



Homeostasis and Health: From Balance to Change

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Abstract

All living systems need to regulate themselves and coordinate the activities of their parts to maintain themselves under changing conditions. Historically, homeostasis is one of the central ideas that have been employed to understand biological regulation. In this article we examine the application of the concept of homeostasis to medicine and its implications for understanding health. We argue that while using homeostasis to characterize health is in line with current criticisms of ideas of health as a complete state of well-being or absence of disease, such an endeavor has been hindered by the adoption of a narrow cybernetic interpretation of homeostasis based on feedback mechanisms and setpoints. This latter interpretation emphasizes stability and balance as the hallmarks of health: a stable physiological state that needs to be preserved or to which an organism needs to return after a perturbation, with change or imbalance as something to be counteracted. William Bechtel has contributed to criticizing this view and reframing the concept of homeostasis by focusing on the organism as a whole. By building on this work and looking at regulation beyond error correction as the organism's ability to modify its internal dynamics in response to varying conditions, we apply this interpretation of homeostasis to health by advocating for a change of perspective: from a notion of health based on stability and balance to one based on adaptive change. We propose an alternative perspective that emphasizes the capability for change as a new lens through which to understand health.

Keywords Adaptivity · Balance · Environment · Organism · Regulation · Versatility

Introduction

In this article we provide a critical analysis of the notion of homeostasis as it is applied in medicine and medical theory. We discuss the implications of different interpretations of homeostasis for accounts of health and, based on recent reframing of homeostasis, we advocate for a view of health as adaptive change.

The notion of homeostasis is generically understood as the capability of a system to resist perturbations by maintaining some of its variables stable within a narrow range

of values or, more generally, its internal conditions in a steady or viable state. The physiological importance of maintaining stable values for physiological variables—or, more precisely, maintaining conditions for the functioning of the tissues (Bechtel and Bich 2024)—was emphasized by Claude Bernard, one of the first biologists to study biological control systems. Bernard (1878) characterized physiological mechanisms as operating to maintain the constancy of what he termed the “internal environment” (*“milieu intérieur”*). Bernard did not describe the processes whereby such control was executed. This task was taken up by Cannon (1929, 1932), who introduced the term “homeostasis” to characterize the physiological processes through which organisms maintain some of their internal features within a range of viability. He paid specific attention to the maintenance of some of the features of the “fluid matrix of the body.” This matrix includes blood and lymph, and some of its features to be maintained are temperature, pressure, and concentrations of ions and molecules, and so on.

The notion of homeostasis was subsequently adopted and reframed by cybernetics (Rosenblueth et al. 1943;

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Wiener 1948; Ashby 1956). Cybernetics looked for a minimal abstract mechanism for the control of the values of variables in both organisms and machines. Specifically, it developed mathematical models of control based on negative feedback loops and applied them to describe phenomena from heterogeneous fields but that exhibit some common features (Bich 2024; see also Serban and Green 2020). Negative feedback was characterized as involving the comparison of the current value of a variable of interest against a setpoint. Mismatch between these two values was characterized as resulting in an error signal, which initiated corrective action. A paradigmatic example is the operation of a thermostat which controls the heating of a room based on measurement of the room temperature against a reference value (setpoint) established by a user. Cybernetics applied this model to biological homeostasis, described in terms of negative feedback. By doing so it associated biological regulation with compensation for perturbations that consists in returning to an initial or stable state defined by a setpoint. An important consequence of adopting this approach to characterize homeostasis is that in each case in which a system is observed as maintaining relatively constant states, one is supposed to look for a mechanism of negative feedback: a setpoint, a comparator/integrator/controller that compares current values to the setpoint, and effectors that are elicited when the value of the regulated variable departs from the setpoint.

The cybernetic model of homeostasis is now employed as a general concept that allows scientists to explain and unify a wide range of phenomena under a common description or formalism. And it has been very successful at doing so. During the 20th century the notion of homeostasis has been generalized to include all phenomena of the maintenance of stable variables or, more generally, regulatory phenomena. Its use is now widespread in all branches of physiology, in medicine, developmental biology, ecology, psychophysiology, engineering, architecture, and so on (Lovelock 1983; Berntson et al. 2016; Wang and Ma 2016; Rubenstein and Alcock 2019; Hagen 2021; O'Malley 2024).

Homeostasis is often invoked as “the central organizing principle upon which the discipline of physiology is built, the very concept we need to return to in order to integrate function from molecule to the intact organism” (Billman 2020, p. 2). In their textbook, Widmaier et al. (2016) claim that physiology as a discipline is centered on the coordinated function of homeostatic control mechanisms. Through human physiology, the notion of homeostasis has been widely applied in medicine (e.g., Huber et al. 2011; Brüsow 2013; Ayres 2020; Sterling 2020; O'Halloran 2025) and also in medical education (see, for example, Loscalzo et al. 2022), where both textbooks of medical physiology (Widmaier et al. 2016; Hall and Hall 2021) and research articles

discussing the medical curriculum (Modell et al. 2015; Michael et al. 2017) give the notion of homeostasis a central place. However, this operation exhibits two main issues: the first concerns the cybernetic characterization of homeostasis; the second the relationship to the notion of health.

The first problem is that starting with medical education, homeostasis is often adopted in its cybernetic characterization based on the notion of negative feedback involving a setpoint, which is considered as a standard for education purposes in physiology (Modell et al. 2015; Widmaier et al. 2016; Hall and Hall 2021; Libretti and Puckett 2023). See Bechtel and Bich 2025 for a discussion).¹ As such, it is applied in medicine to characterize health as a stable physiological state that needs to be preserved or to which an organism needs to return after a perturbation. This static interpretation has been left mostly unquestioned.

