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Essay

# Reflections on the Role of Differentiation Processes in Forming Behavioral Phenotypes: Can These Processes Replace the Concepts of Plastic Phenotype and Reversible Plastic Phenotype?

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**Simple Summary:** In this essay, I argue that the notions of plastic phenotype and reversible plastic phenotype are not compatible with the knowledge that we currently have about the processes involved in the development of phenotypes. I also argue that all phenotypes are plastic and that reversibility has not been demonstrated; therefore, I maintain that describing a phenotype with these adjectives is useless. The argument is organized around comparative analyses of the correlative evolution of developmental and cognitive processes. It is focused on the development of behavioral phenotypes from the differentiation processes that occur during their formation.

**Abstract:** Comparative studies of various aspects of human development indicate that it has slowed down during evolution compared to the development of the great apes. From multiple areas of knowledge and at separate times, several authors have related this characteristic to behavioral phenotypic plasticity. Throughout the text, I keep a comparative perspective that emphasizes the crucial role that the selection of juvenile behavior has played in shaping cognitive behavior in various animal species, a critical factor in the evolution of cognitive differentiation. Anchored to the positive correlative evolution between cognitive behavior and modes of development, this perspective leads to an argument in favor of replacing the concept of behavioral plasticity with that of cognitive differentiation. Behind the classical concept of behavioral plasticity, there is a link between the purpose of the behavior and its genotype; likewise, behind this concept, in any cognitive behavior, there are different pre-existing phenotypic possibilities from a single genotype, each one depending on an earlier evolutionary interaction between genotype and environment. In conceptual contrast, the purpose of a behavioral phenotype developed from a process of cognitive and neural differentiation is evolutionarily independent of previous environmental interaction (i.e., it does not have any preexisting purpose). Understanding the neurocognitive aspects of behavioral phenotypes will allow researchers from several evolutionary disciplines to decouple behavioral purpose from genotype during evolutionary processes.

**Keywords:** behavioral plasticity; human neoteny; adult neuronal differentiation

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## 1. Introduction

### *Human Development Has Slowed Down During Evolution*

Research comparing various aspects of development shows that human development is slower than compared to the great apes, which indicates that the last common ancestor we share with them had a faster development than ours or that our development has slowed down during the last few millions of evolution [1]. This evolutionary change from the ancestral developmental pattern is called neoteny, a type of heterochrony (i.e., changes in the timing of the appearance of a trait relative to the life span of an organism and changes in the rate of development of the trait relative to the ancestral

trait) [1]. Human neoteny is evident in various characteristics, including morphological (as a flattened and broad face; physiological (as a weaker secretion of stress hormones) [2], behavioral (as a prolonged period of dependence after weaning), and cognitive (as an extended learning period), among others [1].

Over time, this phenomenon of neoteny has caught the attention of many researchers in evolution. In the early decades of the 20th century, Louis Bolk conducted developmental studies on several species of primates [3–5]. His comparative approach allowed him to observe, for instance, that, in infants, the position of the foramen magnum does not vary significantly between species, and this location is like that of adult humans. However, in other species, the position of this structure changes considerably during development. In simple terms, the skull of adult humans retains the characteristics of primate infants. Finally, in 1926, Bolk put forward his theory of anthropogenesis as a fetalization process [5].

During the rest of the 20th century, from an evolutionary point of view, the slowdown in human development imposed the need to analyze what the adaptive benefits and costs associated with this trait would have been [6]. In this sense, the earliest adaptive function of human neoteny is that of Konrad Lorenz, presented in 1950 in his essay “Part and Parcel in Animal and Human Societies. A methodological discussion.” [7]. Lorenz explained the concept of the innate releasing mechanism as an adaptation, allowing organisms to react adaptively to biologically relevant situations without needing prior experience. He discussed the social function of this adaptation in humans, focusing on the reaction of tenderness toward infant faces. According to him, specific physical characteristics such as a large head, preponderance of the skull, large low-set eyes, profoundly bulging cheeks, thick, short limbs, elastic consistency, and clumsy movements make human beings as infants, as well as their imitations (specifically, dolls, stuffed animals, or cartoons), seem cute and attractive enough to inhibit our aggressive impulses. He hypothesized that “[the] quality that [human] has of being an unfinished being is a gift that we must thank neoteny itself for. However, for its part, neoteny is probably a consequence of human domestication” [7]. Lorenz did not claim that behavioral neoteny had been directly selected in any way but proposed that the relationship between neoteny and cognition would be a fortunate byproduct of human domestication as an evolutionary selective process diminishing intragroup aggression.

