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Recursive Behavior Recording: Complex Motor Stereotypies and Anatomical Behavior Descriptions

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RECURSIVE BEHAVIORAL RECORDING COMPLEX MOTOR STEREOTYPIES AND ANATOMICAL BEHAVIOR DESCRIPTIONS

by

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ABSTRACT

A novel anatomical behavioral descriptive taxonomy improves motion capture in complex motor stereotypies (CMS) by indexing precise time data without degradation in the complexity of whole body movement in CMS. The absence of etiological explanation of complex motor stereotypies warrants the aggregation of a core CMS dataset to compare regulation of repetitive behaviors in the time domain. A set of visual formalisms trap configurations of behavioral markers (lateralized movements) for behavioral phenotype discovery as paired transitions (from, to) and asymmetries within repetitive restrictive behaviors. This translational project integrates NIH MeSH (medical subject headings) taxonomy with direct biological interface (wearable sensors and nanoscience in vitro assays) to design the architecture for exploratory diagnostic instruments. Motion capture technology when calibrated to multi-resolution indexing system (MeSH based) quantifies potential diagnostic criteria for comparing severity of CMS within behavioral plasticity and switching (sustained repetition or cyclic repetition) time-signatures. Diagnostic instruments sensitive to high behavioral resolution promote measurement to maximize behavioral activity while minimizing biological uncertainty. A novel protocol advances CMS research through instruments with recursive design.

en memoria

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skin orientation. Reporting back to them is a high priority as I frame skin innervation and an extended reflex arc within motion capture.

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LIST OF ACRONYMS (or) ABBREVIATIONS

ABD	Anatomical behavior descriptions
ApEn	Approximate entropy
Bi-	Bilateral movement
CMS	Complex motor stereotypies
CPG	Central pattern generator
Contra-	Contralateral movement
DSM	Diagnostic Statistical Manual of Mental Disorders
Ipsi-	Ipsilateral movement
MeSH	Medical Subject Headings
NAMHC	National Advisory Mental Health Council
NLM	U.S. National Library of Medicine

CHAPTER ONE: INTRODUCTION

An infant's hands erupts and the child has difficulty with motility. Meanwhile, a researcher compares toddlers with restricted repetitive behaviors. The clinical literature has focused on the ability of individuals with CMS and prevalence of CMS (Lewis & Bodfish, 1998). The result is the absence of a standard for diagnostic instrument design for CMS research addressing two questions: Where does data come from? What is the methodical consequence of the absence of time data on CMS? *Operationalized clinical CMS data seem to reflect only late stages of repetitive behavior leaving unaccounted earlier time-behavior pairings, that is, traces of preliminary cortical potentials, allocation of resources, and time variables within the engagement of resources (Figure 17).* Pre-motor cortical potentials (Dirnberger et al., 1998; Hallett, 2007, 2010; Houdayer et al., 2013; Shibasaki & Hallet, 2006) support the presence of cortical potentials before a behavior occurs. Data-driven research leaves CMS research unable *to minimize biological uncertainty and maximize behavioral activity*. A system to recognize variability in CMS warrants further investigation in several areas: the science of behavior markers, graphing local time datasets, and symbolic systematic modeling of CMS sequelae.

Throughout the literature on motion capture and CMS there is no indication of how to measure the severity of CMS in the time domain (Appendix C and Table 7) or the sequential succession of behavioral gestures. Consequently, there is no measurement precise enough to assign signatures to a complex core dataset mapping the severity of CMS.

A starting point in quantitative research on CMS is how to conduct observations. The neurologist Prechtl (1974) introduces a standard of behavioral observation: "Where states distinct brain mechanisms are specific to descriptive behavior categories. A concept of state for quantitative neurological assessment transitory events superimposed on constellations of startles. Sequences of states transformed into discrete vector space...graphically represent state profiles … measure state distributions as percentages of time spent in each state mean duration of state epoch, number of state transitions." Another observational practice defines behavioral research within the time domain. Siegler and Crowley's (1991) microgenetic methodology extend observation time. Using extended observation enables patterns to emerge without using an arbitrary observation duration. The microgenetic protocol attempts to "provide data against which to evaluate the plausibility and power of potential mechanisms." In Siegler and Crowley observations monitor changes *while they are occurring*. Research observation using multiple sessions is consistent with microgenetics approach.

A CMS measurement protocol would differentiate on an individual basis the severity of CMS. The interval of time pairings (from-, to-) serves as a metric to define observational criteria and to direct instrumental design within a heterogeneous framework. Already, Marder (2011) provides evidence of heterogeneous datasets in pyloric rhythmic circuitry. CMS research in repetitive behavior provides no observational criteria to determine the presence or absence of heterogeneous functionality in CMS.

Currently, clinical CMS research persists in statistical techniques without evidence from biological wetlab, advanced computational frameworks., or diagnostic tools with biomarkers. for mental disorders include biomarkers. Biomarkers in psychological research enrich research methodology. Lowe reports on the capacity of biomarkers in investigative research:

> …experimental protocols have given neuroscientists and psychiatrists an increasingly powerful arsenal for acquiring data across multiple spatio- temporal scales, from the level of single biomarker molecules, cellular architectures, neural connectivity to complex, and interdependent metabolic pathway, physiological, and behavioral data (Kotter, 2001; Martone et al., 2004). It is also evident that combining multiple ‘‘omics’’ data with matching detailed imaging, microscopic, physiological, behavioral, and psychiatric codata for complex multigeneic neuropsychiatric and neurodegenerative disorders is a task beyond even the best funded research groups. (Lowe, 2011, p. 390)

A new research framework follows new technologies. Quantitative research on CMS using new technology would place CMS within *direct biological interface*

through nanoscience *in vitro* preparations or wearable biosensors. Already, Feng *et al.'s* (2004) replace video analysis with real-time imaging of to analyze c. elegans (Caenorhabditis elegans) movements using image processing of 144 parameters: (1) digital data information crucial for behavioral analysis; (2) conversion parameter estimation of grayscale image converted to a binary image; (3) back-bone points cross the creatures body; and, (4) measures of specific features based on parameters related to locomotion or morphology (body posture, movement, and locomotion waveform). Meanwhile, other c. elegans researchers conduct movement research using microfluidic channels a nanoscience tool (Ardiel & Rankin, 2008; Chronis et al. 2007; Kawano et al.,2011; Larsch et al., 2013; Nagy et al.,2011; Salvador et al., 2014; Wen et al., 2012). Elegant computational motion capture practices are in a position to register local transitional timings nested within chronological order.