This leads to the second issue: the underlying assumptions and the implications of adopting the idea of homeostasis in medicine to understand the concept and the practice of health have not been sufficiently investigated. Extensive work on either concept has been carried out separately: physiology on homeostasis on one side (e.g., Carpenter 2004; Schulkin 2004; Ramsey and Woods 2014; Hagen 2021; Bechtel and Bich 2024, etc.), and medicine and philosophy of medicine on health on the other (Salomon et al. 2017; Murphy 2023).

In this article we aim to fill this gap by addressing specifically the relationship between homeostasis and health. We do so by adopting a different, non-cybernetic, perspective on homeostasis. This perspective is based on recent work by Bechtel and Bich (2024, 2025), which questions the identification of homeostasis with feedback mechanisms and reframes the notion in the context of the maintenance of the organism. From this standpoint, and in the light of recent history and current work on physiological control, we discuss and put into question the static conceptualization of health as stability, which derives from adopting the traditional cybernetic account of homeostasis in medicine. The limits and scope of the cybernetic interpretation of homeostasis have been discussed in physiology for decades. Several proposals have been stressing different dimensions of physiological control that implied more radical changes in physiological regimes than just stability and error correction (Hagen 2021). A recent example of this debate is the introduction of the notion of *allostasis*, according to which

¹ Modell et al. (2015, p. 261), for example, explain homeostasis in the following terms: “Such a system operates in a way that causes any change to the regulated variable, a disturbance, to be countered by a change in the effector output to restore the regulated variable toward its set point value. Systems that behave in this way are said to be negative feedback systems.” Libretti and Puckett (2023) in their textbook claim that “homeostasis would not be possible without setpoints, feedback, and regulation.”

viability is maintained by modifying the reference values of physiological variables (Sterling 2020). Philosophical work on regulatory control (Bich and Bechtel 2022a, 2022b) and adaptivity (Menatti et al. 2022) have also emphasized physiological control as a source of change. On this view, living organisms are not inherently stable but always need to modify their internal dynamics to remain viable under variable internal and external conditions, which depend on the time of the day, the season, the position in the life cycle of an organism, and so forth.

By looking at how biological systems respond successfully to perturbations, that is, mostly by changing themselves rather than attempting to go back to an initial or normal state, we advocate for a change of perspective on health itself: from an understanding of health based on stability to one focused on change. We propose an alternative perspective that emphasizes the importance of the capability for change as a new lens through which to understand health and disease.

We begin in the second section by analyzing how current literature has addressed the relationship between health and homeostasis in medicine and medical theory. We point out some of the virtues of applying homeostasis to medicine. We then discuss the limits and risks of doing so by adopting the narrow view of homeostasis as negative feedback. To overcome these limits, in section three we analyze the historical debate on the limits of the cybernetic interpretation of homeostasis to understand physiological control. We identify a trend in these criticisms, which emphasizes the importance of adopting a dynamic perspective focused on physiological change over the static one based on feedback and the return to a stable state. By embracing this perspective, in the fourth section we provide a dynamic account of physiological regulation in terms of change, and we apply it to advance an adaptive view of health. In the Conclusions we summarize this dynamic view and discuss some of its implications for a characterization of health.

Health as Homeostasis: Virtues and Limits

Homeostasis plays an important role in medicine, and more specifically in relation to health. This is due to the contribution of homeostatic mechanisms to the integrated functioning of organisms and to how organisms are regulated in such a way that they keep living. In medicine homeostasis is defined as: “1. The state of equilibrium (balance between opposing pressures) in the body with respect to various functions and to the chemical compositions of the fluid and tissues. 2. The processes through which such bodily equilibrium is maintained” (Stedman 2012, p. 792).

Homeostasis is employed to support an idea of health as a regime that needs to be maintained. Generally speaking, this idea of health includes two elements: (1) maintaining physiological functions despite perturbations or recovering them after a disease; and (2) coordinating and integrating different physiological functions or systems.

In medical physiology and immunology, Ayres (2020), for example, emphasizes that organisms exhibit a remarkable plasticity, and that maintaining health is an active process. She characterizes health as *vigor*, a property which is maintained over time by evolved homeostatic control mechanisms, that are constantly operating to control the plasticity of an organism. These homeostatic control mechanisms are described in general cybernetic terms:

These mechanisms participate in a dynamic equilibrium, requiring sensing of a continuously changing internal variable, and integration of this information into a control center that provides output information to mediate an effector response that responds appropriately to these changes to stay within the setpoint for a particular variable. (Ayres 2020, p. 254)

Ayres’s framework and the notion of vigor are introduced to counteract the classic accounts of health as a state of “well-being,” or “absence of disease,” criticized as passive or reactive states. These classic accounts convey the idea that “simply removing an insult or antagonizing a disease pathogenesis pathway is sufficient to promote health” (2020, p. 250). Moreover, she argues, defining health as a state of well-being is vague and, unlike homeostasis, difficult to describe mechanistically. On her view, instead, health is considered as a proactive process, which is constantly promoted and realized by an organism, not only restored by removing a source of disease.

This criticism of the mainstream concepts and definitions of health is common in public health. For instance, Huber et al. (2011) criticize the WHO definition of health as “a state of complete physical, mental and social well-being” (WHO 1948). They argue that it describes a static state, and that it minimizes the role of the individual and the capacity to engage with changing conditions. Moreover, a “complete state” is an idealization that is difficult to operationalize (see also Menatti et al. 2022). A replacement of the WHO 1948 definition is thus proposed in favor of a more dynamic one: “the ability to adapt and to self-manage” (Huber et al. 2011, p. 2). This definition is based on the idea that humans are capable of responding homeostatically to physiological, mental, and social stress by restoring a state of integrity or equilibrium, analogous to the capacity to “maintain a stable environment within a relatively stable state”, Huber et al. (2011, p. 3).

