



REVIEW ARTICLE

Meaning and Agency in Biological Autonomy: The Motor Image in Self Integration

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Abstract

Understanding the physical basis for mediating personal integration constitutes an important domain of investigation for physical and mental health. Among its singular determinants are behavioral influences that plastically shape integration through motor plans and executed movements, and which also fundamentally contribute to cognition. A key requirement of the motor plan is that of framing motions in the context of an agent, where the body is appropriated as an origin of action emergence. Embodied, motor actions propel the consumption of free energy reserves needed to sustain organismal operation in its entirety thereby driving global integration. Free energy influences, however, track energy use homeostatically and are motivationally agnostic with respect to goal selection, suggesting that their influence on integration is broadly systemic and nonspecific. Current research indicates, nonetheless, that the motor plan is teleologically oriented and that motor behaviors are structured uniquely in the context of specific goals. Such goal specific information does not appear to be contained in the action identification processes of the motor plan, however, but instead appears to be bound to the self representation, which is neurally coded in the context of the body. Neural correlates for behavioral integration are thus likely to include two separate and independently engaged global mechanisms: a) A non-specific, bottom up influence associated with enhancing energy efficiency, and b) A goal specific, top down influence that is autonomously executed. The physical instantiation of such strategies likely reflects a metaphysical need for increasing behavioral range that can be autonomously accessed, and has a positive bearing on existential psychology.

Keywords

Motor image, Neural integration, Free energy principle, Body representation

Introduction

Understanding the physical principles that enable

personal integration constitutes an important domain of investigation for physical and mental health. The question of why the neural architecture is ordered to express human ontological faculties as opposed to how it does so, for example, is significant for investing physical reality with anthropological meaning; hence, it is of importance for existential psychology. Among the more extensively studied behaviors shaping integration are motor plans and movements, which are postulated to be fundamental also to cognition [1]; accordingly, they are likely to be singular determinants of mental health.

Much evidence now indicates that an essential prelude to motor movements is the construction of the motor image [2]. In its current formulation the concept of the motor image describes a covert action undertaken mentally as a simulation of non-executed action. Defined in this manner it is understood to contain the elements of the prospective series of motions that are planned for execution. The simulation of a planned trajectory that may then be compared with actions actually undertaken affords the singular prospect of identifying self made actions when reafferent signals match the representational content of the anticipated trajectory [3,4]. Current studies evidence this advantaging when the motor command is sent to the sensory cortex for direct comparison with afferent input from the executed planning events.

Critically, a key requirement in the construction of the motor plan is the need to frame motions in the context of a source [5]. Infants perseverating toward a hidden object where they have previously reached for the object rather than where they have seen it last

hidden, for example, is a failure in an executive control task, an observation showing that such infants are unable to contextualize individual motions. Because motor actions are undertaken in the world, they are necessarily interactivist, which is constitutive to their execution. In the natural world these interactions are open and conditioned by the multiplicity of possibilities that regularly and continually intrude in the performance space. As natural manifestations of a situated existence, such interactions are made in a context-sensitive manner that combine organism environment and organism interior relations in a seamless whole; hence, they are necessarily embodied and, in the construction of the motor plan, referential [6].

Current studies show that the need for contextualizing discrete motions is physically realized through the appropriation of the body as a source of action emergence, where the representational content of the body is captured in neural activity within the brain. The body's representation is fundamental to the construction of the motor image, since in its absence-as in young children, for example-the individual is incapable of orchestrating a new trajectory when faced with novel changes to structured motor activity [7]. In ongoing motions this framework functions as a domain of stability where spatial and temporal coordinates are continually updated, creating a shifting stability-flexibility junction that has been likened to a material phase change [5].

Embodied, motor actions propel the consumption of free energy reserves that are needed to sustain organismal operation in its entirety. Prigogine, for example, early concluded in models of cellular molecular and harmonic exchange that both the conversion and dissipation of energy were openly distributed within the topological perimeter of the organism, a zone he identified as the organism's phase space. Due to the persistence of organismal operation, such energy use is ongoing, transforming acquired free energy to a low energy entropic form that is continually discharged to the environment [8]. Maintenance of this space thus requires an internal and recursive remodeling that reconstitutes the organism's internal organization [9]. Accordingly, the fundamental prerequisite for energy frames objectively ordered performance, where it functions to constrain behavior and meters outcome. In consequence, it has bearing on personal integration.