Systematic study of *behaviors in time* appears as a four-fold problem: (1) present independent time coordinates of locally engaged behavior markers within the behavior marker's genidentic history (Reichenbach *et al.,* 1957) independent of a chronological order; (2) the absence of a descriptive protocol to quantify and reconstruct repetitive behavior within sequelae; and, (3) descriptive tools to differentiate and quantify CMS sequelae. CMS researchers' (Appendices A,B) resort to snapshots and stop watch measurement without tools measuring local networks unrecorded in video analysis.

Heterogeneous or multi-resolution complexity require diagnostic measurement of granularity in behavioral activity. New protocols for new technologies in CMS research would expand the measurement of the allocation of resources evident in multiple streams of information and power process with levels of logical formalized through appropriate scientific workflows.

Motivation. A diagnostic standard for universal measurement of CMS investigates behavioral plasticity a phenomena absent from clinical CMS research on humans. Since Chalfie *et al.,* (1985) behavioral plasticity (switching in cellular function in backward or forward restrictive repetitive behaviors) eclipses the *low variation hypothesis* (Hadders-Algra, 2010; Prechtl, 1990, 2001). Methodical observation of CMS might provide a framework to quantify behavioral phenotypes (jerky or continuous) in a hyperkinetic motor disorder. The NIH Taskforce on Childhood Motor Disorders (Sanger *et al.,* 2010) suggests jerky and continuous movement provide diagnostic criteria to characterize and to identify behavioral phenotypes in CMS. Research on CMS might follow a subject-design (waiting for data) or instrument-design (configuring the phase space of a behavior). What distinguishes subject-design and instrument-design is an open question. One might argue empirical rules produce systematic *observation criteria* to implement instrumental design and to improve data collection.

The anatomical behavior descriptions' taxonomy reflects multi-variant observational criteria. A network of local sensors functions as a multi-faceted data gathering system to quantify micro-events (independent or coordinated) within local timing (asynchronous-schema) and independent of coarse postural sequences. Such a sensor-architecture registers (presence/absence) of behavior markers to characterize lateralized movement defined through descriptive taxonomy (anatomical behavior descriptions, Table 7). Programmed visual tests in motion capture sensors represent the anatomical behavior descriptions' taxonomy to detect types of behavior markers and data capture. The visual tests identify data as: (1) whole-body and regional configurations of movement; (2) sequential subcomponents *en route* to the unfolding of the behavior; and, (3) identifying if behavioral resolution and behavioral plasticity generate indexing data. A system of rules informs movement analysis as linguistic rules formalize phonological analysis.

Instrument-design has consequences for transforming assumptions of variability in CMS proposed in neurological research (Hadders-Algra, 2010) and clinical subject-design studies on repetitive restrictive behaviors (Appendices A,B). *The absence of high behavioral resolution in CMS reflects limitations in the observation of CMS rather than confirming low variation in CMS' structure and function*. In this project instrument-design maps variability as pools of resources in motor function configured during sensory transfer

(touching). Kelso (2012) observes “many different muscle configurations can produce the same outcome” supports a description of variability in a behavior without establishing equilibrium approaching multistability. Another example of multistability in motor function Kelso points out is “the same network activity in central pattern-generating circuits can be produced using many different combinations of synaptic strengths and neuron properties.” The example of the central pattern generator's flexibility and modularity gives researchers a dynamic view of biological movement beyond the literal (non-biological) report of video research on CMS.

Behavioral recording seeks to identify a computational layer to monitor variability in motor function in terms of multistability. Measuring the engagement of resources in CMS has several choices: (1) signal output; (2) behavioral marker; or, (3) defining local neighborhoods related with the behavior marker. If the measurement standard focuses on the signal output from the local history of behavioral marker's activity (Figure 13) and the local neighborhood of the behavior markers (Figure 18) is missing. Kohn *et al.* (2006) diagrammatic protocol maps biological pathways (exist, co-exist, or exclusion) in molecular interactions. Following the example of Kohn and collaborators behavioral recording method would display behavioral markers based on anatomical behavior descriptions (Table 7). Repetitive behaviors as a time related phenomena has notable phenomena unrecorded: sequential

transitions, rates of activity, and switching rates in postures. These observations prompt a novel methodology.

Conducting behavioral recordings is a problem of identifying scientific workflows to differentiate laterality as behaviors indicative of motor circuitry (inhibitory or excitatory). Forming behavioral recording starts with Marder and Calabrese (1996) synopsis of neuronal recording protocols for motor research: (1) *description:* studying a motor system starts with the description of the behavior; (2) *engagement of resources:* determine the sequence of muscles/muscle group simultaneously activated (registered by an electromyogram) producing the behavior; (3) *characterization in the time domain:* neuron detection of interneurons synapse directly on relevant motoneurons, neurons active in time with rhythmic motor pattern, neurons regulation timing including initiation, termination, or change in the expression of perpetual rhythmic pattern; (4) *characterization of neighborhoods:* manage large sets of interneurons with overlapping connections and functions (single neuron manipulation may have little or no influence on the ongoing motor patterns); and, (5) *pattern analysis:* a single neuron displays different activity patterns (single recording will be inadequate for neuron classification). Neuronal recording registers movement as an ensemble of neuronal oscillators, strength of synaptic connections, and the time course of synaptic currents.

Scientific workflows from Marder and Calabrese suggest a progression for behavioral recording.

Step 1: motion capture (*description)* → registration of behavioral markers as a morphological flow of movement

Step 2: post-motion capture (*engaged resources*) → differentiate laterality (diagram testing: lateralized movement and touch)

Step 3: analysis (*characterization of timing and postures within a kinematic neighborhood*) → self-similarity sequelae between touching scenarios and extension/flexion patterns

Step 4: computing local timing (*pattern analysis of transition*) → micro-rhythms in behavior and multi-functionality under the skin

Hypothesis. A measurement standard based upon lateralized movement facilitates monitoring variability (posture and timing in transitions) in repetitive restrictive behaviors. A systematic definition of behaviors in time facilitates CMS data collection (motion capture). *Anatomical behavior descriptions* have computational consequences: (1) universal description of lateralized movement {(ipsi-, independent movement), coordinated movement(bi-, contra-)} in any movement sequence (Table 7); (2) mathematical expectations orient the measurement of transitions {(from- ,evacuating a posture), (to-, occupying a

posture)} in a biological movement (Figure 14); and, (3) precise analysis of each individual's CMS *repertoire* and *sequelae* in a multi-dimensional grid (Figure 13a) based on the punnett square used in genetics. Characterizing (from-, to-) pairings in sequelae provide a potential measurement standard to distinguish behavioral phenotypes in CMS sequelae. In the future this protocol differentiates lateralized movement to determine if top-down variability suggests a neurobiological approximation of motor circuitry (inhibitory or excitatory) in CMS.