Decades later, Stephen Jay Gould also attributed an essential role to heterochrony in human evolution. However, he shifted the focus of selective forces from morphological to behavioral: “Neoteny has been a (probably the) major determinant of human evolution. [...] Retardation as a life-history strategy for longer learning and socialization may be far more important in human evolution than any of its morphological consequences.” [1].

### *Slowed Development and Evolution of Cognition*

Despite their differing proposals on the evolutionary process resulting in neoteny, both Lorenz and Gould underscored the crucial role of slowed development in the evolution of human cognition. They also drew parallels between some notions of human adult cognition and the cognition of young animals, such as the presence of play behaviors in young animals and young and adult humans. More recently, other authors have also recognized the adaptive role of neoteny in the evolution of human cognition [8].

Evolutionary analysis implies recognizing the adaptive advantages of slowed development and its disadvantages or evolutionary costs. In this sense, for example, Bjorklund [8] pointed out that the physical dependence of human babies is much greater than that of other mammals because, at first, they must be carried and held by their mothers for an extended period. Even later, when they can move independently, they still do not acquire the physical and mental skills necessary for independence. In other words, prolonging the infant and juvenile stages produced by the neotenic process in humans has implied the need for prolonged altricial care.

However, most authors agree that the selective costs involved in extending parental care are outweighed by the benefits or advantages offered by neoteny in terms of neural and behavioral plasticity, giving the possibility of increasing cognitive development, both by allowing a more

extended safe period of non-social learning and by facilitating social learning [8,9]. This process may have been an evolutionary pathway by which humans and very diverse species of phylogenetically distant animal groups developed remarkable cognitive abilities. Such is the case of the animal families Delphinidae [10], Psittacidae [11], Corvidae [12], Octopodidae [13], and Hominidae [14]. In support of this, several comparative analyses in birds and mammals have shown that developmental modes (on a continuum from precocial to altricial) are positively associated with both direct measures of cognition (i.e., performance on cognitive tests [15,16] and indirect measures of cognition (e.g., brain size relative to body size [9] or size of the telencephalon relative to total brain mass [17]).

Cognitive processes, whether those called elementary, which involve learning, memory, and emotions, or those called complex, which involve thinking, reasoning, problem-solving, and decision-making [18], are interrelated with phenotypic plasticity because they allow an organism to generate complementarity with its environment. The phenotypic plasticity interrelationships have cognitive-behavioral and neural aspects [8].

### *Phenotypic Plasticity*

The notion of phenotypic plasticity derives from the concept of phenotype. The latter is related to the genotype. However, how the relationship between the two concepts is conceived may vary between research programs and those who carry them out [19]. At the beginning of this essay, the genotype is understood as a specific conformation of nucleic acids, and the phenotype is understood as the product of its expression in a particular environment [19]. However, as my argument progresses, I intend to move to a less distinctive conception between both concepts and more inclusive in the processual sense so that the genotype is understood as an organizational structure that marks the beginning of a developmental process that, at various stages of its progression, can be observed as a successive series of phenotypes [19].

Phenotypic plasticity is often defined as a phenotypic “change” in individual organisms associated with different environments [20,21]. The term “change” is significant here, as it implies a departure from an original plan (i.e., something that supposedly had to have another form), a notion I will explore further later. This concept is significant in contemporary evolutionary biology [22–24]. In several animal species, phenotypic plasticity is more frequent in the early stages than in the later stages of life [25,26].

Several types of phenotypic plasticity have been described based on the durability of the phenotypic change. The first type, known as irreversible plastic phenotype (also known as plastic phenotype and developmental plastic phenotype [27]), involves the ability of developing organisms to produce different phenotypes in correspondence with other environments [28]. The second type, known as reversible plastic phenotype (also known as reversible plasticity, acclimation, activational plasticity, and contextual plasticity [27]), refers to situations in which an individual throughout their life can reversibly and repeatedly modify their phenotype in response to the conditions of its environment [27]. I will return to these distinctions later.

