RRREaT-PT

Editorial, 2025, February

The Difficulty of Understanding Flexibility in Reacting to Situations

When the weather becomes warmer, like in the spring, but also when it becomes colder, like in the winter, certain groups of birds assemble together to form amazingly dynamic swarms in the sky, and also neatly organized V-shapes, in order to prepare for migrating to better suitable climates. For some bird species that are known to migrate every year from one place to another, it is a recurring event. Perhaps even more amazing than the birds' migration in itself is that the birds reach the decision that it has become time to leave a place and they begin to practice for the flight that lies ahead of them. Generally, life in the actual world shows that animals and humans can experience a continuation in events and situations that require *decision-making*. However, not all decisions that are made regarding situations are set in stone, in that situational decision-making can require *flexibility*. In the example of the birds migrating to other places, flexibility can be found regarding the offset of the birds' migration to another place. For example, the date for certain bird species to arrive back again can be very early, but also late in the spring. It raises the question of what encompasses the concept of flexibility regarding the making of situational decisions.

Flexibility is the counterpart of rigidity, in that flexibility refers to being able to change and adapt. Living organisms have the ability to change and adapt to situations should these situations require it, but even then, mostly to a certain degree because the goal of being flexible in decision-making and reacting is to maintain balance. In the biological sciences, it is called homeostasis and it refers to maintaining a relatively *stable internal environment* in cells, tissue, and organisms (Billman, 2020; Hanikenne et al., 2020). Maintaining homeostasis can be said to be a major element for life and living because it is found at many biological levels, such as cell metabolism, nutrient interaction, the functioning of organs, and the existence of organisms, to ward off and recovering from diseases. The maintaining of a stable internal environment can also involve the adjusting to the changes that appear throughout life by keeping a cognitive and affective internal balance by behaving relatively stable. The aim of this article is to present a discussion of the concept of flexibility in situational decision-making to react appropriately by describing the function of flexibility as it is studied in the various sub-disciplines of the biophysical and social and psychological sciences to understand better the role and assessment of flexibility across situations.

Homeostasis and Cell Metabolism

The cell, which is considered to be the basic unit of life, not only maintains a stable internal environment that can ward off disruptions that come from the external environment, but also executes important cellular functions in the face of changeable inputs. The latter refers to cell metabolism or the chemical changes in the living cell that produce energy for vital activities and that enable the continuation of the cell's life (see Reed et al., 2017; Van Veen et al., 2020, for overviews). Homeostasis regarding cell metabolism is a process that consists of dynamic biochemical reactions within the cell in order to stay within a relatively constant range of chemical concentrations to ensure its vital functions. To this end, regulatory mechanisms are needed that signal and control changes in order to adjust the bio-chemical reactions that take place in the cell. It is important for the cell to receive feedback about what is going on, in the inside and the outside, to evaluate if the changes that arise in the cell require further action and which kind of action. It is a kind of biochemical "decision making." There are four kinds of homeostatic regulatory mechanisms acknowledged currently for cell metabolism, namely feed-forward excitation (i.e., activating a catalyzing enzyme to remove a product), feed-backward inhibition (i.e., inhibiting a catalyzing enzyme that is involved in its own synthesis), kinetic homeostasis (i.e., a catalyzing enzyme that becomes homeostatic by losing its kinetic energy), and parallel inhibition (i.e., the substrate A inhibits the synthesis of B and B inhibits the enzyme that catabolizes A). Overall, when the fundamental regulatory mechanisms do not function properly, then it is a matter of the cell being in a state of disharmony.