In the singular circumstances of life's physico-chemical origin the dominant criterion of viability is that dictated chiefly, by free energy availability, which thereby becomes definitional for autonomous existence. By extension, energy constraints pose the chief existential danger to ancient life. As a fundamental prerequisite for autonomous life free energy acquisition retains a key role for the viability of modern, highly advanced organisms, where it likewise drives energy harvesting. Like ancient organisms the behavioral

performance of advanced organisms is also greatly influenced by energy requirements with neural and other mechanisms evolved to accommodate acquisition and to regulate energy use in performance.

This factor accordingly, has propelled a search for neural mechanisms that dictate how energy use regulates organismal behavior. Among the chief mechanisms postulated are those conforming to a Free Energy Principle of active inference that maximizes energy efficiency by minimizing embodied free energy use [10]. Failure to accommodate the principle is proposed to lead, ultimately, to an inability to resist thermodynamic imperatives of entropic equilibrium. Specifically, minimization entails making inferences about energy use from sensory information based on evolutionary, developmental, and experiential models. Accordingly, inferences about free energy consumption inform both the perception of action consequences and their formulation for execution. Indeed, free energy minimization is proposed to drive perspective taking, regulating the "switch" between perception, conception, and action [11].

Since these inferencing mechanisms are likely to be tightly coupled to whole body movement - in order to gauge energy use through multiple cell and circuit dynamics - proponents of the Free Energy Principle are committed to an embodied view of cognition where assessments of energy use function as a strong determinant of cognitive structure and dynamics [11,12]. Inferencing, in consequence, can be expected to influence motor plan construction by linking energy use to bodily representations. Hence, they can be expected to shape the integration of behavior by selecting motor plans that maximize energy efficiency, thereby integrating exterior interactions with interior metabolism.

As a fundamental regulator of actions the proposed free energy determinants situate as efficient causal modes of natural reality. In other words the integration of performance is a causal outcome of the drive to free energy minima alone, or conversely, the escape from entropy wells. Such explanations for the role of energy constraints are notably devoid of intentional actions, which uniquely define behavioral outcome. In fact how such constraints can be selectively exercised is not addressed. Commitments to embodied free energy inferencing, rather, notably posit that there is evolutionary advantage in ordering the cognition of space in order to control spatially distributed information and the consequences of actions; hence, the ordering of cognition drives perspective taking. In particular, probabilistic inferencing is proposed to govern updating and to integrate performance supramodally through affective arbitration [11,13], where consciousness occupies the apex of an algorithmic interactive mechanism. Accordingly, they leave unanswered,

among other observations, the varied appearance of organismally integrated behaviors that are manifestly evident in nature's panoply, and the successive accumulation of a complex and hierarchical behavioral repertoire in evolutionary advance. Indeed, an explanatory commitment to free energy determinants alone implies an absence of goal directed actions and the subjecting of organismal variation to arbitrary and stochastic determination. The variety and advance of integrated behavior thus raise the question of both the stimulus and mechanism(s) that may have yielded such profusion; that is, whether energy use is the sole or even a major determinant of bodily integration in advanced species.

Intuitively, by contrast, the motor image situates as a teleological undertaking. Indeed, intentional actions are uniquely constituted pursuits. Hence, their effect on behavioral integration is characterized by the specificity of their orientation. Accordingly this paper will consider whether the implementation of energy inferencing or that of goal specific information in the motor image may drive the integration of ontologically unique behavior. Whether and how goal pursuit may independently influence integration, moreover, is usefully considered in the context of underwriting self meaning.

