NATIONAL INSTITUTE OF MENTAL HEALTH

RDoC Changes to the Matrix (CMAT) Workgroup Update: Addition of the Sensorimotor Domain

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A Report by the National Advisory Mental Health Council Workgroup on Changes to the Research Domain Criteria Matrix

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Introduction

Motor system disruptions are key features of some mental disorders and are important components of pathology in a number of clinical syndromes, including neurodevelopmental disorders and psychotic spectrum disorders. Recognizing that the Research Domain Criteria (RDoC) matrix did not fully represent motor system pathology, the National Advisory Mental Health Council convened a workgroup to address this gap. The workgroup members carefully reviewed the evidence and rationale for this topic and provided valuable input as to whether a systematic study of motor abnormalities could provide insights into the primary pathophysiology of mental disorders; they then set out to identify the best way to represent disruptions in motor systems within the RDoC matrix. A primary goal was to foster earlier and more precise identification of the role of motor systems disruptions for psychopathology to aid in the development of more effective treatments for affected individuals.

As but one example, the literature regarding schizophrenia illustrates three established reasons for a focus on motor systems. First is the history describing various clinical manifestations as core pathology, using differential motor disruptions to identify variations of the syndrome, and the recognition that clinical problems such as catatonia occur in a number of mental disorders. Second is the observation that developmental motor abnormalities can precede diagnosis, suggesting motor abnormalities may relate to an early stage of certain kinds of pathology as well as a link with recognized childhood disorders. Third, early motor manifestations may provide a marker of risk for development of adult onset disorders independent of a direct linkage to pathological systems.

Despite intriguing reports (e.g., relation of gesture to social communication, hand strength association with cognition, neurologic subtle signs predicting psychosis development, eye movement as part of a phenotype, reduced ability to produce facial expression, and asymmetric crawling in infants associated with later schizophrenia), a systematic approach to the study of motor function in psychopathology has been limited. This may be because there is no research framework to specify the relations of motor systems disruptions to psychopathology mechanisms. Another possible explanation is that, outside the field of neurology, motor pathology is rarely the target for drug, neural stimulation, or behavioral intervention. In addition, pathognomonic motor systems may have been overshadowed by the need to focus on therapeutic drug-induced motor pathology rather than primary pathology of disease.

The Workshop report clarifies options for advances in translational science relating motor pathology to clinical pathology and proposes how these options can be integrated into the RDoC framework.

Background

The National Institute of Mental Health's (NIMH) RDoC Initiative provides a research framework for alternative ways of studying mental disorders based on dimensions of observable behavior and neurobiological measures. It integrates many types of information (from genomics to self-report) to better understand the basic dimensions of function that underlie the full range of human behavior—from normal to abnormal.

The RDoC framework comprises several interrelated components. The initiative emphasizes the importance of neurodevelopment and the environment as highly significant factors that influence functioning, and the incorporation of pertinent aspects of these factors in research designs. Within this overall frame, the dimensions themselves are represented in the form of a two-dimensional matrix, where the rows capture specified functional constructs (each representing a specified functional dimension of behavior) characterized in aggregate by the genes, molecules, circuits, behaviors, and other entities used to measure these constructs. These constructs are grouped into higher-level domains of function, reflecting contemporary knowledge about major systems of emotion, cognition, motivation, and social behavior. Each construct can include one or more subconstructs. Currently, there are five Domains in the RDoC matrix. The definitions of these domains and constructs can be found in Appendix A.

The RDoC matrix is composed of exemplars, and thus the domains, constructs, and the matrix contents are expected to be dynamic and to change with the acquisition of new knowledge. In line with this goal, a "Changes to the RDoC Matrix group" (CMAT) Council Workgroup was formed by the National Advisory Mental Health Council (NAMHC). This Workgroup is co-chaired by David Brent, M.D., and Gregory A. Miller, Ph.D. The CMAT group acts as a screening and coordinating body for considering proposals to amend the RDoC matrix. CMAT meets regularly to screen proposals, recruit subject matter experts as needed, and provide a final report and recommendations. Minor changes (e.g., new elements) to the matrix involve the Council and NIMH RDoC Unit members, while moderate changes (e.g., new or altered construct) require a teleconference or email exchange with subject matter experts. For major changes (e.g., a new domain), the CMAT workgroup convenes a full workshop.

The present report provides a summary of the NAMHC CMAT Workshop convened to discuss a possible Motor Systems domain.

Workshop Proceedings

NIMH's RDoC Unit convened an in-person Workshop on Motor Systems on November 3-4, 2016, at the Neuroscience Center in Rockville, Maryland. The two co-chairs of the meeting were Bruce Cuthbert, Ph.D., Director of the RDoC Unit at NIMH, and Suzanne N. Haber, Ph.D., from the University of Rochester Medical Center (subject matter expert). The entire list of workshop participants is available in Appendix C.