A computational layer in a motion capture system differentiates lateralized movement to determine if top-down variability in the time-regulation of sequelae patterns (ipsi-, bi-, or contra-) suggests a neurobiological approximation of motor circuitry (inhibitory or excitatory) in CMS.

Descriptions with a quantitative capacity transform a diagnostic instruments' utility for motion capture. An advanced model of temporal domain in Figure 17 frames chronological time measurement (duration or order) as an allocation of resources. A *supply-side* view of behavior include several scientific workflows: (1) *motion capture:* transitions (from- evacuation of a posture; to-, entry into a posture) as behavioral-time patterns in lateralized movement; (2) *kinematic analysis:* plasticity and behavioral-time pairings; and, (3) *morphological characterization:* lateralized movement and skin innervation. Since Chalfie *et al.,* (1985) neurobiological research provides behavioral

research with asymmetry in behavioral plasticity in c. elegans (Ardiel & Rankin, 2008; Chronis et al. 2007; Kawano et al.,2011; Larsch et al., 2013; Nagy et al.,2011; Salvador et al., 2014; Wen et al., 2012) MeSH taxonomy on metabolic process, and neural processing in multifunctional patterns (Appendices E). Time-keeping in repetitive restrictive behavior (CMS) warrants a strong visual semantics with a visual formalism.

CMS research aligns video with movement analysis. Visual evidence in the fluctuations of CMS analyzed by point-by-point time series or frame analysis in video recordings (Hadders-Algra, 2010; Teitelbaum *et al.,* 1998; Thelen, 1979) underestimate the role of instrument-design in data collection and the mathematical complexity of directing motion capture (Table 2). Motion capture and time series analysis through a strong visual semantics (porous-solid-fractals, Figure 18) provides a cascading complexity to quantify neighborhoods (flow patterns) in the of repetitive restrictive behaviors (Figure 18, right). Figures 13a, 14 present a visual formalism to communicate the complexity of behavior markers for visualization of local neighborhoods Figures 13, 14 within the framework of a taxonomy (Table 7). Cross-referencing known neurobiology (Table 9) and the medical MeSH taxonomy (Tables 18-21) organize a methodology to index behaviors in time.

Argument

Fractional time measurement of local time behaviors contributes to higher behavioral fidelity and strategies to map regulation in behavioral plasticity. Local sensor distribution facilitates local time measurement to capture independent and simultaneous microevents, without relying upon stopwatch measurements.. as local timings between a primary behavior marker {(to$_{\textbf{\textit{forward}}}$, ipsilateral) or (from$_{backward}$, ipsilateral)} and neighboring secondary behavior marker {(secondary transition, sensorimotor process: toward_touch$_{ventral}$, touch$_{ventral\ |\ dorsal}$, release$_{ventral\ |\ dorsal}$)}. Quantifying the sequelae occurs in several fractional series. A fractional series of behavior-time pairings evaluates descriptive facets (high behavioral resolution or behavioral plasticity). Anatomical behavior descriptions facilitate a recursive assessment of CMS.

Multi-stability (Kelso, 2012) in motor circuitry explains functional transitions. Mircoevents *en route* behavioral plasticity warrant measurement (Figures 9-10). *Behavioral recording is a missing link between behavioral granularity and known motor wire modeling over the time-course of rhythmic motor circuits.*

Quantifying CMS has two mathematical options: component or interactive. Recently, clinical researchers (Gowen & Hamiltion, 2013; Torres,

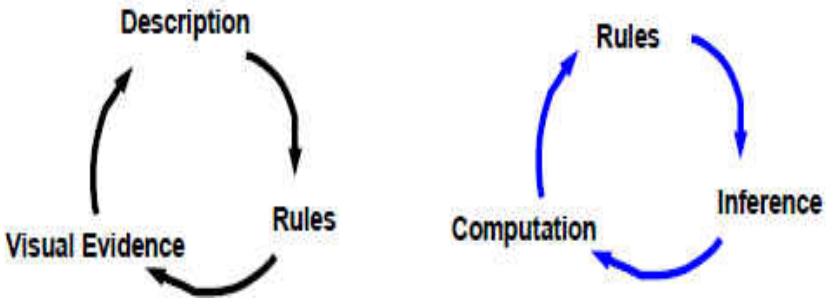
2011, 2012; Torres et al., 2013) use the *component* approach in computational neuroscience (Guigon et al., 2008; Todorov, 2004; Wolpert & Ghahramani, 2000) to model biological movement or the application of optimal control theory in clinical CMS research. But, optimal control theory flattens biological movement without the accuracy to render the transitional complexity using independence, coordination, and switching rates within a granular taxonomy of movement. Anatomical behavior descriptions pursues an *interactive* model of movement analysis.

A novel behavior-time approach responds to the *low variability hypothesis* and the challenge to monitor variability in complex motor stereotypies (CMS). The instrumental proposition moves toward how to read visual evidence at lower levels of behavior in CMS and differentiating regulation of repetitive behaviors.

Improving observational criteria follows Prechtl (1974) view of behavioral states within the time domain. Newell and Slifkin's (1998) view on the importance of variability in motor research remains a claim leading to the need for a new methodology. “In closing, we would stress that it is important that variability is finally treated as a phenomenon or concept of theoretical interest rather than rely on an operational measure (standard deviation)... it would be misleading to imply that the invariance and variance can be neatly partitioned and linked directly to particular output sources.” This project

responds to the challenge to monitor variability, that is, *flow patterns* in lateralized phases (ipsi-, bi-, contra-) across the whole-body Methodical observation of micro-events (e.g., backward series of sequelae) might help to differentiate Hadders-Algra's (2010) repertoire or sequelae in repetitive restrictive behaviors (CMS). Three visual formalisms (Figure 13) record the scheduling of microevents in CMS. Behavioral recording visualizes a recursive network, that is, increasing granularity in CMS during morphological transitions within local time zones (Figure 8, 9).