For cell metabolism to work properly or effectively, maintaining homeostasis in the cell is essential, and this requires energy and flexibility (Decker & Funai, 2024; Li, 2024; Pabst & Keller, 2024; Yang et al., 2021). Plant cells that have chloroplasts can generate chemical energy by transforming sunlight and water into carbohydrates via photosynthesis, which is a process that requires the coenzymes of nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP). In all eukaryotic plant and organism's cells, there are also mitochondria that can synthesize ATP, in this case via oxidative phosphorylation. Mitochondria are cell organelles that can provide for the biochemical energy of ATP and ensure that the supply of ATP for cell metabolism will meet the demands in terms of both the total amount of APT and the rate of APT production. Aside from energy homeostasis, mitochondria are also involved in maintaining the quality of mitochondria (e.g., signaling and adjusting the homeostasis of protein and calcium), synthesizing molecules (e.g., neurotransmitters and hormones), and communicating with other cell organelles, such as the endoplasmic reticulum. A specific feature of mitochondria is their bilayer membrane.

Although our understanding of the structure and functioning of the bilayer membrane is still in its infancy, it is thought that the bilayer membrane's asymmetric and dynamic structure is essential for meeting the constantly changing demands inside and outside mitochondria. The inner and outer membrane of the bilayer membrane consists of lipids with varying compositions and distributions, and their interplay with the membranes' proteins enable a continuous trafficking of lipids, proteins, and other bio-chemicals through the membranes (see Figure 1). The inner and outer membranes are separated by the so-called inter-membrane space that is involved in, among other things, signaling and controlling the metabolic processes and the mitochondrial form and structure. The inner membrane is folded into cristae and the volume of these cristae is thought to influence the electro-chemical acute turns in functioning. Overall, the process of maintaining homeostasis in cell metabolism seems far from rigid and fixed because cell metabolism not only concerns the internal biochemical environment of the proper functioning of the cell's organelles and cytoplasm, it also has to cope with external environmental stressors (e.g., drought and heat), bacteria, viruses, and plant-eating insects and animals.

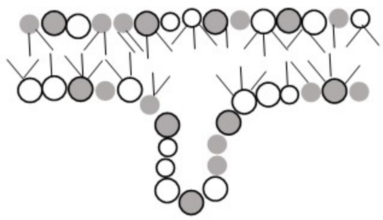

Figure 1. Schematic overview of the mitochondrial asymmetric bilayer membrane.

Figure 1 shows the mitochondrial bilayer membrane, but some other cell organelles also have similar bilayer membranes with cristae (Pabst & Keller, 2024). Although the precise function of the bilayer membrane with its seemingly twofold form, cristae, and disordered structure composition is not yet completely understood, it appears different to, for instance, the DNA double helix structure of organisms' genetic material. Then again, the double helix structure of DNA was not discovered until Watson and Crick in 1953 could synthesize Franklin's X-ray diffraction images to the then-available DNA data. Therefore, in anticipation of continuing technological developments, it appears that where the structured and repeatable double helix form of DNA enables a lot of variation in possibilities of stable genetic outcomes, even though there are only two pairs of components (i.e., AT and GC), the (mitochondrial) bilayer membrane seems to enable adaptations to *quick* biochemical changes across time. To this end, the bilayer membrane provides for multiple components, apparently in a loose structure, a double-check modus via the inner and outer membrane, and the time required for signaling and adjusting, if necessary, via the inter-membrane space in relation to the cristae. In short, the bilayer membrane enables flexibility and as such, it is an ingenious evolutionary invention that can deal with changes across time quickly and appropriately to maintain cell metabolism homeostasis.

Homeostasis in Organs and Organisms

Homeostasis, as the ability to maintain a relatively stable internal environment by regulating internal and external environmental changes, is also found regarding tissue (i.e., multiple cells), organs, such as the skin, (Jiao et al., 2024), and organisms, such as plants and humans (Wang & Qin, 2022). For example, plant health, growth, and crop productivity require an optimal and balanced supply of micronutrients (e.g., zinc and manganese) and macronutrients (e.g., sulfur and phosphate). In nature, plants can encounter multiple combinations of nutrient excesses and limitations, as well as toxic and non-essential elements (e.g., cadmium), which makes it essential to maintain homeostasis, for instance, via the regulation of nutrients in relation to one another (Hanikenne et al., 2020). Another example about plant health in relation to soil, is the review of Husson et al. (2021) that showed that beneficial microorganisms in the soil and an internal homeostasis in the plants could enable plants to minimize the impact of stressors on their health. Hence, maintaining homeostasis by warding off diseases agrees with a dynamic battlefield between the host and the pathogen(s).