Motor Plans and Energy Constraints: Action Identification

Neural representations of energy use reflect global homeostasis

Enabling the integration of motor behaviors are a host of molecular and circuit mechanisms that plastically shape the brain and peripheral nervous system throughout the life of the individual. Skill acquisition, for example, is due to a plastically driven, neural reorganization [14] that facilitates habitual and smooth responses to external or mental stimuli. Accordingly, neuroplasticity constitutes a key neural design enabling the individual to successfully relate himself to the external world [15], assisting in monitoring, comprehending, and engaging a constantly changing environment [16,17]. Hebb's early articulation of the synaptic activity strengthening hypothesis, in fact, led to the identification of numerous mechanisms activated during neural activity, which shape neural circuits to accommodate experiential input, including sub cellular and molecular alterations, microcircuit modifications, and network restructuring, effects mediated on both local and global scales in brain tissue and over short and prolonged time spans [15,18].

Significantly, neural circuits in the brain are molded by sensorial input from the body to generate a functional synergy that is operational in "real time" dynamic behavior. Because this input is uniquely characterized with respect to its bodily mooring, the brain "perceives" the world in the context of the body, that is, motor

responses are determined by the body's configuration [19]. Indeed the choice of sensory modalities shapes the transmission of sensory input, controlling information input that shapes the brain [20].

Motor behaviors further the process of integration by bridging sensorial input with the execution of motor plans. Significantly, energy used in the implementation of motor plans is immanent and holistic, and affects organismal processes as a whole. For example, Prigogine specifically links free energy consumption to the full range of molecular events that are delimited by the topological perimeter of the organisms. In a topologically closed system this means that there is a direct link between organismal performance and energy expenditure, which thus acts as a constraint on behavioral range. This is to say that since organisms possess a global organizational network directed to self maintenance in a continual cycle of organismal action and reconstitution [21], they are thereby limited by global energy needs. In the primitive circumstances described by Prigogine, behavioral ranges are dominated by direct energy acquisition, and there is a direct relation between the ordered configuration of the primitive organism and the energy required to sustain it. This direct relationship between energy use, entropy generation and systemic order is, in fact, pervasive throughout living systems and essential for existence in far from equilibrium states. Formulated in the context of the context of bodily processes, the motor plan thus embraces the full complement of reactions entailed in metabolism during motor performance.

In recognition of this holistic demand the Free Energy Principle proposes that probabilistic inferences about maximizing the energy efficiency likely influence performance behavior; that is, inscribed in the motor planning trajectories are causal probabilistic inferences about energy use in interactive scenarios [22]. In other words, within the representational content of the motor image there exist neural constraints permitting only a certain range of behavioral outcomes that, accordingly, minimize the use of energy; hence, these constitute regulatory mechanisms for maximizing body-wide energy efficiency. Indeed, these cognitive structures function to track the state of the body and encode it [11]. As an objectively assessed, holistic outcome, however, the tracking of energy use is indirectly related to performance execution, where it acts to gate but not define motor imagery. Accordingly, its functional relevance is systemic, where it is employed homoeostatically as a device for preserving autonomy. As a constitutive feature of the living condition, global energy consumption, and assessments thereof, are therefore agnostic with respect to teleological motivation. Regardless of the activity undertaken, provisionally, assessments are structured in the context of a homeostatic equilibrium; that is, they are determined in the context of systemic need and regulated as a

function of state. In fact, behavior requiring less energy than needed to preserve homeostasis is potentially open to motor behaviors indefinite in scope, thus constituting a space of unrestricted performance options with indefinite integrative potential. In advanced organisms that have evolved motor plan mechanisms, indeed, non-linear stochastic variation enables the exploration of an indefinite range of neural events that may participate in the generation of motor activities [23].

Action identification is teleologically neutral: A cybernetic confirmation of motor predictions

From among this broad group of potential actions, motor plans serve as the raw material for plastic integration. Circuit ensembles used for constructing plans and executing motor movements are strengthened and molded according to the form of the motor plan selected. Current research suggests, however, that selection specific information is not contained in the plan's action identification domain; that is, the intentions and desires for a unique goal [2] are not directly linked to their recognition.