This investigation suggests how chronological time series are incomplete measures of CMS. The following cross-references biomedical taxonomies with a description taxonomy (Tables 6-8). Anatomical behavior descriptions serve as a platform for a generative taxonomy (Table 7) where empirical rules (Table 7) modify descriptive expressions of behavioral markers. Several rules parse visual evidence on CMS: (1) *kinematic rule:* each movement is interspersed by a counter-movement and details motion capture of sequelae; (2) *cinematic rule:* repetitions either sustain serialized movements or a *next-step* in a cycle and details sub-division of temporal data; (3) *dynamic rule:* perpetual movement and pace in sequelae quantifies time values of recurrence of the sequelae; and, (4) *filtration rule: s*creening for asymmetric transitions (bi-,contra) does not equal (contra, bi-) or symmetric transitions in the time domain.



Observational criteria
Generative Taxonomy

Local time neighborhoods
Functional Taxonomy

Figure 1 Generative taxonomy for motion capture and functional taxonomy for time series analysis

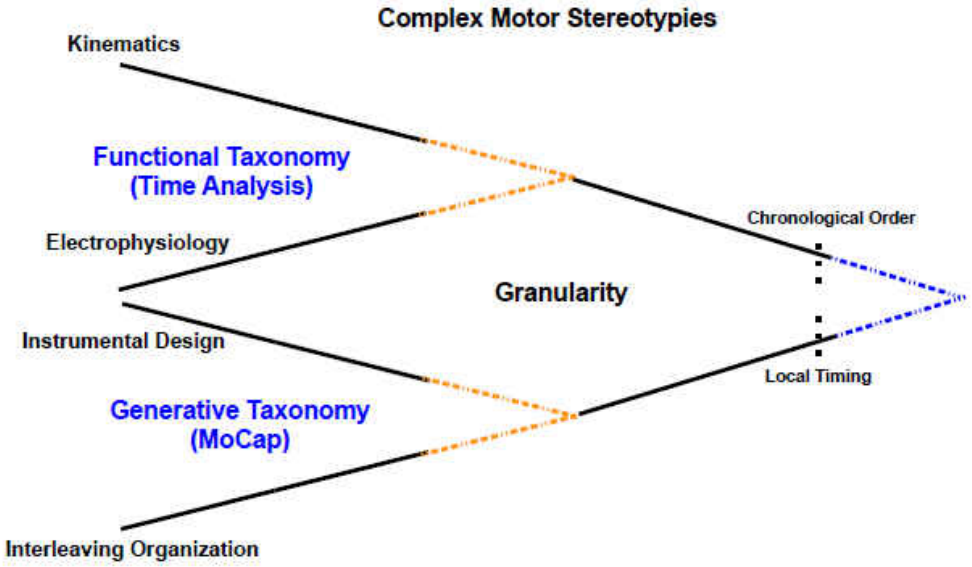


Figure 2 Motion capture and time series analysis taxonomies (chronological and local timing)

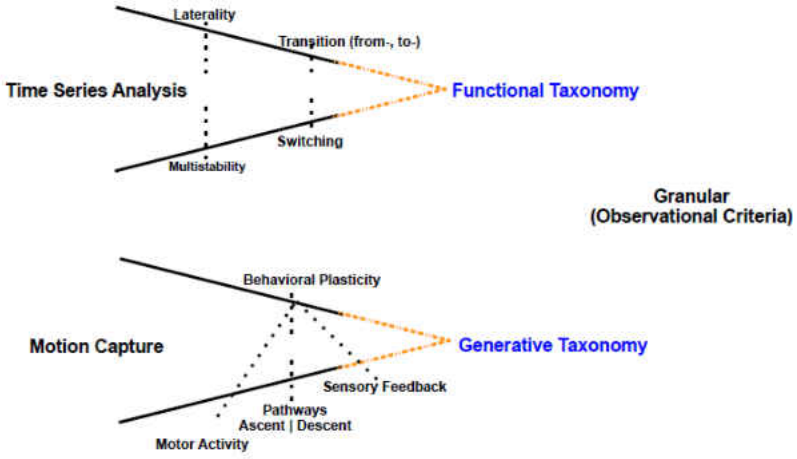


Figure 3 Parameters for generative and functional taxonomies

Background: Clinical Research and Complex Motor Stereotypies

Reviewing literature on CMS research one finds an accumulation of subject-centered research topics: (1) age of divergence of repetitive restrictive behaviors between typically/atypically developing children (MacDonald, 2007); (2) time intervals in repetitive restrictive behaviors are short taking microseconds to complete as micro-rhythms distributed over time to create macro-rhythms on the order of hours (Lewis, 1984); (3) examination of dynamic measures of postural stability function as objective markers of potential differences in motor control, between individuals with stereotypies and individuals with dyskinesias (Bodfish *et al.,*2001); (4) whether human behaviors function similarly to stereotypies behaviors in other species (Thelen, 1979); (5) the gap in knowledge on postural control and sway (Memari *et al.,* 2013); biomedical discussion of motor stereotypies on a pathological and a

physiological basis in the primary condition (typical development) and the secondary (atypical development) (Mahone *et al.,* 2004; Muthugovindan & Singer, 2009); and (7) the proposed CMS neurobiological research agenda to investigate corticostriatal- thalamocortical pathway in secondary using neurotransmitters to study stereotypies (Gao & Singer, 2013). Clinical CMS researchers would benefit from a universal description to guide research methods to support the quantitative measure CMS sequelae or repertoire.

Operational-clinical CMS data seem to reflect the late stages of repetitive behavior leaving unaccounted earlier *en route* behavior- time pairings, that is, traces of preliminary events: cortical potentials, allocation of resources, and complex time variables (within the engagement of resources: (1) *onset-acted*| past; (2) *sustained- retained behavior*| present; and, (3) *replenishment next-step*| future). In Smith and Van Houten (1996) keywords for stereotypies include descriptive terms (involuntary, patterned, repetitive, rhythmic, nonreflex,non-goal directed) and intervention terms (neuropeptides, dopaminergic treatments, and neuroradiologic studies). The descriptive terms have no quantitative component in Smith & Van Houten's study.

How CMS works under the skin or within the time domain remains undocumented in CMS research. Motion capture remains underestimated as a core component of clinical CMS research (Bodfish *et al.,* 2000; Bodfish *et al.,* 2001; Bracewell & Marlow, 2002; Lewis *et al.,* 1984; Lewis & Bodfish, 1998;

Lord, 1995; Lord *et al.,* 2012; MacDonald *et al.,* 2007; Mahone *et al.,* 2007; Richler *et al.,* 2007; Thelen, 1979, 1980, 1981; Yamada, 1995). Sanger's (2003, 2006) research on movement disorders is an exception in the development of motion capture technology to promote quantitative analysis of movement disorders. Recently, automated CMS analysis (Goodwin *et al.,* 2014; Gonçalves *et al.,* 2012; Karch *et al.,* 2012) rely on clinical research criteria to measure repetitive behaviors without considering the neurobiology to isolate time data on behavioral plasticity or severity of CMS (Table 5). Pre-motor cortical potentials (Dirnberger et al., 1998; Hallett, 2007, 2010; Houdayer et al., 2013; Shibasaki & Hallet, 2006) support before a behavior occurs there is the presence of cortical potentials. On instrumental grounds a quantitative methodology explores and quantifies *how CMS works* especially when the phenomena is poorly understood, as in CMS.