Contemporary studies on phenotypic plasticity acknowledge that phenotypes emerge from the interaction between genes and the environment [23,29]. However, Sonia Sultan [29] explained that even in this perspective, where gene expression is inherently context-dependent, the concept of a plastic phenotype as an expected expression of the genotype sometimes persists. Moreover, she clarified that the norms of reaction (i.e., “[...] the array of phenotypes that will be developed by genotype over an array of environments.” [30]) as genotype properties have not been empirically supported. She further explained that several phenotypic expressions are influenced by inherited environmental information, immediate epigenetic modifications of the genome, and conditions encountered previously within the lifecycle. Therefore, she considered phenotypic variations “unscripted” developmental responses to environments [29]. In this line of thought, I will refer to phenotypic plasticity as a developmental process that generates complementarity between the organism and its environment [22]. As I will discuss later, understanding phenotypes as developmental processes provides a consistent approach with a constructive vision of establishing

the correspondence between the organism and its environment, especially in the context of behavioral phenotypic plasticity.

Phenotypic plasticity is a descriptive concept of a phenomenon widespread in all living organisms [31]. This phenomenon describes the ability of an organism to develop different traits, some of which are temporary adjustments, while others are persistent throughout the life of the organism [31]. This diversity has led to different distinctions and classifications of phenotypic plasticity types. For instance, Mirko Farina recently explained that various phenotypic plasticity processes contribute to the evolution of cognition. The philosopher delineated six types of phenotypic plasticity: immunological plasticity, morphological plasticity, physiological plasticity, neural plasticity, cognitive plasticity, and adaptive cultural plasticity. Farina emphasized that behavioral plasticity includes the last five types. He also pointed out that neural plasticity can be structural and functional [32]. His way of nesting the types of plasticity helped develop the following argument.

### *Behavioral Phenotypic Plasticity*

Behavioral phenotypic plasticity allows organisms to adjust their behavior to different situations, helping them to dovetail better into various environments and circumstances.

In the classical concept of behavioral plasticity (i.e., the ability of a genotype to produce different behaviors across environments [33]), there is a connection between the behavior's purpose and the organism's genetic makeup. This connection is assumed to be rooted in the organism's evolutionary history (i.e., to be influenced by past interactions between the genotype and various environments) [29]. As a result of these interactions, a single genotype would give rise to different pre-existing behavioral possibilities (i.e., the reaction norms), each associated with its purpose.

However, the generation of behavior implies not only the formation of a movement but also the elaboration of a specific objective. Behavior is an integral part of cognition. It serves the functions of expressing, carrying out, acquiring, and modulating the flow of information between the organism and its environment and adjusting internal states [34]. In behavior, intentions and plans are carried out rather than muscular movements and, consequently, strictly, what is observed are not movements but actions. The same action can be carried out with different movements, and the same movement can be used for other actions. Actions are structured by perception: they are cognitive [34].

In this sense, developing a behavioral phenotype involves coordinating internal sensations, body awareness, and perception of the external environment to establish a goal and carry out a movement. For example, eating may involve experiencing hunger, searching for food, moving effectively, identifying the edible item, and ingesting it. Behavior, like other phenotypic processes, is an ongoing modular process. Its alignment with the environment requires the successive integration of several phenotypes (for instance, cognitive and neural phenotypes, among many other phenotypical processes). It is necessary to calibrate movement with the goal in real-time to form a behavioral phenotype, which implies incorporating several cognitive processes, such as interoception, proprioception, and exteroception. In short, a behavioral phenotype depends on other phenotypes, such as neural and cognitive [32]. The goal of a particular behavior must be considered a property of the interaction between the organism and its environment; therefore, it cannot be a property of the genotype but is a property of the phenotype. Importantly, this link is distinct from genetic assimilation or epigenetics [35] because each new interaction between genotype and environment leads to a unique phenotypic outcome, creating what Sultan called a "genotype-environment entanglement" [29].

I believe that to define behavioral phenotypic plasticity, it is necessary to separate the purpose of the behavior from its genetic aspect. Therefore, I expand the processual definition of phenotypic plasticity mentioned earlier [22] to include any other developmental process that creates complementarity between the organism and its environment through behavior. Following the embryological tradition, I use the second meaning of plasticity, giving it the sense of a plastic process or a system that takes shape from its interaction with the environment [36,37]. Thus, any behavior can be seen as the result of a developmental plastic phenotype.

### *Neural Phenotypic Plasticity*

The term neural plasticity refers to the ability of the brain of organisms to create and adjust the structure and function of neural networks in response to their environment or a lesion [37]. Plasticity occurs at different organizational levels of the nervous system. Thus, we can speak of nervous tissue plasticity, neuronal or glial plasticity, synaptic plasticity, etc. [37]. In humans, these processes are crucial for learning from experience, forming memories, and other cognitive and behavioral functions. While particularly important in early life, this possibility continues into old age. The brain consistently reorganizes and reshapes itself through interactions with the environment and peripheral organs [38].