Similarly, physiologists and medical doctors define health as “the maintenance of physiological homeostasis through changing circumstances” (Brüssow 2013). Saad and Prochaska (2020) define it as a “maintainable-ease of functioning [...] while] “disease” is a state of prolonged-dysfunction that prevents ease.” Veen et al. (2020) advocate for a dynamic view of health that, they argue, can be conceived as the “ability to maintain homeostasis, i.e., the maintenance of specific variables within an optimal range, regardless of external stimuli.” Wang and Qin (2022) even talk about a “homeostatic medicine” aimed at studying how organisms maintain, or fail to maintain, stable states. Homeostatic equilibrium is considered as the prerequisite for health, while disrupted equilibrium (*dyshomeostasis*) characterizes disease.

In philosophy of medicine and philosophy of biology homeostasis is widely mentioned, mostly to refer to something that is maintained invariant or stable in living organisms. Less frequent are explicit discussions of the role of this concept in relation to accounts of health. Among these, Boorse (1977) criticizes the appeal to homeostasis to naturalize health. He sees homeostatic processes as important for normal or abnormal physiology but not to define health and disease. The reason is that homeostasis is considered insufficient to fully capture the broader idea of the normal functioning of the organism. Instead, he provides a statistical grounding of normal function within a population: the typical biological functioning of the majority of members in a reference class—which Boorse considers to be individuals of the same species, sex, and age—in a “normal” environment. An important implication of this view is that health would not be something dependent on the particular environment or situation encountered by individuals. The biologically normal functioning of an organism is specified with respect to a standardized environment (see Menatti et al. 2022 for a criticism).

As an alternative, in 1985 Bechtel proposed an account of health as homeostasis (Bechtel 1985). Health is conceptualized as the capacity to perform the functions of life. This capacity is understood in terms of homeostasis, which is what allows a system to survive and replicate in face of the fluctuations encountered in the environment. A healthy system is one that is maintained at or near its designed state, while deviations are disease states. To justify why any premium should be placed on maintaining homeostasis, Bechtel introduces teleological considerations: maintaining a system in a homeostatic state with its set of equilibrium points contributes to the survival and reproductive success of the organism in its environment. The resulting view of health is based on two elements: homeostasis as the maintenance of a dynamic regime, and teleology, which characterizes this regime as functional because it allows for the survival of the

organism. The teleological perspective grounds the normative dimension of this account. An implication of this view, in contrast with Boorse’s emphasis on standardized environments and in line with recent debates on the role of environment for health (Menatti et al. 2022), is that health is not just an intrinsic property of a system. It requires focusing both on the organism and on the environment to which a system adapts and to which it responds homeostatically.

Dussault and Gagné-Julien (2015) also directly employ the notion of homeostasis to characterize health. Contrasting Boorse’s view, they argue that homeostasis can ground a naturalization of health that does not recur to the statistics of a population and that accounts for situation-specificity. Similarly to Bechtel, they argue that health is linked to the ability to homeostatically maintain the (normal) functions of the organs and of the body of an organism so that it can survive. They adopt a cybernetic account of homeostasis based on negative feedback and setpoints. They argue that homeostatic accounts of health should include a reference to design: a set of functions characteristic of a class of organisms. Design allows for grounding the role of homeostasis for health. It is what specifies the conditions for the performance of functions (i.e., the situations in which homeostatic corrective processes operate) and the setpoints at which homeostatic responses are supposed to maintain the regulated variables. Based on these considerations, they advocate for a notion of health as homeostatic maintenance (or restoration) of design. Given that homeostasis is a process that depends on measuring variables and eliciting corrective actions, it can account for the situation-specificity of health.

All these accounts that deploy the idea of homeostasis to characterize health focus on the conditions that allow an organism to perform its functions and coordinate them. On our view, applying homeostasis to health has several virtues, among which are the possibility of looking for mechanisms that contribute to health, and the promotion of a dynamic view of health that takes into account how a healthy organism is capable of responding to challenges by mobilizing its internal resources. As we have shown, this idea is advanced in explicit contrast to static characterizations of health as an ideal state (complete well-being) or as absence of disease. Moreover, a homeostatic approach to health is valuable as it stresses the adaptive nature of health, by taking into consideration the environment as a set of changing conditions with which an organism needs to engage with (Bechtel 1985). By doing so, it can account for the situation-specificity of physiological functions (Dussault and Gagné-Julien 2015).

These approaches that connect health with homeostasis, however, exhibit some common limits which, we argue, depend on the fact that they share, with different degrees, a cybernetic perspective on homeostasis based on the notions of feedback and setpoint. This view implicitly conveys the

idea that health coincides with a state of equilibrium, stability or balance: an assumption that is left unquestioned in the debate.

While heuristically valuable for orienting research and studying specific cases and mechanisms (see, for example, Serban and Green 2020), the cybernetic model of negative feedback has often a limited scope of application, especially in the context of complex systems in which many overlapping mechanisms are at work. Problems arise when (1) such limitations are overlooked; (2) one (type of) mechanism is identified with a whole phenomenon such as homeostasis or regulation in general; and (3) generalizations are made from a model of how a specific individual mechanism may work to the conceptualization of the functioning (or malfunctioning) of a whole organism.

The cybernetic idea of homeostasis implies that feedback mechanisms of error correction maintain the values of physiological variables stable around setpoints. When these stable values are perturbed, feedback mechanisms detect the variation and elicit response mechanisms aimed at bringing the variables back to the reference value established by the setpoint. This view presupposes that the system is stable when unperturbed, and it becomes active only in reaction to perturbation, causing it to be brought back to the original stable state. Ideally, the most efficient way to do so would be to avoid any destabilization, by blocking perturbations even before they affect the system (Ashby 1956,1958).

Accounts of health and homeostasis based on the cybernetic interpretation differ depending on what is maintained stable: e.g., individual variables, a whole integrated set of them, or the general capacity to respond to perturbations by bringing the system back to normal. Normal states are characterized in terms of *stability*, *balance*, *equilibrium*, and so on. These terms assume that the desirable state for a healthy organism is a stable one. As change threatens stability, it should be counteracted by bringing a system back to its normal reference state, identified as a setpoint, after a perturbation. In this way health is maintained.