Table 1 Diagnosis and Complex Motor Stereotypies

Autism Spectrum Disorders
• CMS a diagnostic indicator in DSM V (APA, 2013) • assessment & intervention
Child Neurology
• 5 minute assessment (Hadders-Algra, 2010) • diagnosis & neurobiology
Medical Behavioral Assessment
• observe dystonia, dyskinesia, Bradly-kinesia (Maurer & Damasio, 1979, 1982) • traditional medical examination (Maurer & Damasio, 1979, 1982) • NIH Taskforce in Hyperkinetic Motor Disorders (Sanger *et al.,* 2010)

The absence of time data on CMS leads to a weakness in current definitions of CMS (Table 3). Absent from clinical CMS literature are three observational constraints: (1) *physical*, in a swaying movement (minimum of two subdivisions for any behavioral marker); (2) *mathematical*, combinatorial expressivity to accurately register variability in repetitive restrictive behaviors; and, (3) *symbolic*, visualization of patterns in local neighborhoods might reveal hidden patterns in behavioral plasticity in CMS. Measurement of switching and transitions in a repetitive sequence formalize behavioral plasticity in the time domain. Motion capture technology designed to differentiate behavioral-time pairings for dorsal/ventral observations. Forssberg and Hirschfeld, (1994) research with humans suggests postural control studies used to infer cellular motor function.

Table 2 CMS studies automation and feature detection

	Statement of Problem	Data Capture	Transition Complexity; Differentiated
Goodwin *et al.,* (2014)	uncertainty sequence begins/ends**;** *observation concomitant stereotypies*; document high-speed motor sequences	*body rocking/hand-flapping* , three-axis accelerometers	N/A
Gonclaves *et al.* (2012)	insufficient recording *number of occurrences of stereotypies*	*hand-flapping*, RGB camera (Kinect), accelerometer with watch	N/A
Karch *et al.* (2011)	*absence of kinematic description of variation* of infant motility (especially in arbitrary movement patterns)	*upper/lower limb* scoring movement (not morphology)	N/A

Comparing coarse and precise methods in CMS research (Table 3) presents a foundation to implement translational research practices for motion capture based on definitions of: (1) low variation leads to an absence of time data (sustained repetition or next-step repetitions); (2) repetitive restrictive movement results in an inability to differentiate sequential timing in CMS; (3) non-purposeful movements leaves unrecorded local optimality to differentiate phases of lateral movement; and, (4) visual analysis using coarse measurements without monitoring the regulation of transitions.

Table 3 Comparison with conventions on complex motor stereotypies

Criteria in CMS Definitions Coarseness in Complex Stereotypies (APA, 2013; Hadders-Algra, 2010)	*Precise Measures of CMS* Severity of Complex Motor Stereotypies (High Resolution Behaviors & Plasticity)
Absence of variance *Underestimation:* *sustained repetitive motor activity and pace perpetuation*	*Physiological relevancy* *allocation of resources in repetitive behaviors* (sustained or next-step in cycle)
Repetitive restrictive movement *Underestimation:* *serialization/next-step repetition requires sequential timing*	*Differences in regularity* *sequential timing* serialized in transitions
Non-purposeful movement *Underestimation:* *modeling local optimality differentiates internal continuity*	*Self-similarity local optimality* *levels of movement sub-secs within a core dataset in CMS*
Coarse Visual Assessments *Underestimation:* *unrecorded sequential time data*	*Behavior-time pairings in sequential pattern regulation*

A system of behavioral recording poses the opportunity to quantify repetitive movement's complexity using descriptions of high behavior resolution and behavioral plasticity evident in two avenues of research: (1) the multi-functional architecture of motor substrates (Arber, 2012; Briggman & Kristan, 2008); and, (2) multi-stability theory of motor circuitry (Kelso, 2012). There is the challenge to monitor behaviors on two scales (morphological and cellular) and within a heterogeneous framework of biological boundaries. Behavioral recording with high fidelity to the complexity of motor function contributes to taxonomical mapping of time data and biological aspects of a motor disorder. A top-down behavioral recording paradigm promotes further neuronal

computational recording practices (Aur & Jog, 2007; Pais-Vieira *et al.,* 2013; Nicolelis *et al.,* 1995, 1997) from the perspective of high behavioral resolution is no longer secondary to the principles of central pattern generators.

Anticipated Results

The proposed methodology functions within a direct biological interface, that is, a paradigm eclipsing indirect methods without neurobiological grounding. Milestones in a systematic direct biological interface include several points: (1) *multi-site recording* in the concurrent time-dependent interactions between large neuronal population Nicolelis *et al.,* 1995, 1997); (2) *specification of neurodynamics of neural spikes* (action potentials) as a neural code: spike directivity (preferred direction of electrical propagation), charge movement during action potential, and the use of tetrode (4 tip electrophysiological probe) (Aur, 2010. Aur *et al.,*2006; Aur & Jog, 2007; Jog *et al.,* 1997); (3) *co-cultures of nervous membrane on silicon chips* (Fromherz, 2002); (4) *the body on the chip incubation of human stem cells in in vitro assays* (Das *et al.,* 2006; Smith *et al.* 2013, 2014; Sung *et al.,* 2013); and, (5) the *shared work in brain-to-brain interface* (Pais-Vieira *et al.,* 2013) a progression in Nicolelis' research on multi-site neural recording techniques. Behavioral recording in this case addresses a system for use by a wide range of researchers (clinical, bioengineers, neuroscientists), that is, the goal is a system useful to quantify CMS dimensional variability rather than seeking a unique dataset to

define CMS behavior. Behavioral recording points toward the heterogeneous, that is, a state where variable parametric functions yield the same state as discussed in Marder's (2011) work on pyloric rhythmic circuits. Instrumental design becomes essential to deal with this level of complexity.