Following an introduction, Dr. Cuthbert explained that the idea of a Motor Systems domain arose during discussions at the Cognition domain workshop in 2011. The NIMH RDoC workgroup subsequently held a series of informal discussions with a small group of subject matter experts who supported the inclusion of Motor Systems in the RDoC framework. Formal consideration of this possibility required that a clear, generalizable process be developed for making changes in the matrix. Once this process was established in 2016, steps were taken to undertake a workshop regarding the viability of adding a Motor Systems domain to RDoC and to consider possible constructs that should be part of that domain.

The goals of the workshop were to (1) discuss the relevance of motor systems to psychopathology; (2) reach consensus on the need to add a Motor Systems domain to the RDoC matrix; (3) arrive at a set of suggested constructs for a Motor Systems domain, with an agreed-upon definition for each; (4) provide an annotated listing (based on current knowledge) of the elements that would populate the biological units of analysis for this domain (e.g., molecules, cells, circuits, physiology, behavior); and (5) identify promising and reliable behavioral methods to assess function within each construct.

A copy of the meeting agenda is included in Appendix D.

NIMH's Request for Information

In preparation for the workgroup meeting, NIMH published a request for information (RFI) titled "Adding a Motor Systems Domain to the NIMH Research Domain Criteria (RDoC) matrix" on October 7, 2016, to seek input from the field. Responses to the RFI were due November 3, 2016. Through the RFI, NIMH gathered information about the suitability of adding a Motor Systems Domain to the RDoC matrix, as well as specific nominations for constructs and subconstructs that should be considered for the domain. NIMH received ten responses. Of these, all ten included new suggestions for constructs to be considered, and four included general comments for the domain. All responses were provided to the workgroup at the time of the in-person meeting and were used during those proceedings and in subsequent follow-up meetings, although they were not available for any of the discussions that took place prior to the in-person meeting.

Newly Proposed Sensorimotor Domain

Organization

The following is a schematic of the new organization of the domain.

Sensorimotor Domain

Construct/Subconstruct
1. Motor Action
1.1. Action, Planning, and Selection
1.2. Sensorimotor Dynamics
1.3. Initiation
1.4 Execution
1.5 Inhibition and Termination
2. Agency and Ownership
3. Habit
4. Innate Motor Patterns

Definitions

The consensus definitions of the Motor Systems domain, the constructs, and their subconstructs are provided below.

Sensorimotor Domain

Systems primarily responsible for the control and execution of motor behaviors, and their refinement during learning and development.

1. Motor Actions

A multifaceted construct comprising the processes that must be engaged during the planning and execution of a motor action in a context-appropriate manner. Component processes include action planning and selection, sensorimotor dynamics, initiation, execution, and inhibition and termination. Of note, these processes will often be recruited in conjunction with motivational processes described in other domains, as when appetitive motivations drive approach behaviors. This construct explicitly includes the modulation and refinement of actions during development and learning. The list of subconstructs is not intended to imply a specific order or sequence.

1.1. Action Planning and Selection

Processes whereby an individual engages a plan for spatial and temporal components of possible purposeful movements, which match internal and external constraints to achieve a goal. This may also include cost-benefit calculations in the development and selection of motor plans.

1.2. Sensorimotor Dynamics

Processes involved in the specification/parameterization of an action plan and program based on integration of internal or external information, such as sensations and urges and modeling of body dynamics. This process is continuously and iteratively refined via sensory information and reward-reinforced information.

1.3. Initiation

Processes involved in the initiation of a selected action plan; this may include timing of movement onset.

1.4. Execution

Processes involved in the actualization and adaptation of the action implementation.

1.5. Inhibition and termination

Processes involved in the inhibition of motor plans, either before or after an action is initiated, and the sense that a motor plan has been successfully completed. The inhibition subconstruct is commonly operationalized as motor response inhibition and has conceptual overlaps with the Inhibition/Suppression subconstruct of the Cognitive Control construct within the Cognitive Systems domain.

2. Agency and ownership

The sense that one is initiating, executing, and in control of one's volitional actions and their sensory consequences and the sense that one's body or body parts belong to oneself. This may include the comparison of the predicted and actual sensory consequences of one's action, awareness of the intention to move, temporal binding of self-generated action and their immediate effects, and attenuation of sensory consequences of self-generated actions.

3. Habit

Learned stimulus-response mappings triggered by internal or external stimuli that are autonomous of the current value of the outcome or goal. Habits may include overlearned sequences. Habits are implicit and efficient, requiring few cognitive resources, but can also be maladaptive under novel circumstances. Habits are based on previous positively or negatively reinforced learning and commonly occur after extended learning. Both habit formation and expression are commonly operationalized within motor control systems.