This view exhibits several issues that reflect the problems mentioned above. The first group of issues is specifically technical and concerns whether we can actually ascribe setpoints to living organisms and identify them. Whereas the cybernetic view tends to identify homeostatic regulation with negative feedback to a setpoint (problem 2 above), the presence and localization of setpoints for physiological variables, or evidence of mechanisms that measure deviations from a setpoint of certain variables such as temperature, glucose concentration, or body weight, has been deeply questioned in different branches of physiology (Müller et al. 2010; Speakman et al. 2011; Romanovsky 2018; Bich et

al. 2020; Kandel et al. 2021).² Adopting the cybernetic idea of feedback with a setpoint, although it can be heuristically useful, often provides a simplified depiction of biological processes, overlooking the complexity and the interplay of causes underlying physiological phenomena (problem 1). The strategy of looking for setpoints and feedback loops can even be detrimental for medical diagnosis and treatment, by masking or misidentifying pathologies, overlooking different types of regulatory mechanisms at work, or suggesting interventions that tend to aggravate the processes at the root of a problem (problems 1 and 2). Well-known examples are diabetes type 1 (Salehi et al. 2006; Bich et al. 2020)³ and type 2 (Stumvoll et al. 2003),⁴ obesity (Speakman et al. 2011),⁵ fever management (El-Radhi 2012), congestive heart failure (Hartupee and Mann 2017), inflammatory

² See Bechtel and Bich (2024) for a discussion.

³ Glycemia regulation is a phenomenon usually described through negative feedback to a setpoint. In this system, glucagon is secreted by pancreatic alpha cells in presence of hypoglycemia, to stimulate the production of glucose from glycogen stored in the liver. In diabetes type 1, instead, there is a paradoxical secretion of glucagon in response to hyperglycemia (even before the destruction of pancreatic beta cells which in normal conditions produce insulin, an inhibitor of the secretion of glucagon, among other effects such as glucose uptake and transformation into glycogen). This paradoxical secretion depends on direct effects of hyperglycemia on the alpha cells, which impairs their activity. Such effect is not accounted for in the feedback model (see Bich et al. 2020 for a discussion).

⁴ Type 2 diabetes has some features that escape or are invisible from the perspective of negative feedback. At the early stages, the system compensates for insulin resistance by increasing insulin production, keeping blood glucose levels within an apparently normal range. The problem is thus masked and the process of diagnosis delayed. The feedback model also overlooks several underlying factors such as inflammatory and metabolic conditions, and glucose variability which is hidden in the measurement of average values. Moreover, it cannot account for the fact that the system does not necessarily simply maintain a fixed glucose setpoint but undergoes physiological adaptation to chronic stress, where higher glycemia is necessary to continuously trigger β -cells, to ensure a greater insulin secretory response to the next glucose uptake (Stumvoll et al. 2003). Focusing only on the feedback loop and insulin treatment overlooks both the underlying conditions and the type of mechanisms involved. It can lead to adverse effects such as increasing insulin resistance or causing hypoglycemia (Amiel et al. 2008).

⁵ The setpoint model of body weight regulation implies that fat produces signals (such as those involving leptin and other hormones) that are sensed by the brain, where they are compared with a target level of body fatness. A discrepancy between the target (a setpoint embedded in the brain) and the signals would trigger changes in energy intake or expenditure that would bring the levels of body fat back toward the target state. While valuable, this model struggles to explain the wider phenomenon of obesity, by overlooking the crucial environmental and social influences and especially the increasing incidence of obesity that has been observed in different categories in many societies over the past decades. According to Speakman et al. (2011) this invalidates the utility of the notion of setpoint itself for understanding this phenomenon: "If the set point changes in response to our social class, our marital status, or whether or not we watch TV, then it is not a 'set' point" (p. 735).

cascades (Lu et al. 2020), autoimmune disorders (Moudgil and Choubey 2011), chronic inflammation (Kotas and Medzhitov 2015), and so on.

It has been argued that the notion of setpoint should be abandoned and replaced by that of “settling” or “balance” points (Speakman et al. 2011; Romanovsky 2018). These terms denote values that are not necessarily targets of specific mechanisms. Instead, they are values to which physiological variables tend to converge through the integrated contribution of different regulatory processes: they are consequence of the interplay of different processes rather than causes themselves.

The second group of issues is at a more fundamental level. This perspective conveys the implicit assumption that balance, stability, and equilibrium are good and should be associated with health, while unbalance, disequilibrium, and instability are not, and pertain to pathologies (problem 3 mentioned above).⁶ These assumptions both facilitate the adoption of the cybernetic view and at the same time are reinforced by it.

O'Malley (2024) has investigated the role this family of assumptions plays in microbiome research and how they facilitate the unquestioned acceptance of hypotheses with conceptual flaws. She focuses on *dysbiosis*, a key notion in microbiome research: a pathology that is believed to be caused by disruption of the balance of the organism's microbiota, that is, by a failure of homeostasis. She shows how concepts like balance lack precision, how they hinder research on healthy states, and how adopting them “leaves unexplored the question of whether imbalance and health can co-exist” (2024, p. 3). Sumrall and O'Malley (2024) further argue that considering health as balance and disease as unbalance may be an inheritance from pre-modern medicine, such as Galenic medicine with its focus on the balance of humors. This is problematic insofar as it brings to the core of accounts of health assumptions that are not scientifically grounded. These assumptions in turn guide experimental and theoretical research as well as practice, by supporting the search for balances (or setpoints), and by overlooking the role of change and imbalance for health and by associating them with pathology. The cybernetic view of health based on feedback and of healing as the return to an initial healthy state also conveys assumptions from

this premodern family of ideas. This link is even explicitly revindicated by some advocates of homeostatic medicine, who refer to Galenic and traditional Chinese medicine as the sources of the idea of health as homeostasis and disease as *dyshomeostasis* (Wang and Qin 2022).