This systematic observational protocol draws upon animal models of neurobiology and biological mathematics to monitor regularity (repetition) of behavior markers (laterality, extension/flexion, and skin innervation as a geography of touch fields) within variable pathological conditions. The reader will find below a protocol to standardized measurement and classification of CMS severity: (1) regulation of CMS sequelae quantified by transition patterns (from-, to-); (2) a descriptive taxonomy and rules to conduct behavioral recording to computationally define observational criteria for motion capture (biosensors); (3) local time complexes (from the viewpoint of microevents) contribute to time series analysis in CMS; and, (4) weighting the persistence of behavior makers to provide fractional series for time series analysis. CMS in this project act as a mobile boundary system to further understand behavioral function under the skin. *A missing link in known motor wire modeling is behavior recording over the time course of rhythmic motor circuits.* By defining a novel methodology and measurement standards research on CMS (Figure 2) will study local time complexes in: (1) concurrent facets (laterality, touching, or switching rates in behavioral plasticity); (2) preliminary stages of sensorimotor

engagement (*en route* to the completion of a chronological sequence); and, (3) the allocation of resources (in the time domain). MeSH taxonomy maintained by the U.S. National Medical Library is a resource for developing the proposed systematic research. Anatomical behavior descriptions function as a computational protocol to capture local timing neighborhoods and marking intensities of difference (laterality, transition, plasticity, switching rates) (Table 3) in repetitive sequences.

An observational taxonomy leads to exploratory studies and scientific workflows to keep pace with the challenges of exploration and isolation of phenomena in a disorder without an etiological explanation. The expressivity of anatomical behavior descriptions monitors visual evidence using several rules on CMS visual evidence: the kinematic rule, each movement interspersed by a counter- movement; the cinematic rule, repetitions (sustained serial or next-step in a cycle); dynamic rule perpetual pace (sequelae); and, filtration rule, asymmetric transitions $\{\text{from}_{(\text{bi-,contra})} \neq \text{to}_{(\text{contra, bi-})}\}$. Observing CMS as local fractional series replaces chronological order with local and retrospective time analysis (Figure 3). In the anatomical behavior description taxonomy CMS are a repetitive environment staging recursion.

Table 4 Comparison of temporal organization for "behaviors in time"

Categories	*Chronological Order*	*Temporal Complexity*	*Transition*
Formalism	historical order, duration	action, retention, potential	real-time, non-redundant
Intervallic Structure	points, signals	independent, parallel (physical relationships)	(from-, to-),allocation of resources,
Order & Meaning	Milestones	asynchrony, synchrony	sequential dynamics (local)
Attributes	features (reaction, frequency)	neighborhood (tempi, rhythm, deformation, emergent, non-linear)	local optimality
Hierarchy	component, psychometric	molecular	interactive (modularity, variability)

Anatomical behavior descriptions facilitate a recursive assessment of CMS as local timings within a primary facet and neighboring secondary facets. Observing CMS sequelae as recursions (multiple viewpoint) drills down into a broad behavioral-time pairings (from-, to-) or the reversal of a very brief behavior-time pairing. A precise model of CMS captures patterns in time series under several measurement methods: (1) when an unexpected strength occurs during the *gearing down* of sub-second micro-events (e.g. touching) as a motor hiccup (burst);(2) the bi-directional perspective of a facet takes a primary role followed by secondary facets; or, (3) anomalous behavior-time patterns in switching or whole-body events (independence or coordination). Framed by the completion of an onset interval confirms the low-variation hypothesis but within the completion of an onset there is a transitional complexity, that is, the *en route*

intermediate timings in CMS found through recursion in anatomical behavior descriptions.

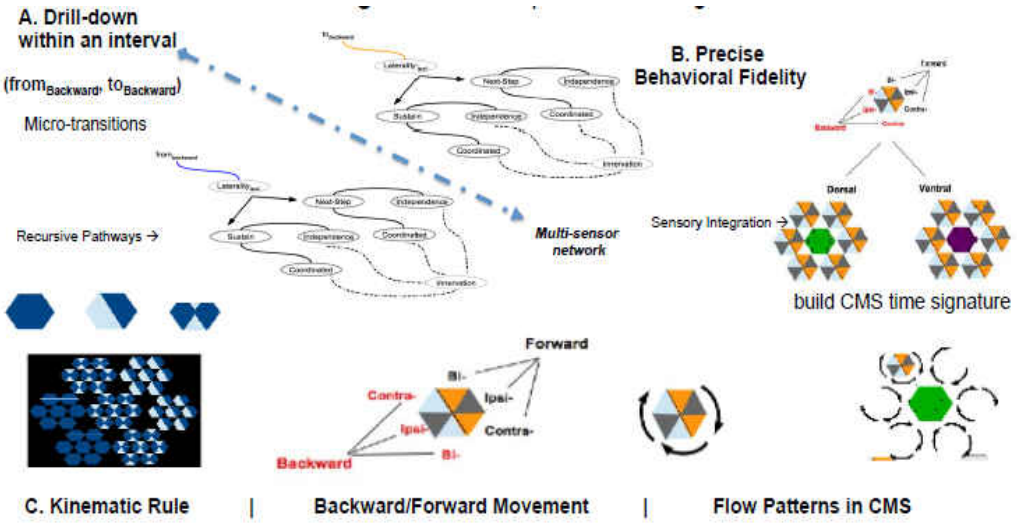


Figure 4 Three graphical applications of anatomical behavior descriptions

The strength of observation for motion capture would benefit by descriptions capable of quantitative and biological expressivity. Mechanistic models of movement would benefit from the observation of several layers as claims:

> "Movement is generated by the activity of neuronal circuits collecting and integrating information, ultimately leading to precisely timed skeletal muscle contractions. Work of many years had demonstrated that the motor control system exhibits a multitude of interleaved layers of organization." (Arber, 2012, p.975)

Arber summarizes research on motor circuitry using three key components: (1) developmentally infused component: neurons project and

innervate the spinal cord during motor activity (rhythmic and patterned); (2) neurophysiological component bi-directional communication in the brainstem's ascending and descending channels, between spinal circuits and supraspinal centers; and, (3) sensory feedback systems monitor consequences of motor action illustrates touch-induced movement in the escape case (organism-environmental) case and the integration of touch-movement patterns.

Taking visual evidence into a mathematical organization is central for anatomical behavior descriptions to explore how an individual occupies 3-D space and the distribution of whole-body engagement. Identifying a network of movement (Figures 13, 18) contributes to visualizing additional components in complexities unfolding (enumerated) within biological movement. Additionally, the tools used to quantify repetitive movement will compute while observing layers of variability in the description of visual evidence in repetitive restrictive.