When habit formation is motivated by reward learning it overlaps with the Habit construct within the Positive Valence domain.

4. Innate motor patterns

Unlearned action plans that may be triggered by internal or external stimuli. This can include such behaviors as stereotyped expressions of affect, orientation to salience, innate approach and withdrawal phenomena, and startle responses.

Summary of Workgroup Discussion

Preliminary Discussion

The NIMH RDoC working group initially proposed seven constructs representing aspects of motor control with clearly defined neural circuitry and a potential link to one or more manifestations of psychopathology. These included Praxis, Motor Inhibition, Motor Coordination, Motor Learning, Habit/Compulsions, Volition (including Agency and Motor Initiation), and Involuntary Movements. Based on each individual's scientific expertise, the workshop participants were assigned to one of three "construct groups": (1) Skilled Movement, moderated by Don Gilbert and Dagmar Sternad; (2) Learning/Habit Formation, moderated by Valerie Voon and Christopher Pittenger; and (3) Voluntary Movement, moderated by Kevin Black and Robert Chen.

At pre-workshop webinars, subject matter experts were oriented to RDoC and initiated discussions about the potential Motor Systems domain and the suggested constructs. Each group was tasked with deciding whether the draft constructs assigned to the group needed to be revised (e.g., by refining the nature of or discarding the original constructs or adding additional constructs). As a result of the pre-workshop teleconferences, participants in two of the construct groups decided to discard the original constructs which were focused more on motor dysfunctions. In keeping with the other domains, they selected constructs which reflected the elements of normal motor function.

During the preliminary discussions on the first day of the workshop, each construct group was split into two parallel breakout groups to facilitate discussion and encourage exploration of divergent opinions. Following breakout group meetings, the construct groups (and then the entire group) reassembled for further discussion and refinement of the constructs as necessary.

Construct definitions and their matrix elements were not fully complete at the end of the in-person workshop, so the participants were asked to finalize them via email and to come to consensus on the final draft. Participants were divided into two groups with the following moderators: Valerie Voon, Chris Pittenger, Jane Clarke, and Vijay Mittal. The moderators then sent the final document to the NIMH RDoC workgroup.

Following is a summary of the discussions of the two construct groups.

Construct Group Deliberations

The material in the following sections is intended to provide background and context for the final definitions provided above. A variety of considerations and perspectives were discussed by the workshop participants; the set of constructs and their definitions emerged from these valuable discussions.

In the first plenary session, the participants discussed the high relevance of motor dysfunction within psychopathological syndromes and reached consensus on the need to include a Motor Systems Domain in the RDoC matrix. Accurate goal-directed movements are a result of a dynamic coupling or integration of the motor and sensory systems. Therefore, the participants of the workshop agreed that the title of this RDoC Domain should be “Sensorimotor Domain.” They emphasized the need to include developmental aspects of motor constructs in the definition of the Domain. The group then approached the constructs proposed by the NIMH RDoC workgroup, basing their discussion on the following criteria required for a construct: (1) evidence for a specifiable functional dimension; (2) clear link to a particular neural circuit or network; and (3) relevance to one or more mental disorders. In addition, other considerations for including a construct included (1) measurable in humans; (2) available animal model; and (3) assessed by specific tasks or measures.

Skilled Movement

This included praxis, coordination, and motor inhibition. The participants agreed that a better way to approach skilled movement was with constructs related to the planning and execution of skilled movements, for example intentional systems (e.g., when to perform an action) and praxis (e.g., how to perform an action). These are associated with specific neural circuits and their dysfunctions are known to be present in mental illnesses.

Learning and Habits

The participants agreed to keep the habit formation construct but thought that motor learning was intrinsic to every skilled motor function and so should be included in the overall definition of the Domain.

Involuntary Movements

The proposed construct group was titled Involuntary Movements; however, following discussion in the pre-meeting groups the participants rejected involuntary movements as a construct since it did not reflect the model for constructs set up in the RDoC matrix, which posit a range of function from normal to abnormal. The discussion then focused on Voluntary Movements.

During the workshop, the participants agreed that a sense of volition or “agency” was an important aspect of motor systems. Examples of a sense of loss of motor agency in mental illnesses included those observed in obsessive compulsive disorder and addiction. One possible way to assess this could be through sensory attenuation (a phenomenon associated with normal movement where there is a different perception of identical sensory inputs depending on whether they are self-generated or externally generated).

The group added the construct of innate motor patterns which includes unlearned action plans such as stereotyped expressions of affect, orientation to salience, innate approach and withdrawal phenomena, and startle responses. These movements can be reduced or exaggerated in mental illnesses (for example, reduced or exaggerated startle response in different anxiety disorders).