Homeostasis in human cells, tissue, and organs is similar to homeostasis in plants and animals, in that homeostasis is required for cell growth and proliferation, the functioning of organs, and metabolism to ward of diseases (Wang & Qin, 2022; Wen & Turrigiano, 2024). To this end, humans have certain so-called autonomic buffer systems (Alzeer, 2023) that entail an acting and a counter-acting part. This twofold action system that is found in, for instance, the sympathetic and para-sympathetic regulation of blood vessels, the glucose-insulin regulation of blood sugar, and the excitatory and inhibitory regulation of neurotransmitters, is vital for optimal physical functioning and for some buffer systems to operate cooperatively. Overall, these autonomic regulatory buffer systems act when certain levels of imbalances are reached. Humans also have a homeostatic functional state that consists of multiple layers of dynamic reactions that connect cells, tissues, and organs (e.g., the immune system). Such an intricately intertwined biochemical regulation is not considered to be a uniform way of "housekeeping," but rather that "many of these core metabolic processes can play vastly different roles within the same lineage of cells, depending on the functional problem they adopt" (Shyer et al., 2020, p. 656). It refers to a *differentiating in functioning*, which can even result in certain interconnected cells that depend critically on some pathway, then meet an alternate regulation program that impedes the same process for enabling an overall process to act adequately and as quick as lightening.

In this respect, Kotas and Medzhitov (2015, p. 820) argued that in cells, tissues, and organs, the "homeostatic variables are not maintained at a constant level, but rather within a certain range of values." For example, plasma glucose levels are regulated over a wider range of values than plasma calcium levels are. Kotas and Medzhitov also mentioned to suspect that certain physiological processes (e.g., lipid and glucose metabolism) may operate under a narrow range of conditions to maintain homeostasis, thereby being vulnerable to dis-regulation and homeostasis disruption and, hence, susceptible to chronic diseases, such as inflammation (e.g., diabetes type 2 and other auto-immune diseases). Sensitivity to a range of values may also direct prioritization of homeostasis, and when the internal environment changes, then the sensitivity to a range of values may also change. For example, hormonal changes during pregnancy produce a change in insulin sensitivity that appears as a diminished insulin responsiveness. Severe external environmental changes, such as an infection, injury, and stress, may produce greater ranges of insensitivity, which may result in chronic diseases. Therefore, maintaining homeostasis in the continuously changing actual world, which requires energy and flexibility, raises questions regarding the role of differentiating in functioning and working within certain ranges of values, and whether or not this is directed via genetics, experienced history or memory, severity of the challenges (e.g., overload) to maintaining homeostasis, and a combination of these factors. Moreover, it raises the question of how individual-specific is the maintaining of homeostasis?

As the aforementioned examples can show, the maintaining of homeostasis is such a complex process that an understanding of homeostasis is still in its infancy. It also is difficult to understand homeostasis because it can involve multiple layers of cells, tissues, and organs, and it requires feedback loop reasoning with indirect relationships and inverse conditions (Kiesewetter & Schmiemann, 2022). To assess such a complex and dynamic process that is the maintaining of homeostasis in organisms, Van Veen et al. (2020) tackled this issue regarding the diagnosing of patients' health by examining their individual homeostatic functioning rather than their physiological functioning (e.g., temperature and blood pressure) at (often) a single measurement point in time. Van Veen et al. (2020, p. 1) argued: "Health may be better measured and assessed by studying the body's ability to maintain homeostasis . . . [because] many of today's most prevalent chronic illnesses, such as hypertension, diabetes, obesity, and depression, can be considered failures of the body's ability to maintain homeostasis or to keep physiological signals within a normal working range." However, assessing a body's ability to maintain homeostasis is easier said than done because it can raise several questions. For instance, whether an individual patient's homeostatic functioning needs to be compared to a base reference model or when does a healthy homeostatic functioning becomes unhealthy? Is the base reference model obtained via the overall mean or a confidence interval, an individual range of values, and a holistic range of values that include the context of a particular homeostatic functioning? Is it possible to find a simple scoring system to assess the complex homeostatic functioning model and the individual's homeostatic functioning? The solution proposed by Van Veen et al., (2020) is to describe the homeostatic functioning as a control system that is independent of the underlying physiology, but that does depend on the body's current state and recent history, to model the dynamics of a homeostatic functioning.