Table 5 Visual Observation and Visual Evidence (Interdisciplinary Mathematical Origins)

Variability (motor research)	*phenomenon* or *concept* of theoretical interest rather than operational measure (Newell & Slifkin, 1998)
Regulation (repetitive sequelnce)	*motor function* linear, dynamic, equilibrium (homeostasis)(Kelso *et al.,* 1981)
Cellular (heterogeneous)	*multistable* many different combination (synaptic, neuronal*) produce* same network activity (CPG) (Briggman & Kristan, 2008; Kelso, 2012; Marder, 2011)
Morphology (motion capture)	*transitions* in repetitive sequential motion, pairings *t'{(from, evacuate a posture), (to, enter a posture)}*
Taxonomy (behaviors in time)	*high behavioral resolution* many behavior markers ➔ mark difference in repetition

Early Measurement Standards

Historical views of measurement in human performance fall into several categories: behavior, pathology, and physiology. Measuring physiology establishes methodologies for psychometrics (sense perception), experimental psychology, and clinical psychological interventions. The physicians Ernst Heinrich Weber (1795-1878) and Gustav Fechner (1801-1878) combine medicine and physics to initiate a quantitative foundation for psychological phenomena through psychophysics. Weber–Fechner law supplies future experimental psychology with a quantitative axiom where measurement of stimuli and psychological events occur. This law relies on just-noticeable difference (JND) where a difference between things carries along measurable

comparisons. The road toward measuring physiology leads from the mathematical expression in Weber and Fechner to pathology seen through instrumental observation of neuroanatomy by Cajal (1852-1934) awarded the 1906 Nobel Prize Medicine for his detailed illustrations on the microscopic structure of brain. Another advancement for pathological research is the discovery on chemical nerve function and the electrical function in cell neurophysiology by Otto von Loewi (1873-1961) 1936 Nobel Prize Medicine.. The psychologist Donald O. Hebb (1904-1985) combines behavior, Lorente de No's neural anatomy, and firing neural networks (Hebb, 1980). The neuroanatomical structural mappings in Cajal and the neurosphyiology contributions of Loewi and Hebb establish a version of behavior within a neurobiological foundation.

Along with mathematical-physics and neurobiology there is a strand of measurement quantifying behavior for behavior modification and behavioral psychology John B. Watson (1878-1958), Skinner behavioral psychology (1904-1990), Arnold Gesell (1880-1961) behavior or educational standards on child development and metrics for school readiness: motor, cognitive, linguistic modification psychology pediatrics. Completion of a subject design protocol combines physiology and pathology to assess behavior. The influence of developmental child psychology Jean Piaget (1896-1980) and Heinz R. Prechtl (1927-2014) provided the foundation for the assessment of general movement

and modern developmental neurology,

An alternative form of quantitative measurement integrates: subject-design, neurophysiology, and clinical objectives (experimental psychology) appears in Hebb's research. In the *Essay on Mind* (Hebb, 1980) maintains the claim “cells that fire together wire together” a theoretical framework on excitatory/inhibitory functions during psychological process. Hebb's well-accepted theoretical framework brings to experimental practice biological process. The psychophysics in Fechner codifies quantitative practices physics-like measurement standard with formula precision. Hebb's research method integrates biological, psychological, and scientific inquiry according to low level scales of function (neurological operations, genetic operators) and behavioral states (concentration and high-level functioning). The methodology in this project aligns with Hebb's research method by pursuing empirical interactions across scales (cellular and behavioral) while subject-design does not minimize biological uncertainty in behavioral research.

There are several cornerstones in early measurement practices including: Frank Gilbreth (1886-1924) pioneering motion study devices or computational models based on Nikolai Bernstein (1896-1966) dynamics of motor mechanics (Pellis, 2010; Thelen, 1995). In each of these cases instrumentation facilitates subject design research to conduct quantitative research. An instrumental measurement standard has the opportunity to use advanced technologies

(nanoscience and neuroscience) to monitor biomarkers and behavioral markers. The point of demarcation for advanced measurement standards revolves around instrumental measurement standards. Clinical CMS researchers are left with fitting into behavioral, physiological, and pathological measurement protocols dating back to Weber-Fechner's psychometric measurement standards or Lilian and Frank Gilbreths' motion analysis photography to measure work productivity. Research on animal models introduce advanced measurement standards to monitor behavior and neurobiological interface. Feng *et al.* (2004) introduce phenotypic parameters to monitor c. elegans behavior. An advanced instrumental measurement standard isolates markers (biomarkers and behavioral markers) to improve motion analysis to capture functionality (Weber-Fechner) or competency (Gessell). Markers appear as a missing key registered by advanced instrumental measurement standards to bring a novel computational perspective: functional-structural measurement across two scales.

Avenues between Psychometric and Diagnostic Measurement Standards

Since early standards of quantitative measurements in Weber and Fechner's psychometric measures depend increasingly on subject-design oriented protocols diagnostic assessments in motor stereotypies are observations of the presentation of CMS, to make determinations on behavior, physiology, and pathology. A substitute for subject observation would investigate equilibrium as a function of variability occurring at a level of biological

automation, regulation, and switching. Behavioral and clinical views of repetition maintain a psychological perspective of compulsion or rigidity with a formal representation in terms of prevalence (Lewis & Bodfish, 1998). But prevalence does not offer time data. Kelso's (2012) biological theory accounts for multistability and multifunctionality. In two cases (psychometric and multistability) quantitative research examines some degree of behavior, physiology, and pathology. The development of translational quantitative research might point toward the fulfillment of variability under distinct biological contexts of multistability without waiting for the presentation of a subject's CMS. Visual formalisms (e.g, the punnett square and self-similar patterns) and literature on bioengineering (Bahn & Guest, 2011) and nanoscience (Das *et al.,* 2006) establish a demarcation from subject-design oriented protocols to move toward the granularity (multi-resolution), that is, a drill-down variability of biological systems (Figures 10,11).

In anatomical behavioral descriptions repetitive restrictive behaviors display switching and granularity warranting precise computational measurements in the time domain rather than viewing repetitive behavior in terms of the individual's performance competency or behaviors as compulsive. To frame standards of measurement based on the literature, this project introduces the following: (1) limitations of definitions of hyperkinetic movements within subject-design protocols (Sanger *et al.,* 2010); (2) the

application of MeSH taxonomy as an investigative biological resource when examining an organism's complexity; (3) MeSH as an interdisciplinary peer-reviewed resource provides a drill-down hierarchy pre-empting the need for initial subject observation and, (4) the use of time analysis (Pincus, 1991; Pincus & Goldberger, 1994) to promote research on equilibrium and regulation.