Relation of Sensorimotor Constructs to Others in the RDoC Matrix

The participants noted that, although Agency is included in the Social Processes Domain, and Habit in the Positive Valence Domain, it is important to include them in the Sensorimotor Domain to encourage research from this angle. For instance, when Agency refers to movement, it affects motor systems, whereas when it refers to sense of self, it affects Social Processes. The construct Habit already exists in the Positive Valence Domain, to capture the noted relationship of positive or negative rewards associated with forming habits. There is, however, an additional component to Habits concerning their execution and maintenance, that are heavily based on motor actions and supported by those neural circuits. Consultation with the content experts of the Valence Domain[1] resulted in concurrence with the general sense of this argument, with both groups agreeing that formation aspects of Habit are better classified under a Positive Valence Domain, and execution/maintenance aspects fit best with the Sensorimotor Domain. The definitions of these two parallel constructs should reflect this delineation. While we point out the distinctions pertinent to the overlaps of constructs found in more than one domain, research concerning these topics does not have to be confined to one domain or the other.

Refinement of Constructs

During the workshop and post-workshop meetings, the participants refined the constructs mentioned above and their discussions are reflected below.

Action Planning and Selection indicates how an action is done. It reflects an effort minimization algorithm in an adaptive system that chooses, among different options, the most efficient way to execute a strategy (e.g., which strategy will be employed in a multi-jointed movement). It is distinct from the higher-level selection of a goal and choosing how to attain the goal, which are represented in the Cognitive Domain. Action selection can be framed in terms of basic principles—top-down versus bottom-up, learned (habit) versus innate (reflex), and proactive inhibition. The selection of an action often occurs at a low level as a decision requiring minimal effort. However, the selection can be recapitulated at a higher level, which would be in the Cognitive Domain. Action selection also includes evaluation of success (e.g., completion of the action rather than judgment

[1] Thanks to Diego Pizzagalli, Mauricio Delgado, Paul Glimcher, Greg Hajcak, Michael Treadway, and Ben Yerys for their input on the Habit construct.

about whether the action is appropriate, which would be in the Cognitive Domain). Although the distinction between Action Selection in the Sensorimotor Domain and Cognitive Systems Domain may require more refinement, the participants agreed that it was appropriate to include it in the Sensorimotor Domain in order to emphasize the lower-level cost minimization strategy.

Sensorimotor Dynamics are the complex computational processes that link our body knowledge with the goal and turn it into an action. They include internal models of action with ongoing sensory-based monitoring and feedback control. They also include scaling and slowing of movement, predictive control, and preemption. They are crucial for learning as well as for controlling movements.

Initiation of an action refers to the onset of movement. There may be a trigger component to it that can be a sensation (e.g., urge) and may be related to context. The process is separable from execution both neurally and behaviorally (e.g., measures of initiation time, i.e., time from the signal to move to the initiation of action) versus response duration (duration of the movement execution). Deficits are present in different forms of psychopathology (e.g., catatonic immobility and mutism, psychomotor retardation).

Execution represents the final common pathway of the motor systems. It includes the processes involved in the actualization and adaptation of the action implementation. This refers to the many phenomena that happen downstream in the nervous system. Aspects of execution comprise muscle tone, reflex excitability, strength, and gain control (e.g., in the spinal cord that amplify or reduce the command during execution), allowing continuous adjustment of the action as it occurs. It includes the concept of implementation of an action, which is the transformation of the perceptual representation into a movement pattern.

Inhibition and termination include both those processes involved in the inhibition of motor plans, either before or after an action is initiated, and the sense that a motor plan has been successfully completed. The inhibition has conceptual overlaps with the Inhibition/Suppression subconstruct of the Cognitive Control construct within the Cognitive Systems domain. It does not include the inhibitory processes that, when deficient, result in overflow or mirror movements.

Agency and ownership refer to the feeling of control or generation of an action (agency) and the feeling of ownership (e.g., body ownership). The sense of agency manifests in several domains of function: motor systems, cognitive systems, and social processes. For this reason, even though all agency is affected through the motor domain, it is appropriate that it be addressed in more than one area of the RDoC matrix.

With regard to motor systems, the sense of agency is related to functions of the motor cortex and disorders of these functions are found in, for example, functional neurological disorders (abnormal movements generated through the voluntary motor system that the subject does not recognize as voluntary). This is distinct from the sense of self (or lack of it) as represented, for example, in the Social Processes Domain. Motor aspects of agency include comparison of the predicted and actual sensory consequences of one's action, awareness of the intention to move, temporal binding of self-generated action and its immediate effects, and attenuation of sensory consequences of self-generated actions. A number of measures currently in use are thought to assess motor aspects of agency, such as physiological measures of readiness potential and efference copy, and tasks including visual feedback mismatch, Libet's clock, sensory attenuation paradigms, intentional binding, rubber hand test, and mirror test.

