems phenomena. On the other hand, all of these structures are not considered by Noakes' theory.

III) Does Noakes' CGM explain a greater number of facts than Hill's theory?

Answer: No! Noakes raised only one fact, which is the Central Nervous System has a role in triggering the exhaustion. On the other hand, the current version of Hill's theory explains several facts from cell metabolism to organic systems.

IV) Does Noakes' theory resist to more facts which refute Hill's theory?

Answer: No! The oxygen uptake plateau was not tested by Noakes through suitable ergometric protocols. So, in order to measure the gas exchanges on the mouth that actually represent the cell's metabolism, a steady state effort, without previous workloads, with large muscle groups, and an effort with more than 2 min of duration is necessary.[48] Noakes had not showed the absence of oxygen uptake plateau under these conditions and that exhaustion could be explained by his CGM.

V) Has Noakes' theory proposed and resisted new tests that Hill had not considered in his theory?

Answer: No! Noakes did not show evidence that CGM had occurred during the exhaustion from the maximal effort, with or without the oxygen uptake plateau.

VI) Does Noakes' theory show problems which need to be isolated?

Answer: Yes! But there are not new tests to access the encephalon directly and efficiently during the maximal effort.

Therefore, it is possible to conclude that there are no advantages in changing from actual version of Hill's theory to the 'Central Governor' theory proposed by Noakes.

Notes

1. The assumptions which scientists agree to support are called paradigms by Kuhn, and the theories and experiment proposals are guided by these paradigms. In 'normal science' every datum and result is used to support the paradigm success. If a crisis happens, because of anomalous results, which cannot be explained by the paradigm, a 'scientific revolution' occurs. In this way, the old paradigm is replaced by a new one. Thomas Kuhn believed that it is not the observation or the logical analysis to determine the paradigm changes, but the consensus and negotiations among scientists. Therefore, in Kuhn's ideas every truth is relative.[12]
2. In Popper doctrine, "Every 'good' scientific theory is a prohibition: it forbids things to happen. The more a theory forbids, the better it is. Also, a theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory […] but a vice." (p.48).[14]
3. The epistemological pessimism, like Kuhn's relativism, drives us to believe that the objective truth is a myth that is impossible to reveal. (p.140).[15]
4. It is important to emphasise that epistemological optimism has been responsible for the greatest society developments since the Enlightenment period (p.7).[19]
5. Popper believed that Plato's cave allegory introduced pessimism in the epistemology. In this story, knowledge is only a shadow of the reality. It is easy to conclude that this analogy destroys the truth meaning (p.5).[24]
6. This is the concept that a non-mechanical universe does not exist. Therefore, it is impossible to have random phenomena and/or phenomena with issues that the human mind cannot understand. Also, the closed rationalisation drives us toward a homogenous thought. Therein, it becomes an instrument of power. Thus, it imposes on us only one way of understanding reality. This belief, like moralism, disrespects the human dignity and promotes the irruption of barbarism.[26]
7. Theories can be classified in logical and/or mathematical; empirical and/or scientific; and philosophical and/or metaphysical. (p.266).[23]
8. In this case, the trail and error method should be applied to show the contradictions between the theory and the reality part which is manifested when this theory is rejected (p.423).[49]
9. An individual concept is that one by definition needing a proper name, or other equivalent sign. If it is possible to eliminate the discussion about the proper name, then this is a universal concept. Therefore, a universal concept is the name of a set, and an individual or specific concept is the name of an element (p.69).[25]

Conflict of interest

Fernando A.M.S. Pompeu, don't have any potential sources of conflict of interest to disclose. I don't have any interest or relationship, financial or otherwise that might be perceived as influencing my objectivity, which might be considered a potential source of conflict of interest. There is not any directly relevant or directly related interest to the work that I describe in my manuscript. I know that the potential sources of conflict of interest include, but are not limited to: patent or stock ownership, membership of a company board of directors, membership of an advisory board or committee for a company, and consultancy for or receipt of speaker's fees from a company. I also know that the existence of a conflict of interest does not preclude publication. I have no conflict of interest to declare, I also state this at submission. I'm the only one author of the manuscript and I reviewed this policy. Sincerely.

Submission statement

This paper, which is entitled "Why Pheidippides could not believe in the 'Central Governor Model': Popper's Philosophy Applied to Choose between Two Exercise Physiology Theories", has not been published previously, it is not under consideration for publication elsewhere, its publication is approved by the author and by the responsible authorities from Rio de Janeiro Federal University, where the work was carried out, and, if it is accepted, it will not be published elsewhere including electronically in the same form, in English or any other language, without the written consent of the copyright-holder.

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