Finally, adopting the cybernetic view risks hindering the achievement of some of the very goals that motivate the application of homeostasis to health. One is the consideration of the environment to understand health, as already developed by Bechtel (1985). The cybernetic interpretation provides a very limited characterization of the environment: a source of perturbations that need to be blocked or compensated for (problem 1). The dynamic view of health is similarly limited by adopting a cybernetic view. While it is true that the organism recruits a host of feedback mechanisms and processes to compensate for perturbations, in the cybernetic view such activity is mostly limited to bringing back the system to the unperturbed healthy state (problem 2). Activity is somehow restricted to a compensatory response. Health risks being characterized again as a static ideal state of equilibrium or rest, defined by the setpoints of physiological variables (problem 3).

In the next sections we provide a more dynamic interpretation of homeostasis which better accounts for an idea of health not centered on the mere idea of stability or balance.

Rethinking Homeostasis: A Dynamic View

The high generality and widespread use of the cybernetic interpretation of homeostasis based on feedback, while enabling the application of the concept across disciplines, have come at a great cost: it conveys the static idea that any form of regulation, including the biological one, consists in maintaining stability and balance. In this section we rethink homeostasis through the recent account developed by Bechtel and Bich (2024, 2025), that puts the cybernetic view into question by focusing on the integrated functioning of the organism. We widen this account towards a specific aspect of the debate: the role of change versus stability or balance.

It is important to note that the early physiological studies of homeostatic processes have been carried out on specific variables in adult organisms, studied in controlled invariant laboratory conditions rather than in their environments, which are often characterized by radically changing conditions (Hagen 2021). Less attention was initially paid to how regulatory phenomena take place in whole organisms that radically modify their physiological regimes and the related variables in response to environmental change or depending on the stage of their daily, seasonal, and life cycles.

⁶ In immunology, for example, Eberl (2016) defines health as a homeostatic equilibrium between different types of immune activities, and an unhealthy state as one exhibiting disequilibrium. In philosophy Lemoine (2025) views health as the balance and integration, however imperfect, of different homeostatic mechanisms at different levels of organization. Disease is what impairs this state. This view is somehow shared in medical education. In the Preface to their textbook in medical physiology, for example, Hall and Hall (2021) define disease as a state in which “functional balances are often seriously disturbed, and homeostasis is impaired” (p. vii).

However, since its early formulation by Cannon, the limits and scope of the notion of homeostasis have been put into question. This resulted in a proliferation of attempts to reconceptualize the notion or to advance complementary or replacement concepts. Each stresses different dimensions of physiological control but mostly emphasizes the importance of a dynamic perspective: from *hyperexis* (Richards 1953), to *heterostasis* (Selye 1973), *rheostasis* (Mrosovsky 1990), *allostasis* (Sterling and Eyer 1988), and *allodynamics* (Bertson et al. 2016). Further attempts include the notions of *homeoresis* from developmental biology (Waddington 1968) and *homeodynamics* from systems theory and evolution (Rose 1999). The debate over whether new concepts are needed, or all these ideas can still be unified under a more general reconceptualized notion of homeostasis, is ongoing and has received new impulse in the last two decades (Carpenter 2004; Schulkin 2004; Ramsay and Woods 2014; Schulkin and Sterling 2019; Sterling 2020).

Bechtel and Bich (2024, 2025) have recently shown that this long-lasting debate mostly revolves around the cybernetic interpretation of homeostasis conceived as negative feedback to a setpoint. What has been at stake is the status of the notion of setpoint: the optimal reference value for physiological variables. They identify three core topics in the debate: (1) the idea that setpoints are not fixed but variable and adjustable; (2) the idea of physiological regulation as anticipation of future variation, with setpoints adjusted in preparation for changes and not only in response to them; and (3) the rejection of the notion of setpoint itself as not accurate for describing what happens in biological systems. They argue that Bernard and Cannon not only did not employ the notions of feedback and setpoint but had a broader vision than the one later promoted by cybernetics (Bechtel and Bich 2025). Bernard and Cannon's view was centered on the physiological goal of regulation: to maintain, in different ways, conditions in which organs and tissues could function. In a nutshell, organisms regulate their internal conditions so that they can carry out the activities they need to perform to continue their existence.

By recovering the core of the original vision on homeostasis, Bechtel and Bich (2024) advocate for a perspective on physiological regulation focused on the whole organism rather than single (feedback) mechanisms. Foregrounding organisms and considering them in their changing environments can lead to considering the value of variables as the results, rather than the targets (or goals), of the interplay of different regulatory mechanisms, which are aimed at maintaining the conditions under which living organisms can carry out their activities and keep living.

Our analysis is grounded in the interpretation recently proposed by Bechtel and Bich, yet our purpose is to widen it towards acknowledging the role of change. This is a further

topic on which the debate on homeostasis has attempted to overcome the limitations of the idea of feedback and distance itself from the cybernetic view.

The association between stability, balance, and homeostasis has started being put into question while describing malfunctioning responses to perturbations. Richards (1953), for example, introduced the notion of *hyperexis* to account for error-correcting homeostatic processes gone wrong with extreme responses: both by “overreaching” themselves in the intensity of response or by unbalancing one process in the attempt to balance another. An example is an excessive reaction of the immune system, which causes damage to tissues. This idea, however, still considers balance as the goal of physiological control mechanisms. In 1961, instead, Adolph questioned the association between regulation and balance by arguing that not all regulation is concerned with constancy, and sometimes it departs from homeostasis while still contributing to the life of the organism (Adolph 1961). Along these lines, and by observing that organisms establish new patterns of responses in the presence of stressors, Selye advanced the idea of *heterostasis* (1973, see also Selye, 1950). It accounts for active responses to stressful situations that imply drastic changes (nervous, immunological, hormonal). *Heterostasis*, as opposed to reactive homeostatic responses, implies the establishment of new steady states (“abnormal equilibria”) to protect the organism under conditions that threaten its survival.