Like any other organ, the brain's formation begins as a process of cellular differentiation. At early stages, brain development follows a sequence of steps largely conserved across species [39]. However, the duration and speed of the unfolding processes vary across and within species. It also varies among brain regions and cell identities [39,40]. As maturation progresses, neurons grow, increasing their size, morphological complexity, excitability, and connectivity [39]. It is important to note that epigenetic pathways regulate neural events in the brain and other parts of the central nervous system throughout life [39,41]. Human brain development, particularly its neuronal maturation, is prolonged compared to other species [39]. Neural phenotypic plasticity is fundamental to brain development [42].

The brain exhibits various types of phenotypic plasticity based on its durability. Some electrophysiological states are fleeting, while others are a permanent part of their anatomical structure. Neural plasticity can lead to anatomical changes at different levels. For instance, the formation of new connections between neurons (synaptic plasticity) enables the early development of neuronal networks, which can later be refined through experience or altered due to injury [43]. Two additional forms of plasticity occur in the adult brains of various species, including humans. These are the functional differentiation of neurons from stem cells (adult neurogenesis) and the functional differentiation of neurons from immature cells (cortical immature neurons) [43]. These two cellular differentiation processes vary widely across vertebrate species regarding their developmental trajectories, but both are believed to play a dominant role in cognitive processes [43].

These neural aspects are related to human neoteny, and human synaptic neoteny has been linked to the evolution of human cognition [44].

### *Cognitive Phenotypic Plasticity*

Neural and behavioral phenotypic processes have cognitive aspects. As Cecilia Heyes explained, cognition is a generic term referring to various phenomena such as learning, memory, perception, attention, categorization, and motor control that, in turn, consist of multiple processes [45]. According to Cecilia Heyes, there are two ways of understanding cognitive processes. One view suggests that cognitive processes involve reasoning, that they operate with propositions (i.e., statement-like representations), and that they involve desires, beliefs, and other intentional mental states; furthermore, these processes could be available to consciousness. The other view suggests that a process is cognitive when it adaptively uses information and can be modeled as an algorithm [45]. The latter definition aligns better with the content of this text.

A cognitive phenotype is an informative solution to a problem by appropriately deploying relevant knowledge made available through interoception, proprioception, and exteroception. Cognitive phenotypic plasticity refers to information processes (i.e., cognitive phenotypes) produced according to different percepts [46].

Animal cognition is plastically adjusted to the environment through individual experience. A striking example of this cognitive phenotypic plasticity is observed when comparing individuals raised in impoverished environments with individuals raised in enriched environments. Enriched environments imply changes in the brain and improve cognitive abilities in various species. For example, Montalbano and colleagues showed that guppy fish that were raised in a fish tank with other individuals, gravel on the bottom, natural and artificial plants, and live prey showed better performance in tests of learning (i.e., where the individual must learn to discriminate a color to obtain

a reward), reversal learning (i.e., where the individual has to choose the color option that was not rewarded in the learning test), and self-control (i.e., where the individual must refrain from attacking prey that is behind a transparent barrier) compared to individuals that were raised in impoverished environments [47].

There is evidence that cognitive flexibility is associated with levels of neurogenesis in the hippocampus [48]. In mice, cognitive decline associated with aging involves a reduced ability to adjust previous experiences to solve tasks involving new combinations of familiar contexts and cues, and it is correlated with decreased numbers of mature neurons or newly generated immature precursors in the hippocampus [48]. However, it is unclear what all the neural features that enable complex animal cognition might be [49].