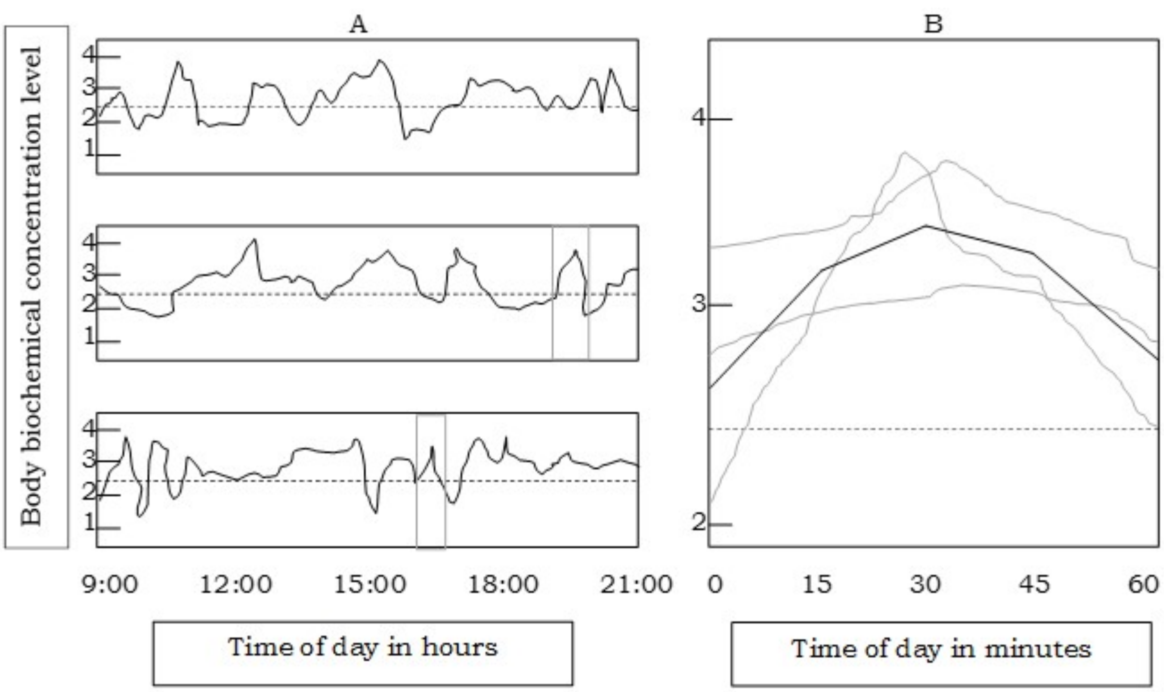

Figure 2. A patient's glucose levels across time. A = three days of raw data. B = the three selected peaks (grey) and the representative peak (black). Adapted from Van Veen, L., Morra, J., Palanica, A., & Fossat, Y. (2020, p. 3), NPJ Digital Medicine, 3: 77. Https://doi.org/10.1038/s41746-020-0283-x. Copyright 2020 by Springer Nature.

Figure 2 shows the principle of detecting the feedback loop of healthy bodies in maintaining homeostatic functioning, as proposed and described by Van Veen et al. (2020). Healthy participants, who were not diagnosed with any medical condition, wore monitors to obtain continuous measurements regarding a physical homeostasis process (i.e., monitoring glucose levels) for three consecutive days. The aim was to model the dynamic function of maintaining homeostasis by studying the feedback control function via several peaks in the raw data. Figure 2A shows three such peaks in the grey boxes, in that each peak begins and ends at the baseline (i.e., the dotted line at approximately 2.4 of the body biochemical concentration level), and all have comparable width, to obtain the feedback control function as a response proportional to a deviation. To confirm the universality across persons of this feedback control function for maintaining homeostasis, Figure 2B shows how the three selected grey peaks are fitted into one representative peak per individual participant, which are later optimized into a dimensionless indicator of the responsiveness of the feedback control functioning. Although this procedure is less complicated than the present dynamic control procedures that measure a multitude of biophysical processes rather than the feedback control function itself, as a next step, variations in the height and width of the peaks could be associated with other biophysical processes that make up the context of the raw data.