This absence is in fact suggested from experimental studies that have classically underwritten the motor image paradigm. Results from these studies reveal that action identification depends upon the recognition of an a priori selected motor sequence involving mutual and complementary contributions from central and peripheral nervous systems. Lashley's observations notably showed that subjects were able to generate actions despite deafferentation of spinal dorsal motor roots [24], that is, a lesion in the immediate locus of afferent input to the motor neuron junction. When the original relationship between the movement and its spatiotemporal origin had been altered limb movements failed to correspond to their expected trajectories [3]. Together, these results have been interpreted to mean that subsequent movement, undertaken when the respective relative coordinates are altered, responds to a centrally evoked motor command that is sent to the sensory cortex, termed an efference copy or corollary discharge. In Held's now classical proposal bodily actions are then distinguished from a surrounding and mobile terrain by comparing them with their efference copy stored in the sensory cortex. Actions consistent with the planned trajectory can be identified thereby as dynamic events belonging to the body. Sensory cues are thus needed for motor execution both to identify the movement as one's own and to correct motor trajectories. Moreover in continuous motions an ongoing stream of sensory updating that continually adjusts motor execution is also needed.

In this forward model action identification only confirms the source of actions and their discrepancies from projected movements. Given the spectrum of actions that potentially occupy a performance space,

on the other hand, the variety of neural circuits that could be activated is as broad as the spectrum of actions available for selection. In other words action identification is characterized only by a cybernetic confirmation of predicted and previously chosen motions, which is agnostic to selection specificity. Indeed, the potential for motor plan variation is a strong indication that action identification is a distinct process from action selection; hence, it is indeterminate with respect to the form of neural integration achieved.

Confirmation of their independence, in fact, has been demonstrated in individuals incapable of identifying and selecting motor plans as their own. Experimental results in schizophrenia patients, notably, show that they are capable of automatically identifying their actions in visuomotor conflicts as well as normal individuals, reaching their targets despite distorted visual feedback [25]. Since the correct motions are unconsciously made in these experiments the patients appear to be unimpaired in their identification, automatically making needed predictions about their performance and incorporating them into efficient and coordinated motor strategies. On the other hand, such patients are consistently worse than normal individuals in consciously attributing their movements to themselves or to another individual. In patients with first rank symptoms, that is, with symptoms most indicative of the disease, attribution errors amounted to nearly 80% of all detected, compared to 30% for normal individuals. Stated otherwise, schizophrenia patients appear to lack a capacity to consciously undertake the selection of motor actions, but are nonetheless capable of their identification.

The distinction between these processes thus also reveals that the specific form of integrated motor behavior is not dependent on mechanisms of action identification per se. In this regard action identification resembles the non-specificity of energy constraints in promoting the integration of bodily action. In other words both action identification and energy constraining influences mediate integrative effects irrespective of the action plans that are selected. Both influences structure integrated, but nonetheless arbitrary, performance systems. *Hence, mechanisms that integrate specific behaviors, must situate outside either of these systemic influences.*

Motor Plans and Energy Constraints: Intentionalizing Action

Nonetheless, the inscription of intentions and goals in motor behavior is intuitively evident. Kant notably proposed that living organisms are whole and purposeful entities, solely dependent on themselves. Organisms, accordingly, need to be regarded as dynamic entities whose actions entail global and oriented performance. In other words, while integration is necessarily

determined by systemic influences like energy needs, these are not sufficient to determine how integration will be uniquely expressed through intentional motor behavior, which defines the organism ontologically.

Both systemic and ontological influences, indeed, are manifestly evident in evolution, where they drive the acquisition of ever more integrated organismal capacities, including not only the progressive specialization and differentiation of the nervous system, but also the ordering of effector performance and metabolic needs to the unique ontological form of the organism. The requirement for both influences, in fact, is universal whether for a single celled organism or a multicellular one. In both cases the organism is pitted between the need to sustain its own internal network and the circumstances under which that network can effect its existential program. This pitting amplifies molding pressures that are directed to ever greater control over interior and exterior domains, that is, to an improvement in organizational integration that is inwardly and outwardly directed to the betterment of total performance [6]. The need of a constant energy and material stream, in fact, only establishes the operational possibility for this relationship with its particular circumstances of expression. When this need falls below or extends beyond the ability of the living system to accommodate variation, behavioral autonomy is no longer possible, limiting the environmental range that can be occupied. With a suitably broad zone, circumstances of autonomy assume widely divergent models with vastly different organizational networks and differing topological boundaries.