#### *From Types of Phenotypic Plasticity to Aspects of Phenotypic Processes of Differentiation*

Emilie Snell-Rood [33] distinguished two types of behavioral phenotypic plasticity: developmental and activational. As I understand her approach, developmental-behavioral phenotypic plasticity can be tied to different developmental trajectories deployed in various environments. In this definition, developmental-behavioral phenotypic plasticity encompasses morphological, physiological, and neural aspects relevant to a particular behavior. Instead, activational-behavioral phenotypic plasticity is an immediate response to the environment referring to the differential activation of an underlying neuronal and muscle network [33]. The distinction between the two types of behavioral phenotypic plasticity rests in the process associated with the neural network. The developmental type refers to the conformation of the network, while the activational refers to the initiation of those networks. There is a difference in the time scale. Snell-Rood warns her readers that a single behavior may include aspects of both types of behavioral phenotypic plasticity [33]. The instance she uses is that: “(...) listening to a conspecific song may result in activational plasticity in the short term (such as territory defense) and developmental plasticity in the long term (such as learning neighbor songs or changing testosterone expression)” [33]. The theorist also enlisted the evolutionary balance between costs and benefits associated with each type of behavioral phenotypic plasticity: increasing the activational type would cover the costs of increasing the number of neurons while increasing the developmental type would cover the costs of cognitive processes [33]. She also explained that the environmental variation between generations or coarse-grained environmental variation would facilitate the evolution of developmental-behavioral phenotypic plasticity; in contrast, the environmental variation within the lifetime of an organism or fine-grained variation would facilitate the evolution of activational-behavioral phenotypic plasticity. It is important to note that Snell-Rood recognized the importance of behavior in structuring environmental variation (in fact, she distinguished various methods that could potentially increase, reduce, or maintain environmental variation) [33].

In this essay, I argue that the activation behavioral phenotype described by Snell-Rood [33], also called reversible plastic phenotype, could be considered a step when constituting a developmental-behavioral phenotype, also called irreversible plastic phenotype. In this sense, it could be said that the activational type is an indeterminate developmental-behavioral phenotype as it still corresponds to multiple components of the environment and not just one. The beginning of an indeterminate phenotypic process would occur from the conformation of the percept or the activation of neural networks that, consecutively, would have to reduce the possibilities of action of the organism. Reducing these possibilities would co-occur with the search for correspondence through cognitive processes of recognition, categorization, characterization, comparison, and evaluation. Thus, while the system advances in the conformation of the percept, its possibilities of action are successively reduced and specified, and it can be said that the phenotype is in the process of determination. A differentiation process would occur in parallel with each aspect of this determination. For example, in the cellular aspect, this process of phenotypic determination would correspond to cellular differentiation. Processes of this type would be momentary but would allow a developmental-behavioral phenotype to have time to form itself, that is, to reach a more precise correspondence with the environment. Accordingly, the prior formation of multiple categories, such as color or shape,

which are relevant aspects of behavioral phenotypes already formed or previously determined during development, would be involved in the formation of behavior in front of a novel object through the activation of specific neuronal networks based on its categorizable characteristics, such as its color or shape. After this moment of the phenotypic process, probably after a restful sleep, a new neuronal differentiation process would intervene, leading to the development of a much more precise and, in truth, specifiable behavioral phenotype.

The cellular systems that correspond to these processes are very sophisticated and contain diverse elements (e.g., associative, inhibitory, and excitatory) organized hierarchically [50]. I intend not to review the state of the art in this matter.

I think, for instance, of the moment of a person's first encounter with another and the moments of their subsequent encounters. When a person has their first interaction with someone new, a neural network is activated in their brain. This activation can happen when they see the person's face, hear their name, or engage with them by any other sensory modality or by two or more modalities combined in any way. At this moment of interaction, the precision of the network concerning that person's identity depends on the categories already formed in the brain and the possibility of including the person in those categories from what is being perceived, such as whether the person is a colleague or a teacher or if they are older or younger. During this initial encounter, the ongoing cognitive process of fencing or reducing the possibilities of action toward the new acquaintance depends on the cognitive phenotypes already formed in the brain. The various neural networks that can be activated are not specific to that person, so the resulting actions, such as a polite greeting, are impersonal. However, in subsequent encounters, the person will be recognized individually, guiding behavior toward them in a more specific and familiar manner. This process involves both neural and cognitive aspects. Similar processes apply to other components of the environment, like physical objects, chemical properties, prey, predators, and more. However, I will use this example to further my argument.

Individual recognition is a crucial cognitive ability for social interactions in various animal groups, including vertebrates like fish, birds, and mammals and invertebrates like arthropods. This capacity is essential for appropriate behavior in diverse social contexts like cooperation, competition, and parenting. Regardless of the sensory modality each group uses (e.g., chemical, visual, or auditory), their neural systems must be able to differentiate individuals [51]. Facial recognition has been widely studied in humans, with impressive results. For example, Quiroga and colleagues found that a specific region of the brain contains neurons selectively activated by different instances of a well-known actress, whether in the form of her picture, a drawing, or her name written [52]. The authors were cautious in interpreting their data but suggested that future research might reveal an explicit and invariant encoding of visual percepts [52]. Moreover, studies indicate that new neurons added to an adult brain could replace older neurons or provide additional cells to expand an existing network [53]. With this evidence in mind, immature neurons can likely be utilized to develop the finest phenotypes needed to specify the interaction with the environment, either neuronal, cognitive, behavioral, or else.