Others have emphasized how these changes are not exceptions but are common in the daily life of an organism. They allow organisms to adapt to the different conditions they normally encounter during their life cycle (e.g., day and night, seasonal changes, etc.). Mrosovsky (1990) introduced the notion of *rheostasis* to account for all these phenomena in which changes in the level of the variable are not limited to exceptional conditions. *Rheostasis* is defined as the condition in which homeostatic mechanisms are at work, but in time there is a change in the level that is defended.⁷ In a similar vein, the notion of *allostasis* introduced by Sterling and Eyer (1988) emphasizes how stability is achieved through multiple changes, for example, by establishing new setpoints or anticipating changes in the internal environment on the basis of past experiences. They point out: “the question arises as to what other physiological parameters

⁷ Temperature is an example of variation in the values of a core variable, with constancy as a possible artifact of laboratory research (Mrosovsky 1990; see also Hagen 2021). Animals exhibit a wide range of variations of body temperature, for example between day and night. Fever is a case of modulation of temperature (through metabolism, or behaviors like shivering) to a different regime (higher temperature) to create an inhospitable environment for pathogens. Mammalian hibernation also involves modification of body temperature, which is reduced below the environmental one and raised periodically.

besides blood pressure covary with behavioral state. The answer is, essentially *all* of them” (1998, p. 633). On this view, “to maintain stability an organism must vary all the parameters of its internal milieu and match them appropriately to environmental demands” (1998, p. 636).

More radical views have been proposed that depart from the very notion of stability and setpoints. The notion of *alldynamics* was introduced by Berntson et al. (2016) to account for the possibility that physiological processes may not always be regulated with regard to setpoints. It focuses instead on the variability of the processes and dynamics that underlie shifts in physiological parameters. This is in line with recent debates that have questioned the presence and localization of setpoints for physiological variables and that proposed to replace setpoints (pre-established reference values for physiological variables) with settling points (values to which physiological variables converge through the contribution of different processes). The idea is that the values of those variables or features that are maintained within range are not the specific target of physiological regulation but rather the result of the coordinated operation of different controllers.

Overall, the accounts discussed advocate for change over stability: first limited to stress responses in exceptional circumstances, then extended to account for everyday physiological activities. They question and overcome the ideas of balance, equilibrium, and stability implied by the cybernetic view, which associated homeostasis with negative feedback mechanisms designed to restore the setpoint. A common feature to many of these replacement conceptions is a recognition that what is being maintained is a dynamic adaptive capability rather than a fixed state.

In this brief historical overview, we have shown that the cybernetic interpretation is not the only possible one to understand how an organism regulates itself and achieves health. In order to overcome the limitations of the cybernetic interpretation of homeostasis and of its application to health, discussed in the previous section, one needs to change perspective from one centered on balance to one acknowledging that a living organism needs to change itself to maintain viability.

Adaptivity and Versatility as the Basis for Health

Overcoming the cybernetic interpretation of homeostasis and accounting for change implies addressing the role of biological regulation through a dynamic framework with a focus placed on the whole organism rather than on individual feedback mechanisms. In this section we provide such a framework and apply it to the characterization of health. We do so by expanding on insights from the organizational

account and “Bechtelian” new mechanism (Winning and Bechtel 2018; Bich and Bechtel 2022a; Menatti et al. 2022).

According to the organizational account, living organisms, including humans, maintain themselves alive through a host of mutually dependent activities such as procuring and taking in food, processing it, building and repairing their parts, moving around in the environment, and so on. In order to carry out these activities in a way that contributes to their maintenance and survival, living organisms need to regulate themselves based on their internal physiological state and environmental conditions (Bich 2024). To do so, they employ a host of control mechanisms that modify different physiological and behavioral activities by measuring appropriate conditions and acting upon those measures in a manner that contributes to the maintenance of the organism (Bich et al. 2016; Winning and Bechtel 2018).

Living systems are not only continuously interacting with a changing environment to maintain viability, but also undergoing internal modifications. One reason is that their structure is in continuous variation: it is intrinsically unstable or “precarious” (Di Paolo 2005), regardless of whether it is perturbed by the environment or not. Components need to be constantly repaired, degraded, or replaced. Another reason is that their internal activities cannot all be realized simultaneously and are not always compatible. Selecting those activities that are given priority in each situation (e.g., digestion, movement, heat production, immune activities, etc.) must be constantly adjusted to the needs of the organism while avoiding potential conflicts (Bich 2024). Physiological regimes are also changed depending on the time of the day, the season, and the position in the life cycle of an organism.

Accordingly, different organisms, or the same organism at different moments, may exhibit distinct values of their physiological variables. Deviations of physiological variables from a usual range of values are not necessarily deleterious. Likewise, their maintenance is not necessarily functional: their role depends on the general state of the organism and its adaptive needs, but both are the result of regulatory modulation (Bich and Bechtel 2024). This capacity has been understood in terms of adaptivity: the capability of an organism to respond to changing circumstances by means of internal reorganizations (see Meyer 1967; Piaget 1967; Di Paolo 2005; Menatti et al. 2022).⁸

⁸ The focus here is on physiological and behavioural adaptivity, which is present oriented. It differs from evolutionary adaptation, mainly historical. The latter explains the evolution of organisms with respect to environmental pressures, which cause changes in organisms that are explained in terms of differences in fitness. The two dimensions, however, are mutually dependent, and further work is needed to understand whether they can be integrated: for example by discussing work in evolutionary medicine on the conceptualization of disease in terms of “mismatches” between adaptive capacities of organisms and their environments (e.g., Griffiths and Bourrat 2023).