The motor plan and teleological actions

The motor plan and teleological actions

Crucially, interactivity with the external environment must be coordinated with internal metabolic order to secure free energy that can replenish energy dissipating, recursive remodeling [26]. The need for coordination between interactive exterior motor behaviors and interior metabolism thus places formative constraints on the organizational structure ultimately adopted, creating a system wide web of interdependencies. The organism as a whole must therefore achieve integration to sustain environmental independence. Accordingly, there is an explicit relationship between the activities that an organism performs and how he is constitutionally defined, which shapes organizational and functional relationships into a cohesive whole [27]; conversely, if the activities were not relevant, that is, they were not ontologically ordered, it would cease to exist. Self-integration thus becomes key to performance [28].

Critically for integration, such features need to emerge from the organism's systemic organization, evoking not simply executive and motor neural circuits, but

entailing body wide internal constraints that mutually inform and integrate goal oriented performance. Purposeful behaviors thus link self circuitries to subordinate processes that, cumulatively, improve pursuit of organismal goals and environmental interactivity. As a needed holistic the various multicellular parts and processes must work in unison to achieve these behaviors. Glial cells and neurons, for example, must work in unison or forfeit the end of their behavior.

Embedding goals in motor activity

Which factors induce an inscription of goal directed neural correlates? Proponents of the Free Energy Principle cast decisional determinants as mutual features of control and motivation, mediated neurophysiologically through reciprocal operations of the dorsolateral and medioventral frontal cortical regions [11]. These features are hypothesized to comprise drive to goal actions where decisional effectiveness is hierarchically parceled and linked to probabilistic generative models servicing maximal self preservation energetically. Cast in this formulation, decisional outcomes bind self to body via goals in probabilistic action sequences, with the role of choice in predictive inferencing thereby "eluded", restricted to inverting a generative model that infers an action sequence. By this interpretation saliency is understood to be decisional and incentivized, rather than orthogonal to executive control, and to relate high prior probability to high motivational value [11]. This interpretation suggests that decisional events emerge from learned, randomly inscribed variation in prewired contingencies, which are linked to saliency mechanisms and so constrained by generative, predictive modeling.

The emphasis on predictive modeling of inferred sequences, however, leaves the attainment of goals to probable outcome alone. Goal directed saliency, by contrast, is better ordered to improved outcome. That is, saliency can be understood, instead, as inductive, instilling repetition, and conferring precision [11]. Goal progression, for example, increases the likelihood that it will be attained. With the inference of precision, successful behavior creates positive feedback [29]. In consequence, saliency induces a form of meta-learning, where outcomes are precisely linked with action, rather than with probabilistic inferences. Execution of actions can be expected to increasingly select from such meta-learning paradigms to reduce uncertainty and improve consequence. With improved precision, goal directed behavior thus confers a salience on predictive reliability, freeing inferencing from its material dependency to probable free energy exigencies and creating the primitive circumstances for causal inferencing, that is, the primitive for rational behavior. Indeed, the differences between conscious and unconscious goal directed behavior seen in schizophrenia patients suggest that predictive assessments are not the only form of assessing outcome, but rather occur as a

bimodal staging, involving lower probability levels and higher, rationally deductive ones.

Goal specific information modulates effective neural connectivity: Accordingly, we can expect goal specific information to be embedded in motor planning sequences that contain self representations, where it modifies the physiological properties of the brain. Consistent with this expectation [30] Corbetta shows that intentional acts in developing infants, whether to crawl or stand upright, are mapped differently depending on the action intended. The specificity of this mapping is an indication of the inscription of information linking the goal to a single individual for whom the goal is intended. Here actions are framed in terms of their agent. Young infants can thus be understood as incapable of updating goal directed behaviors because they lack the neural mechanisms for binding goal related information to the whole individual [5].

Significantly, diseases known to affect self-recognition processes that link agency with self identification, such as schizophrenia or autism spectrum disorders, are postulated to be deficient in somatic recognition [31,32]. Insights from studies of the motor image in schizophrenia patients reveal, for example, that bodily representation is a key feature where the agent is inscribed with an objective destination. So inscribed, actions are thereby executed as a coherent and coordinated dynamical ensemble, which have a causal origin traced to the whole individual. Hence they include selection specific information taken from the space of available action sequences, which are inscribed as intentions and goals in the motor plan. This means also that representational self content varies as a function of the specific goals consciously embraced by the author of those intentions.