Habit formation is driven by reinforcement; however, once a habit is acquired, then, by definition, it is no longer motivated by reinforcement as it is automatic and occasioned only by context or sensory stimulus. This execution and maintenance of habits is driven much more by sensorimotor systems than by reinforcement. As such, the definition of habit in the Sensorimotor Domain includes not only learning that involves the cortex and the lateral striatum, but other automatic processing or automatically driven behaviors, which may involve other circuitry such as cerebellum or parietal cortex. Although a Habit construct is already included in the Positive Valence Domain, it could be better served by also including an aspect of Habit in the Sensorimotor Domain. One domain (Positive Valence) is concerned with the formation of habits by reinforcement, and the other domain (Sensorimotor) is concerned with the execution and maintenance of habits through motor systems; however, research concerning these topics does not have to be confined to one domain or the other.

Innate motor patterns include unconsciously driven repetitive behaviors that are not habits, e.g., instinctual orienting to salient stimuli. These behaviors are not learned but can be adapted through learning. For instance, approach or avoidance behaviors in response to a stimulus are often present prior to affective evaluation of that stimulus. Dysfunctions of innate motor patterns exist in certain psychopathologies, e.g., greatly accentuated avoidance behavior in post-traumatic stress disorder (PTSD).

Motor Learning: Except for Innate Motor Patterns, all constructs included in the Sensorimotor Domain involve learning. Motor learning is a well-defined and highly researched construct. There are different types of motor learning, with some more dependent on the cerebellum and others more dependent on cortical processes. Since learning is a central concept in understanding brain function, it was decided that Motor Learning should be mentioned in the definition of the Sensorimotor Domain itself.

APPENDIX A: *RDoC MATRIX DEFINITIONS*

Arousal/Regulatory Systems: Systems responsible for generating activation of neural systems as appropriate for various contexts and providing appropriate homeostatic regulation of such systems as energy balance and sleep.

- **Arousal:** Arousal is a continuum of sensitivity of the organism to stimuli, both external and internal. Arousal:

  - facilitates interaction with the environment in a context-specific manner (e.g., under conditions of threat, some stimuli must be ignored while sensitivity to and responses to others is enhanced, as exemplified in the startle reflex);
  - can be evoked by either external/environmental stimuli or internal stimuli (e.g., emotions and cognition);
  - can be modulated by the physical characteristics and motivational significance of stimuli;
  - varies along a continuum that can be quantified in any behavioral state, including wakefulness and low-arousal states including sleep, anesthesia, and coma;
  - is distinct from motivation and valence but can co-vary with intensity of motivation and valence;
  - may be associated with increased or decreased locomotor activity; and
  - can be regulated by homeostatic drives (e.g., hunger, sleep, thirst, sex).

- **Circadian Rhythms:** Circadian Rhythms are endogenous self-sustaining oscillations that organize the timing of biological systems to optimize physiology and behavior, and health. Circadian Rhythms:

  - are synchronized by recurring environmental cues;
  - anticipate the external environment;
  - allow effective response to challenges and opportunities in the physical and social environment;
  - modulate homeostasis within the brain and other (central/peripheral) systems, tissues, and organs; and
  - are evident across levels of organization including molecules, cells, circuits, systems, organisms, and social systems.

- **Sleep and wakefulness:** Sleep and wakefulness are endogenous, recurring, behavioral states that reflect coordinated changes in the dynamic functional organization of the brain and that optimize physiology, behavior, and health. Homeostatic and circadian processes regulate the propensity for wakefulness and sleep. Sleep:

  - is reversible, typically characterized by postural recumbence, behavioral quiescence, and reduced responsiveness;

  - has a complex architecture with predictable cycling of NREM/REM states or their developmental equivalents. NREM and REM sleep have distinct neural substrates (circuitry, transmitters, modulators) and EEG oscillatory properties;
  - intensity and duration are affected by homeostatic regulation;
  - is affected by experiences during wakefulness;
  - is evident at cellular, circuit, and system levels; and
  - has restorative and transformative effects that optimize neurobehavioral functions during wakefulness.

Cognitive Systems: Systems responsible for various cognitive processes (e.g., attention, perception, memory, language, cognitive control).