The fact that the parts of an organism are dynamic and capable of multiple activities, and that physiological processes are not fixed to one or few stable regimes, provide multiple degrees of freedom that allow an organism to face a variety of situations. Regulatory mechanisms are sensitive to different features of the internal and external environment, often integrating information from multiple sources and about multiple variables, and affecting a host of processes, thus giving rise to a coordinated set of activities. This means also that multiple mechanisms can affect the same physiological processes in different ways and on the basis of different measurements. On the one hand, this provides the organism with what has been defined as *versatility* (Bich and Bechtel 2022b), that is, the possibility to enact and modulate different viable activities in relation to a variety of circumstances. On the other hand, when one mechanism fails, other mechanisms whose activities overlap may be upregulated so that the deficiency is mitigated.

Adaptivity, versatility, and change are three features that define a different framework for the relationship between homeostasis and health. The view of health that emerges from this framework is that living systems need to continuously undergo internal as well as behavioral changes in order to maintain viability. Instead of looking for balance and to how a system restores the “normal value” of a variable and possibly returns to its initial conditions after a destabilizing perturbation, the focus here is different. It is placed on the capacity to change how the system operates—even by modifying the values of its core variables—in such a way that it can keep performing its life functions coherently with internal and external conditions. In some cases, this activity may result in keeping some variable stable, but it is not necessarily so and, most importantly, it is not the ultimate goal of physiological regulation.

This account has a teleological dimension. Built upon the organizational framework, it grounds teleology in the contribution to the maintenance, at the physiological scale, not of a setpoint but of the organization of the whole organism (see Bich 2024). The normative value of homeostatic mechanisms for health consists in establishing and modulating those conditions that are necessary for the functioning of the parts, so that the parts can contribute to the maintenance of the whole system.

Following this reframed view of homeostasis, health can be characterized in terms of adaptivity and versatility, that is, of the capacity of an organism to recruit its physiological resources to modify itself in order to maintain viability in multiple and changing circumstances. The maintenance of the capacity to perform the functions of life, which is associated with health (Bechtel 1985), requires continuous

modification of the ongoing physiological regimes.⁹ We illustrate this through a couple of examples, before moving on to the last section to draw some general conclusions about the adaptive view of health.

Acclimation to high altitudes is a case of broad adaptive physiological changes towards a new regime compatible with environmental conditions. Rapid physiological responses to altitude include, among others, increased breathing and heart rate, suppression of non-essential body functions such as digestion, and so on. Long-term acclimation involves deeper physiological changes to function in a low-oxygen environment, by enhancing oxygen delivery and utilization (Young and Reeves 2002). These changes include increased red blood cell production and blood hemoglobin concentration, which improve oxygen-carrying capacity. Cardiovascular adaptations also occur such as higher capillary density and heart right ventricular hypertrophy to sustain higher pressure in the pulmonary artery. These are accompanied by metabolic changes such as an increase of concentration of aerobic enzymes to improve oxygen utilization efficiency. Finally, renal excretion of bicarbonate allows for adequate respiration without risking alkalosis due to increased breathing rates.

The second example refers to the fact that organs and tissues are also subject to constant change during the life of an organism. While steady states are achieved under relatively constant conditions, organs and tissues have the ability to respond dynamically to functional demands such as variation in food uptake, the reproductive status of the organism, environmental variation, and injuries (O'Brien 2022). This is achieved by modulating the ratio between cell production and cell loss and driving the system to a regime of repair, remodeling, or resizing according to circumstances. Organs and tissues deploy multiple strategies to do so by controlling

⁹ We have focused here on living organisms as the bearers of health. However, research on host–microbiota and, more generally, symbiotic relationships characterized by close functional ties seems to point to the possibility to extend these considerations to entities that transcend individual organisms (e.g., Gilbert et al. 2012). Indeed, the role of the microbiome for the health of the host has been widely discussed, with work such as O'Malley's questioning the adoption and value of the notion of dysbiosis (Hooks and O'Malley 2017; O'Malley 2024). The framework we developed here does apply in principle to larger entities, such as some cases of host–microbiota relationships, that are sufficiently integrated to be considered self-maintaining and self-regulating teleological organizations in the sense discussed in this section. Such integration is necessary in order to consider different homeostatic mechanisms as contributing to the maintenance of the system. This requires metabolic co-dependencies but most importantly, it requires that regulatory mechanisms operate not only within but across the entities that participate in the larger system (see Bich 2019, 2024 for a discussion). Applying this framework to other collective entities (e.g., a collective, an ecosystem, the planet, etc.) would not be straightforward but would require case-by-case examination.

different steps of the cells' life cycles, for example by modulating stem cell activation and division, cell terminal differentiation to account for the current needs of the tissue, cell size, apoptosis and elimination of dead cells, and so forth.

These examples show how the versatility of regulatory mechanisms deployed by living organisms, such as humans, allows them to mobilize resources and adaptively change a host of distinct physiological processes and parameters to meet changing (internal or external) conditions. As has been argued by advocates of notions such as allostasis and allodynamics, discussed in the previous section, many if not all parameters need to be adjustable and to vary in order to maintain the system in each new circumstance.¹⁰

Conclusions: Health as a Continuum

Employing the notion of homeostasis can foster a dynamic view of health compared to common views such as a complete state of well-being or absence of disease. However, this attempt has been hindered by the adoption of a narrowed account of homeostasis based on the cybernetic model of negative feedback to a setpoint, which associates health with balance or stability, and healing with returning to an initial or normal state after a perturbation. We have questioned the assumption, inherited from traditional medicine and the cybernetic notion of feedback, that balance is good, and imbalance and change are not, and argued that an alternative perspective is possible. This alternative view focuses on health as the capability for adaptive change, i.e., to realize different viable physiological regimes adapted to the internal and external conditions an organism faces at a given time. We have mainly focused on the physiological debate on homeostasis. However, notions such as homeostasis and adaptive functions have also been discussed in relation to mental health (see Sterling 2014; Khalsa et al. 2018; Garson 2022; Plutynski 2023). One clear example is Sterling's definition of mental health as "responsiveness of the conscious and unconscious mind to the full range of signals from many sources: current thoughts, personal and family memories, innate memories and appetites" (2014, p. 1193). While it is not clear whether our framework could be applied to mental health right away, exploring the interplay and trade-offs between physiological and mental functions within a dynamic view of health is a promising avenue to explore.¹¹

¹⁰ Such variability is of course limited by general viability constraints, such as, for example, the range of temperature within which proteins are functional and do not denature, or organism-specific ones such as trade-offs between the needs of different vital processes (e.g., changes in a process that causes disruption in others, and consequently death).