As a corollary, this also predicts that schizophrenia patients will be deficient in inscribing goal specific features within the self-representation; that is, the representation of the self in such patients can be expected not only to differ with respect to the self-representation of normal individuals but also with respect to how that representation varies in different goal contexts. These differences are usefully considered here in two cases of willed actions that significantly differ with respect to the nature of the goal for which the actions are willed, self/other social interactions and action attribution.

In the first, social interactions uniquely require self representations to be distinguished from subjective features that characterize other individuals [33]. Research from social psychology notably demonstrates not only uniqueness of the self representation but also the presence of common features useful in identifying others like oneself. Developmental processes for self-other perceptions, for example, entail two stages, one in which the self-percept is configured first through

its association with the body, and second through its elicitation by inter subjective interactions [34]. In fact, social neuroscience has revealed a broad cluster of dedicated cells, circuits, and zones that assist in distinguishing others like oneself which are now classed under theory of mind [35]. Significantly, as a proxy for self-other interactions recognition of self involves the identification of the spatial locus around the body as a "self domain". As a representation of self, information about bodily location is amenable to experimental displacement. However, this displacement has a finite range beyond which the self is no longer recognized, a limitation resulting from the need to associate the space with the body, which is needed to configure it. Significantly, the ability to localize this space is substantially altered in subjects who have schizophrenia, where it is characterized by a weak and shallow gradient between self and other, diminishing the ability to distinguish the two [36].

Goal directed actions involving only the agent, on the other hand, do not require the clear demarcation between self and other that are characteristic of social interactions. Instead, the self representation is modified by action specific information about the pursuit of a goal objective. Studies where the motor trajectory entails the intentional use of utensils [37], for example, show that such self-mapping overlaps with actions required for employing the utensil, thereby revealing a coincidence between the goal and the intended motor movements.

Taken together, the inability of schizophrenia patients to consciously attribute bodily actions to the self-reveals a failure to link the intentions and desires of a protagonist to an intact representation of the body. Conversely, this means that during conscious actions normal individuals inscribe not only the bodily representation in the representational content of the self but also intentional information that is related to the goal being sought. Jeannerod [38] specifically identifies within this content the intentions, plans, and desires of the author of these actions; that is goal specific information appears to be bound to the self through the bodily representation.

The differences in the representational content of self in its conscious appropriation from that acquired unconsciously in action identification-or as a function of varying goal contexts-suggests that there is a fundamental difference between conscious and unconscious control over the execution of motor movements. Since this difference does not appear to relate to the bodily representation itself-schizophrenia patients apparently have an intact body representation for automatically adjusting their movements-mechanisms linking goal specific information to the body's representation appear to be affected.

By selecting specific motor plans conscious and willed actions assist in the integration of specific motor

behaviors, unlike action identification processes, which do not code goal specific content. Significantly, energy constraints are likely to influence action identification processes, since such inferencing likely requires a tight coupling to the whole body in order to gauge potential energy use, a coupling also required in unconscious actions. On the other hand, conscious actions are unlikely to be influenced by energy inferencing mechanisms used for maximizing free energy efficiency, since these are independent of action identification mechanisms.

Conclusion and Summary

Key determinants affecting plastic integration of motor behavior include energy use and goal directed activities. The holistic requirement for total body metabolism implicates a non-specific and systemic influence on motor integration that is likely to be mediated within bodily frameworks directed toward homeostatic regulation. Specific effects on motor integration, by contrast, are likely to emerge from selection-associated mechanisms linked to goal directed activity that influences motor planning and execution. The presence of both non specific and specific influences on motor planning and execution implicate two general mechanisms of integration, one that is mediated non-specifically from the bottom upwards and a second, complementary one involving specific top down, goal directed planning. The physical instantiation of such strategies likely reflects a metaphysical need for increasing behavioral range that can be autonomously accessed, and has a positive bearing on existential psychology.

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