- **Attention:** Attention refers to a range of processes that regulate access to capacity-limited systems, such as awareness, higher perceptual processes, and motor action. The concepts of capacity limitation and competition are inherent to the concepts of selective and divided attention.
- **Perception:** Perception refers to the process(es) that perform computations on sensory data to construct and transform representations of the external environment, acquire information from, and make predictions about, the external world, and guide action.
- **Declarative Memory:** Declarative memory is the acquisition or encoding, storage and consolidation, and retrieval of representations of facts and events. Declarative memory provides the critical substrate for relational representations—i.e., for spatial, temporal, and other contextual relations among items, contributing to representations of events (episodic memory) and the integration and organization of factual knowledge (semantic memory). These representations facilitate the inferential and flexible extraction of new information from these relationships.
- **Language:** Language is a system of shared symbolic representations of the world, the self, and abstract concepts that supports thought and communication.
- **Cognitive Control:** A system that modulates the operation of other cognitive and emotional systems, in the service of goal-directed behavior, when prepotent modes of responding are not adequate to meet the demands of the current context. Additionally, control processes are engaged in the case of novel contexts, where appropriate responses need to be selected from among competing alternatives.
- **Working Memory:** Working Memory is the active maintenance and flexible updating of goal/task relevant information (items, goals, strategies, etc.) in a form that has limited capacity and resists interference. These representations: may involve flexible binding of representations; may be characterized by the absence of external support for the internally maintained representations; and are frequently temporary, though this may be due to ongoing interference. It involves active maintenance, flexible updating, limited capacity, and interference control.

Negative Valence Systems: Systems primarily responsible for responses to aversive situations or contexts, such as:

- **Responses to acute threat (Fear):** Activation of the brain's defensive motivational system to promote behaviors that protect the organism from perceived danger. Normal fear involves a pattern of adaptive responses to conditioned or unconditioned threat stimuli (exteroceptive or interoceptive). Fear can involve internal representations and cognitive processing and can be modulated by a variety of factors.
- **Responses to potential harm (Anxiety):** Activation of a brain system in which harm may potentially occur but is distant, ambiguous, or low/uncertain in probability, characterized by a pattern of responses such as enhanced risk assessment (vigilance). These responses to low imminence threats are qualitatively different than the high imminence threat behaviors that characterize fear.
- **Responses to sustained threat:** An aversive emotional state caused by prolonged (i.e., weeks to months) exposure to internal and/or external condition(s), state(s), or stimuli that are adaptive to escape or avoid. The exposure may be actual or anticipated; the changes in affect, cognition, physiology, and behavior caused by sustained threat persist in the absence of the threat and can be differentiated from those changes evoked by acute threat.
- **Frustrative non-reward:** Reactions elicited in response to withdrawal/prevention of reward, i.e., by the inability to obtain positive rewards following repeated or sustained efforts.
- **Loss:** A state of deprivation of a motivationally significant con-specific, object, or situation. Loss may be social or non-social and may include permanent or sustained loss of shelter, behavioral control, status, loved ones, or relationships. The response to loss may be episodic (e.g., grief) or sustained.

Positive Valence Systems: Positive Valence Systems are primarily responsible for responses to positive motivational situations or contexts, such as reward seeking, consummatory behavior, and reward/habit learning.

- **Reward Responsiveness:** Processes that govern an organism's hedonic response to impending or possible reward (as reflected in reward anticipation), the receipt of reward (as reflected in initial response to reward) and following repeated receipt of reward (as in reward satiation); across these subdomains, reward responsiveness primarily reflects neural activity to receipt of reward and reward cues and can also be measured in terms of subjective and behavioral responses.

  - **Reward anticipation:** Processes associated with the ability to anticipate and/or represent a future incentive—as reflected in language expression, behavioral responses, and/or engagement of the neural systems to cues about a future positive reinforcer.
  - **Initial Response to Reward:** Processes evoked by the initial presentation of a positive reinforcer as reflected by indices of neuronal activity and verbal or behavioral responses.

- **Reward Satiation:** Processes associated with the change in incentive value of a reinforcer over time as that reinforcer is consumed or experienced, as reflected in language expression, behavioral responses, and/or engagement of the neural systems.

- **Reward Learning:** A process by which organisms acquire information about stimuli, actions, and contexts that predict positive outcomes, and by which behavior is modified when a novel reward occurs, or outcomes are better than expected. Reward learning is a type of reinforcement learning.

  - **Probabilistic and Reinforcement Learning:** The ability to learn which actions or stimuli are associated with obtaining a reinforcer, even when a particular action or stimulus is not always associated with obtaining the reinforcer.
  - **Reward Prediction Error:** Processes associated with the difference between anticipated and obtained rewards are important for reinforcement learning. The error can indicate that the reward received was either larger than expected (positive prediction error) or smaller than expected (negative prediction error).
  - **Habit:** Sequential, repetitive, motor behaviors or cognitive processes elicited by external or internal triggers that, once initiated, can go to completion without continuous effortful oversight. Habits can be adaptive by virtue of freeing up cognitive resources. Habit formation is a frequent consequence of reward learning, but, over time, its expression can become resistant to changes in outcome value. Some habit-related behaviors could be pathological expressions of processes that under other circumstances subserve adaptive goals.