Balance, Flexibility, and Habit in Human Behavior

As aforementioned, homeostasis refers to the ability of maintaining a relatively stable internal environment, which concerned the biophysical perspective. But how about human behavior and maintaining a stable internal environment in terms of dealing with external environmental challenges, which concerns the psychological and social perspective? To the best of my knowledge, research on human behavior does not mention homeostasis, but rather balance and flexibility (see Lomas, 2021; Yildirim et al., 2022, for reviews) to react appropriately to the environment, which can refer to psychology (e.g., maintaining positive emotions and a meaningful life) and sociology (e.g., maintaining social support). For example, to maintain balance between work and life is essential behavior for people who work in organizations because of the changes that people and organizations can go through across time (Kalliath & Brough, 2008). Another example is Kashdan (2010, p. 866), who argued that psychological flexibility is a key hallmark of human behavior because it can "capture the dynamic, fluctuating, and contextually-specific behaviors that people deploy when navigating the challenges of daily life." Flexibility enables humans to make mental and behavioral shifts in reacting, maintain balance among important life domains (e.g., work-life), avoid depression, shift attention and cognitive sets rapidly, and invest effort into interpreting the current surroundings while conserving mental energy for approaching situations.

However, humans do not only behave flexibly, they also like to have fairly stable habits (i.e., someone's usual manner of behavior or customary and learned behavior), in that some behavioral changes can become consolidated into lasting habits, but then the habits in turn might oppose humans in resorting to flexible behaviors (David et al., 2024; Verplanken & Orbell, 2022). Gardner et al. (2020) questioned whether habits could weaken the relationship between intention and behavior. Their review implies that rather than studying how and under which conditions habits and intentions interact, social psychologists should focus on *whether* habits moderate intention-behavior relationships, because there is conflicting evidence that shows that habits can have the potential to dominate over intentions, whereas intentions can have the potential to dominate over habits. Similarly, in their meta-analysis, Hagger et al. (2023) observed profound habitual behavior in studies with a higher opportunity for habit formation and a lower complexity (e.g., by measuring the frequency of behavior), which led them to conclude that future research should use experimental methods and not self-reported frequency items. Similar remarks have been made by Kashdan (2010), based on a review of the many fluctuating and conflicting forces that people encounter in the external environment, which led to Kashdan arguing that context-dependent reactions span a wide range of human abilities. That is, the research on social and psychological flexibility is fragmented because of the dynamic processes involved, such as adapting to fluctuating situational demands, reconfiguring mental resources, shifting one's perspective, and balancing competing desires and needs. Kashdan (2010, p. 20) concluded: "Dynamic constructs require dynamic [measurement] approaches," which could be achieved by incorporating temporality and person-situation interaction because not assessing the continuous interaction between the person and the situation can easily lead to misunderstandings.

To summarize, maintaining balance in behavior consists of two counterparts, perhaps similar to the aforementioned (bio-) physiological homeostasis, namely behavioral flexibility and habitual behavior because both are important for reacting appropriately to external environmental challenges. Additionally, humans require time to process information about the environment, which means that the gaps that can arise in the information perceived about the external environment may need both quick fixes and process time. Flexible and habitual behaviors are made possible through learning by discovering and mimicking better-appropriate behaviors, but it also raises the question of when the one or the other is being used and how to assess and analyze this context-related dynamical construct of flexibility appropriately.