¹¹ We thank an anonymous reviewer for the interesting suggestion.

The view of health in terms of adaptivity and change can be operationalized by identifying multiple mechanisms involved in physiological regulation, unlike classical accounts of health as well-being and absence of disease. Most importantly, it abandons the assumption that balance is the core of health, and it does not incur in the limitations exhibited by the cybernetic view. It can fully account for those aspects emphasized by the advocates of a homeostatic view of health, such as the need for a dynamic and proactive perspective that takes into account the integrated functioning of the organism. Moreover, it can account for the role of the environment in health, the importance of which has been stressed, among others, by Bechtel (1985), Dussault and Gagné-Julien (2015), and Menatti et al. (2022). From this perspective, the interaction with the environment is constitutive of the health of an organism, which needs to manage a host of different positive and negative interactions in such a way as to maintain itself in a viable regime. Regulatory mechanisms involved in this activity operate based on the specific features of the environment they sense. However, they do not only respond conservatively by counteracting perturbations that menace the balance and survival of the organism or destabilize some variables. For example, day and night, seasons, different steps in an organism's life cycle, and so on, are not perturbations, but settings in which an organism needs to operate to maintain itself. Thanks to their internal variability, organisms can adaptively engage within these settings. To keep living, they modify themselves to enact different physiological regimes compatible with ever changing circumstances.

For the practice of health this account raises important questions. Following Partridge (1982, p. 175) one can ask: "Does the teaching of the concept of homeostasis lead to overzealous attempts at medical restoration of 'normal values' instead of acceptance of more of the observed variations as adaptive?" We can answer by conceiving of health not as a fixed state of the organism, be it of well-being or absence of disease, but rather as an adaptive process taking place in interaction with the environment. As we argued, given the dynamicity of living organisms in which physiological demands constantly fluctuate, what is important is not necessarily to keep parameters stable but to be able to modulate them according to physiological and environmental needs. We have discussed in the second section some of the problems for diagnosis and treatment that can derive from employing a cybernetic view of homeostasis. Similarly, with regards to addiction and mental health, Sterling (2014, 2020) emphasizes the importance of restoring responsiveness and letting all parameters vary. He contrasts his view with the strategy of blunting parameters, for example pharmacologically, that derives from the cybernetic interpretation of homeostasis based on stabilization and

tends to reduce the synaptic variations essential to normal thought, attention, and mood.

Conceptually, the adaptive view of health aligns also with ideas of health as a *continuum*—as proposed by Antonovsky (1979; see Menatti 2025) and more recently by Ayres (2020)—that challenge the health/sickness dichotomy.¹² More precisely, health, rather than a yes or no property, can be seen as adaptive variation along a continuum, with an ideal state of health and death as the two poles. The continuum is defined by the action of regulatory mechanisms and environmental conditions. Given the omnipresence of environmental stressors and changing circumstances, and the variation in internal conditions, movement along the continuum depends on whether and to what degree adaptive regulatory mechanisms are at work in the different situations. This accounts for the fact that health requires the instantiation of new physiological regimes in different situations, rather than the maintenance of a number of setpoints for physiological variables. Moreover, in the context of constant fluctuation of the internal and external environment, these regimes are the result of trade-offs between distinct regulatory mechanisms that responds to different conditions or needs.¹³ It follows that a complete state of health is only an ideal and a system is always in movement along this continuum, by deploying strategies that are suboptimal and constantly revised. On this view, individuals throughout their lives employ their regulatory mechanisms to navigate between healthy conditions, sickness, and recovery.¹⁴ The emergence of a disease does not necessarily equate to a complete loss of health but rather represents an inflection

point, a shift along the continuum. Recovery can imply the reestablishment of a given physiological regime as well as the realization of a different one under distinct internal and external conditions.

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Declarations

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¹² The debate on the conceptualization of health and disease is usually characterized by two main philosophical approaches: naturalist-descriptivist and constructivist-normative. The naturalistic approach relies on biological, statistical, and value-free notions of health and disease (Boorse 1977, 1997; Scadding 1990), while the constructivist ones base their understanding of health on social values (for an overview of the debate see Schramme and Edwards 2017; Stegenga 2018; Murphy 2023). While in this article we mainly focused on physiological aspects of health, usually discussed by naturalists, our framework may be closer to hybrid approaches (Wakefield 1992; Stegenga 2015). The idea of continuum challenges the binary opposition between naturalists and constructivists. The continuum, for example, rejects the idea of biological statistical normality which is fundamental to define what is health and what it is not for authors such as Boorse. Moreover, it puts into question the radicality of the opposition ease/dis-ease. Also, the social and constructivist dimension is referenced within the idea of the continuum, as health is understood as the capacity to adapt to various types of stressors. For example, in the work of Antonovsky, a central role is played by the sense of coherence—a fundamentally individual and collective social capability.

¹³ Trade-offs are not only physiological but can be also developmental and evolutionary (see, for example, Matthewson and Griffiths 2017).

¹⁴ It is important to point out that the idea of health that emerges from this framework is not univocal, but the position along the continuum may depend in each case on the specificity of individual, populational, environmental, and social factors.

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