- **Reward Valuation:** Processes by which the probability and benefits of a prospective outcome are computed by reference to external information, social context (e.g., group input), and/or prior experience. This computation is influenced by preexisting biases, learning, memory, stimulus characteristics, and deprivation states. Reward valuation may involve the assignment of incentive salience to stimuli.

  - **Reward (ambiguity/risk):** Process by which the value of a reinforcer is computed as a function of its magnitude, valence, and predictability.
  - **Delay:** Processes by which the value of a reinforcer is computed as a function of its magnitude and the time interval prior to its expected delivery.
  - **Effort:** Processes by which the value of a reinforcer is computed as a function of its magnitude and the perceived costs of the physical or cognitive effort required to obtain it.

Systems for Social Processes: Systems that mediate processes to interpersonal settings of various types, including perception and interpretation of others' actions.

- **Affiliation and Attachment:** Affiliation is engagement in positive social interactions with other individuals. Attachment is selective affiliation as a consequence of the development of a social bond. Affiliation and Attachment are moderated by social information processing (processing of social cues) and social motivation. Affiliation is a behavioral consequence of social motivation and can manifest itself in social approach behaviors. Affiliation and Attachment require detection of and attention to social cues, as well as social learning and memory associated with the formation of relationships. Affiliation and Attachment include both the positive physiological consequences of social interactions and the behavioral and physiological consequences of disruptions to social relationships. Clinical manifestations of disruptions in Affiliation and Attachment include social withdrawal, social indifference and anhedonia, and over-attachment.

- **Social Communication:** A dynamic process that includes both receptive and productive aspects used for exchange of socially relevant information. Social communication is essential for the integration and maintenance of the individual in the social environment. This construct is reciprocal and interactive, and social communication abilities may appear very early in life. Social communication is distinguishable from other cognitive systems (e.g., perception, cognitive control, memory, attention) in that it particularly involves interactions with conspecifics. The underlying neural substrates of social communication evolved to support both automatic/reflexive and volitional control, including the motivation and ability to engage in social communication. Receptive aspects may be implicit or explicit; examples include affect recognition, facial recognition, and characterization. Productive aspects include eye contact, expressive reciprocation, and gaze following. Although facial communication was set aside as a separate subconstruct for the purposes of identifying matrix elements, social communication typically utilizes information from several modalities, including facial, vocal, gestural, postural, and olfactory processing. Social Communication was organized into the following subconstructs:

  - **Reception of Facial Communication:** The capacity to perceive someone's emotional state non-verbally based on facial expressions.
  - **Production of Facial Communication:** The capacity to convey one's emotional state non-verbally via facial expression.
  - **Reception of Non-Facial Communication:** The capacity to perceive social and emotional information based on modalities other than facial expression, including non-verbal gestures, affective prosody, distress calling, cooing, etc.
  - **Production of Non-Facial Communication:** The capacity to express social and emotional information based on modalities other than facial expression, including non-verbal gestures, affective prosody, distress calling, cooing, etc.

- **Perception and Understanding of Self:** The processes and/or representations involved in being aware of, accessing knowledge about, and/or making judgments about the self. These processes/representations can include current cognitive or emotional internal states, traits, and/or abilities, either in isolation or in relationship to others, as well as the mechanisms that support self-awareness, self-monitoring, and self-knowledge. Perception and Understanding of Self was organized into the following subconstructs:

- **Agency:** The ability to recognize one's self as the agent of one's actions and thoughts, including the recognition of one's own body/body parts.
- **Self-Knowledge:** The ability to make judgments about one's current cognitive or emotional internal states, traits, and/or abilities.

- **Perception and Understanding of Others:** The processes and/or representations involved in being aware of, accessing knowledge about, reasoning about, and/or making judgments about other animate entities, including information about cognitive or emotional states, traits, or abilities. Perception and Understanding of Others was organized into the following subconstructs:

  - **Animacy Perception:** The ability to appropriately perceive that another entity is an agent (i.e., has a face, interacts contingently, and exhibits biological motion).
  - **Action Perception:** The ability to perceive the purpose of an action being performed by an animate entity.
  - **Understanding Mental States:** The ability to make judgments and/or attributions about the mental state of other animate entities that allows one to predict or interpret their behaviors. Mental state refers to intentions, beliefs, desires, and emotion.