Actual Situations, Balancing Behavior, and Data Collection and Analysis

As aforementioned, flexible human behavior is dynamic behavior that arises from internal cognitive-affective interactions with the external environment. It is person specific, in that the individual's experiences in the past has led to learned habits, and the recent or near-present moment has led to the construction of an interpretation or storyline of what has happened in a series of situations, and it now will influence whether or not flexible behavior is needed for the present situation. As such, the study of behavioral flexibility is a further step in understanding the role of conditional information that Van Velzen (2024) employed to illustrate the identification of inter-individual groups based on person-specific intra-individual data (i.e., preferred or habitual behavior that consists of the individual's knowledge in connection to the remembered context, and personal and situational circumstances). However, when the individuals that form an inter-individual group, are actually present in a situation that can challenge their preferred habitual behavior, then their personal characteristics in situation interpretation, which affects future situational decision-making, can come to the surface. That is, the study of behavioral flexibility is oriented on the *individual process* of maintaining behavioral balance, in that the emphasis still lies on the person who interprets the situation, but now as an *actually* interpreted storyline across time and the adapting to this storyline, if necessary. It is a personal interpretation, to a certain degree because there is the objective situation as well, and it can showcase personal changes in decision-making as the characteristics of the person being in the situation. It is why people may deviate from their customary behavior in situations as a consequence of the internal values reaching the necessity to change their behavior. Therefore, the individuals in an identified inter-individual group may have similar preferred habits to a certain specified situation (e.g., the homework situation), but the basis for individual decision-making may deviate somewhat from one another due to variation in personal characteristics, thereby creating the setting for deviations in actual behavioral decision-making across time for that same situation.

This person-situation flexibility in actual behavioral decision-making across time raises the question of whether there is a pattern in the kinds of behavioral decision-making that a person employs to maintain behavioral balance in a range of situations that belong to a phenomenon, such as learning in the homework situation and working in the organizational situation. Overall, the existence of interactions between the human brain and the external environment, where (a) the brain requires time to process external information and, thereby, needs time to fill the gaps that can arise in between the observations of the environment, and where (b) the interpreted storyline (i.e., enabled as well through personal memory) of what is happening has to deal with foreseen and unforeseen events, both require a circular processing of what the person considers to be essential information. This interacting between the person internal and external environment while requiring time and keeping track of a storyline is likely to be enabled via feedback loops. Feedback loops, defined as the return of (a part of) previous input to build on future output, might be useful for data collection and analysis regarding processes (e.g., reactions) across time, such as the process of behavioral decision-making (see Figure 3).