Recently, Gordon and colleagues [54] generated a series of high-fidelity, highly individual-specific functional connectomes. This is a much less invasive neuroimaging technique than the one described above, but it also provides evidence that neural phenotypes are generated and specified through interaction with the environment. Their approach revealed interindividual variability in the spatial and organizational distribution of brain networks associated with the cognitive tasks performed by the individuals studied. The authors reflected that these interpersonal variations in connectomes may be related to demographic, cognitive, or personal differences [54].

There is also evidence that facial recognition in other animals occurs through environmental interaction with the environment. For example, in the case of two species of the same genus of wasps, geographic variation in individual face learning is not based on genes but on social experience: the individual learns to distinguish and remember the unique phenotypic features of another individual's face and to associate them with aggressive and affiliative social behavior [51].

#### 4. Discussion

In this essay, I argue that the notions of irreversible plastic phenotype and reversible plastic phenotype are incompatible with the current knowledge about the processes involved in developing phenotypes. I also say that all phenotypes are plastic and that reversibility has not been demonstrated; therefore, I maintain that describing a phenotype with these adjectives is useless. I argue that so-called reversible plastic behavioral phenotypes could be considered stages in the constitution of highly differentiated irreversible plastic behavioral phenotypes.

I have presented an explanatory hypothesis about the relationship between neural differentiation and the creation of a novel behavioral phenotype, a topic that is inherently complex and multifaceted. This hypothesis, which includes neuronal, neural, cognitive, and muscular aspects, is a testament to the intricate nature of phenotypic development. It is important to note that, in this view, elaborating the specific goal of this behavioral phenotype (i.e., its purpose) requires interaction between the organism and its environment. Therefore, perceptual construction is considered a phenotypic property. I start from the premise that every phenotype is plastic since its generation is contextualized. Furthermore, I argue that interactions between the organism and its environment (whether material or mental) can occur from already-established behavioral phenotypes (i.e., previously generated in the life of the organism). These interactions will reach certain degrees of generic complementarity but not all the specificity some interactions require (for example, social interactions). The generation of a more specialized behavioral phenotype is slower than the generation of a more generalized behavioral phenotype. Generating a new behavioral phenotype that increases complementarity with the environment requires the activation of previously established neural networks (ranging, for example, from sensorimotor structuring to the formation of a percept and an intention). Still, new neural units are required to form a more specialized network. In this sense, novel behavioral phenotypes imply the functional differentiation of new cells. Greater behavioral specificity (for example, behaving with a person uniquely depending on their recognition and the circumstance in which the interaction is occurring) is acquired by forming a neural network with a distinctive element of the percept.

An essential characteristic of the hypothesis presented here is that all phenotypes are irreversible because their creation involves differentiation processes, whether functional, cellular, or of any other type. As I have argued above, the hypothesis agrees that differentiation processes are hierarchical and irreversible. The prolongation of the infantile and juvenile stages produced by the neotenic process in humans has implied the need for prolonged altricial care. Consequently, it has allowed the prolongation of the creation of highly differentiated behavioral phenotypes into adulthood. This process has not been exclusive to the human species. It may have been the evolutionary solution to the need to develop remarkable cognitive capacities in various phylogenetically distant animal species since these modes of development show positive correlative evolution with direct and indirect measures of cognition. It seems feasible to speculate that in species with slowed development compared to the speed of development in the ancestor species (i.e., neotenus), new highly specialized behavioral phenotypes can be created through neural differentiation during most of life. This hypothesis refers particularly to behavioral phenotypes (and so, also neural and cognitive phenotypes) but can be generalized to any phenotype (i.e., physiological, hormonal, morphological, etc.).

#### 5. Conclusions

The notions of irreversible and reversible plastic phenotypes are incompatible with current knowledge about the processes involved in developing phenotypes. All phenotypes are plastic, and they are not reversible. Describing a phenotype with these adjectives is useless. The so-called reversible plastic behavioral phenotypes could be considered stages in the constitution of highly differentiated irreversible plastic behavioral phenotypes.

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