APPENDIX B: *NAMHC ROSTER*

National Advisory Mental Health Council

DEPARTMENT OF HEALTH AND HUMAN SERVICES
NATIONAL INSTITUTES OF HEALTH
NATIONAL INSTITUTE OF MENTAL HEALTH
NATIONAL ADVISORY MENTAL HEALTH COUNCIL
(Terms end 9/30 of designated year)

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APPENDIX C: *WORKGROUP ROSTER*

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[†]Gregory A. Miller, Ph.D., University of California, Los Angeles

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Jean Noronha, Ph.D., NIMH

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Don Gilbert, M.D., M.S., Cincinnati Children's Hospital
Suzanne N. Haber, Ph.D., University of Rochester Medical Center
Kenneth Heilman, M.D., University of Florida
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Georg Northoff, M.D., Ph.D., The Royal and the University of Ottawa
Gillian O'Driscoll, Ph.D., McGill University
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Arina Kadam, M.P.H., Management Analyst, Office of the Director
Sarah Morris, Ph.D., Associate Head, RDoC Unit, Division of Translational Research

[*] NAMHC member at time of workgroup formation, has since rotated off council.

[†] Current NAMHC member

Jenni Pacheco, Ph.D., Scientific Program Manager, Office of the Director
Uma Vaidyanathan, Ph.D., Scientific Program Manager, Office of the Director

NIMH Staff Members
Matthew Rudorfer, M.D., Program Chief, Division of Services and Intervention Research
Janine Simmons, M.D., Ph.D., Program Officer, Division of Neuroscience and Basic Behavioral Science

APPENDIX D: *WORKSHOP AGENDA*

NIMH Research Domain Criteria

Motor Systems Workshop

Wednesday, November 2, 2016; 6:00 – 8:00 PM

6:00 – 8:00 pm	Meet and Greet - Informal reception at Garden Inn Hotel

Thursday, November 3, 2016; 8:30 AM – 6:00 PM

8:30 am	Welcome and Introductions
9:00 am	Plenary Session: Report out of Construct Group Webinar discussions
10:15 am	Coffee Break
10:45 am	Construct Groups Session #1: Define constructs and associated circuits
12:00 pm	Construct Subgroups meet to integrate constructs and definitions
12:30 pm	Lunch: First report-out period (plenary session): Report of construct definitions and circuits (including any new constructs)
1:30 pm	Discussion & Integration
2:45 pm	Coffee Break
3:15 pm	Construct Groups: Clean up definition
5:00 pm	Plenary Session: Day 1 summary and discussion
6:00 pm	Social hour at Redwood (7121 Bethesda Ln, Bethesda, MD 20814)

Friday, November 3, 2016; 8:30 AM – 3:00 PM

8:30 am	Summary of Day 1; issues for Day 2
8:45	Construct Groups Session #2: Discuss matrix specifications and select tasks to include in Common Data Elements
10:00	Coffee Break
10:30	Construct Groups Session #2 (continued)
11:45	Plenary Session: Final report-out for matrix elements
12:45 pm	Lunch: Use of the motor constructs in the study of psychopathology
2:00	Plenary Session: Final review, consensus, and integration
2:30	Critique and discussion of process; next steps
3:00	Adjourn

APPENDIX E: *SENSORIMOTOR DOMAIN GUIDE NOTICE*

A Guide Notice was published in the NIMH Guide, to offer guidance about what types of sensorimotor projects will and will not be considered for funding by NIMH. The text of that notice appears below.

NOT-MH-18-053

NIMH is issuing this Notice to inform potential applicants of the addition of a Sensorimotor Domain to the Research Domain Criteria (RDoC) matrix, and to clarify the scope and limitations of NIMH support for projects within this domain.

The essence of RDoC is to identify organizing dimensions that cut across multiple psychiatric disorders as traditionally defined, and to promote research according to these dimensions, complementing traditional diagnostic categories that addresses both psychological and biological theory and phenomena. The RDoC matrix depicts functional domains of behavior that are relevant to mental disorders and provides a framework for future research on psychopathology. RDoC plans to recognize the importance of motor dysfunction in psychiatric disorders by adding a Sensorimotor Domain to the matrix. The primary goal of this change is to stimulate *clinical research* in this neglected area. NIMH will be accepting applications focused on motor processes and systems *only* in the context of human psychopathology. All such applications should be directed to programs within the Division of Translational Research.

NIMH will not be changing its priorities within the Division of Neuroscience and Basic Behavioral Sciences (DNBBS). Although NIMH supports basic, mechanistic neurobiological studies within the areas of cognition, affect, social, and regulatory processes, NIMH *will not* accept applications designed primarily to investigate basic neurobiological questions related to motor function in animals or healthy human subjects. Topics related to motor function that fall outside of the purview of DNBBS/NIMH include, but are not limited to: motor actions, motor learning, motor habits, and innate motor patterns.