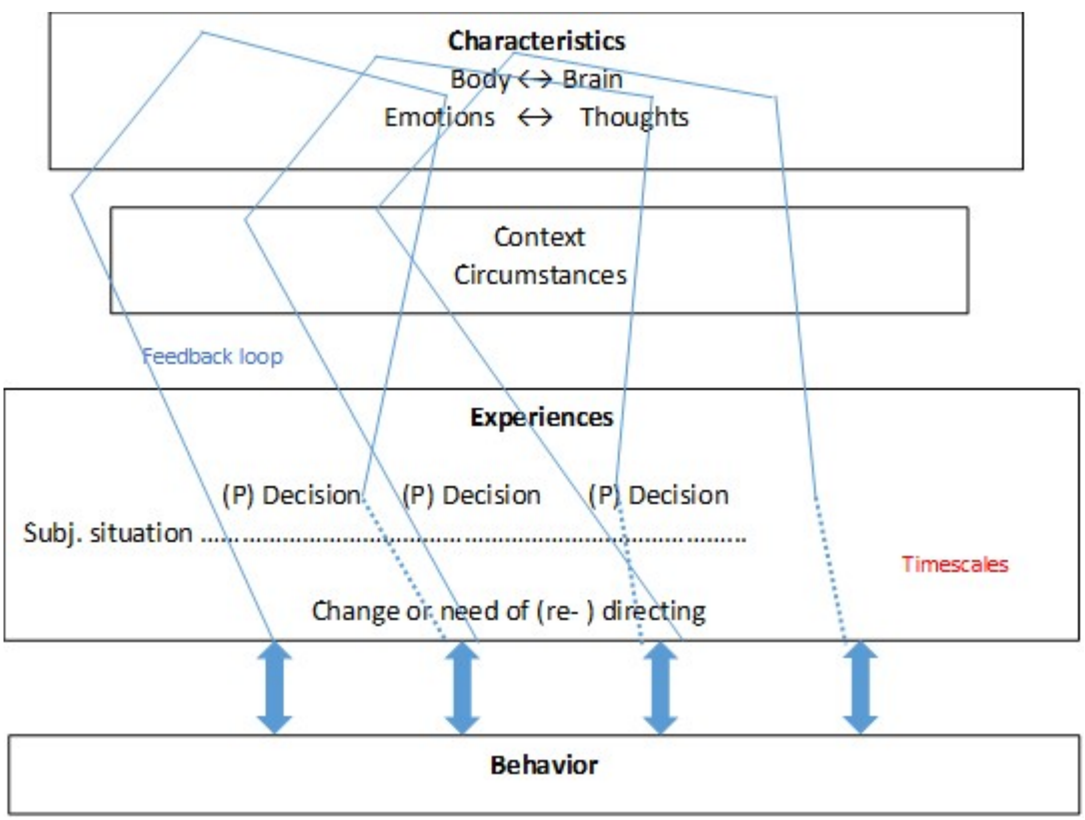

Figure 3. Schematic presentation of the interconnection between the person and his or her behavior in the situation via the process of behavioral decision-making.

Figure 3 presents a schematic account of the continuously ongoing of feedback loops (i.e. the blue colored lines) of an individual person, who goes through a series of situations by making behavioral decisions, each decision based on the person's near-present interpretations of what is happening. Each feedback loop begins with the registration of a moment of the person and the behavior in the situation, to then take up information about the context and one's circumstances that the brain further connects to information about the body, thoughts, feelings, knowledge that is stored in long-term memory, and relatively recent experiences: it is a kind of "holistic inter-person travelling." Taking into account the context and circumstances of the near-present moment (i.e., which can include information that goes somewhat further back into the past), can help to interpret oneself in the present situational moment and to make a decision or to consider a probable decision. The probable decision is illustrated by the dotted blue line in Figure 3: before being sure, another feedback loop can be set off (a) to create time to consider the suitability of certain kinds of behavior and (b) to provide for further information about possibly suitable behavior. The specific moments in the situation as they are captured by the individual are influenced by person-specific timescales (i.e., temporal window frames or the degree of intensity of thoughts and feelings for a specific observation moment regarding what is happening in the situation). Finally, each feedback loop brings with it the essence of previous feedback loops as a consequence of one's actual behavior in the interpreted storyline of the situations, which is why these feedback loops all begin in the behavior box in Figure 3, but they have different places in the person-characteristics box to indicate that it is holistic work in progress that can add various personal information, although it can be assumed that this personal information is not ad hoc information (i.e., memories from many years back) because the near-present situation likely will leave its stamp on remembering (c.f., Harris et al., 2016).

To conclude, the discussion in this article shows that the reaction processes of living organisms in external environments, such as metabolism and human behavior, are not just complex, but also dynamic in terms of being able to respond quickly to changes in the environment. Although most biological processes take place with the help of specialisms (e.g., organs) and counterpart systems, it hardly simplifies the complexity and dynamics of the processes because the specialisms and counterpart systems are not self-sufficient "islands," rather they are interconnected holistically as parts of the organism in the environment. Nevertheless, the possibility to change, on the one hand, slowly through certain degrees, ranges, and thresholds regarding functioning and, on the other hand, quickly by redirecting functioning, suggests that flexibility in human behavioral decision-making can be open to scientific inquiry if patterns or tendencies could be found that make personal characteristics known. Although, it does raise methodological questions about collecting and analyzing data appropriately, the study of human behavioral flexibility via feedback loops might help to obtain a more thorough understanding of personal ways of deciding on maintaining behavioral balance in actual situation across time as a means to supplement the meaning of inter-individual groups.

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