Alongside the general quantitative measure of behavior and in subject design there is a specialized area of research: motion capture. Motion capture is essential to understand one of the basic aspects of activity of whole body movement namely to quantify the core dataset in the time domain. Along with the protocol outlined in Chapter 1 and Chapter 3 the literature review plays an essential role to present best practices, new advances in the body of knowledge in bioengineering, and the neurobiology of motor activity.

Kelso's (2012) multistability theory observes “many different muscle configurations can produce the same outcome.” This alone supports a description of variability in a behavior without measuring the relationship between (Kelso *et al.,* 1981) and experimental study on Kelso’s multistability. In another example Kelso points out “the same network activity in central pattern-generating circuits can be produced using many different combinations of synaptic strengths and neuron properties.” The example of the central pattern generator's flexibility and modularity complements behavioral research observation in an instance where the dynamic of biological movement is less

literal than what eye-witness research reports or data-driven point-set evaluations.

Indexing behavioral markers as they occur in time define a mechanism to monitor Kelso's biological theory on equilibrium articulated by two concepts: degeneracy and multifunctionality. Early quantitative measurement standards establish the conventions of psychometric and subject-design without addressing the regulatory function (time function) or incremental organization of CMS as degrees of severity within measures of involuntary engagement. According to the literature review below biomedical definitions of CMS (Hadders-Algra, 2010; Maurer & Damasio, 1979, 1982; Prechtl 1999; Sanger *et al.,* 2010) go as far as awaiting for behavior to present to CMS.

Early measurement standards in psychometrics pioneered by Weber and Fechner point to the importance of physiological grounding of behavioral measurement. The empirical contributions by Nobel Prize researchers Cajal's illustrations of neuroanatomy and Loewi's experiment confirm chemical and electrical synapses in neurophysiology suggest an empirical basis absent from definitions of hyperkinetic movement. The absence of time data on hyperkinetic movements guides the literature review in this project. MeSH is a hierarchical taxonomy with a systematic overview of several facets of CMS research: behavioral, physiological, and pathology absent from clinical research CMS research (Appendices A,B). This includes the recent definitions of hyperkinetic

movement (Sanger *et al.,* 2010). Biomedical definitions of repetitive restrictive behaviors (Maurer & Damasio, 1979, 1982) underestimate the dynamics of behavioral plasticity and repetitive movement sequences. Since Chalfie's *et al.* (1985) c. elegans research precise nanoscience measurement (Ardiel & Rankin, 2008; Chronis *et al.* 2007; Kawano *et al.,*2011; Larsch *et al.,* 2013; Nagy *et al.,*2011; Salvador *et al.,* 2014; Wen *et al.,* 2012) and imaging of techniques with neurobiological evidence (Feng, 2004) would provide additional data to the coarse video analysis (Campbell *et al.,* 1990; Loh *et al.,* 2007;; MacDonald, 2007 ;Richler *et al.,* 2007; Teitelbaum, 1998) or clinical stereotypies with some empirical methodology (Bodfish, 2001; Lamoth *et al.,* 2009; Lewis *et al.,* 1984; Memari *et al.,* 2013; Ross *et al.,* 1998; Yamada, 1995).

Diagnostics and Definitions for Clinical Motion Analysis

A taxonomy for clinical motion analysis is a starting point to calibrate biosensors for granular motion capture. Instrumentation houses the working logic necessary to conduct measurement procedures (Table 5). For the proposed diagnostic instruments design there is two missing ingredients: diagnostics criteria and definitions of hyperkinetic movements in childhood.

A diagnostic criteria might bring to motion capture a bridge between the absence of biomarkers indicative of involuntary movements and comprehensive terminology on hyperkinetic movements found in Sanger *et al.,* (2010). Some

biomedical CMS researchers organize methodical investigation of CMS. Maurer and Damasio (1982) attempt to conduct time-measurement studies but only looked at an isolated movement without indexing adjacent or complementary movement evident during data collection on the targeted movement. Gao and Singer's (2013) study signal the importance of neurobiological markers related with pathways corticostriatal-thalamocortical measured using neurotransmitters to understand the neurophysiology in CMS.

The morphological level presents a possible observation practice to consider: (1) CMS in the time domain; (2) severity of CMS; and, (3) regulation of CMS. Myoclonus, a hyperkinetic movement, according to the Sanger and collaborators' review illustrates how instrumental design might conduct complex motion capture with detailed time data. The alignment of behaviors on the morphological scale and the proposed switching on the cellular scale the proposed indexing system introduces a measurement standard across scales.

Bioengineering diagnostic instrument design has two levels of motion capture: (1) computational layer input processing; and, (2) timekeeping of clinical behaviors output processing. The computational layer hosts mathematical expectation (Figure 8) in a hierarchical tree. Clinical definitions and biological systems (MeSH) provide variables to formalize data capture contributing to diagnostics registration of the behavior. The stronger the index of MeSH variables the stronger the instrument's diagnostic potential. While the

sensitivity of the diagnostic instrument depends on the strength of MeSH variables and the engagement of the instrument's modules while monitoring repetitive restrictive behaviors.

Clinical Research without Reconstructive Diagnostics

A provisional revision of diagnostic assessment phenomena without etiological recognizes three definitions for diagnostic measurement. First, there is the non-equilibrium diagnostics using data points to statistically characterize a behavior. Second, what is the data range for the functional characterization? Lastly, there is the biological isolation for interactive characterization Arber's (2012) use of viral tools. *The development of diagnostic instrument represents an exploratory (motion capture) research practice rather than quantifying behavioral output.* Variables monitor CMS input and establish a system to record and reconstruct repetitive restrictive behavior. A systematic diagnosis will monitor the networks of engaged variables (Table 7), various inactive variables, and documenting the sequential results of the repetitive restrictive behavior. A systematic diagnostic protocol would distinguish between sequential build-up of mirco-rhythyms in the CMS (*en route*) and results of the behaviors' (chronological order).

Measurement standards with a precise approximation bring a measurable terminology to index restrictive behaviors missing from narrative

characterizations of repetitive restrictive behaviors found in the Autism Diagnostic Interview-Revised (ADI-R) (Lord *et al.,* 1994). The narrative characterizations include the following: repetitive use of objects, unusual sensory interests, hand/finger mannerisms, compulsions and rituals.

Ability measurement in clinical CMS research remains goal-oriented in terms of the measurement as a competency without a neurobiological metric. The literature on the measurement of planned motor activity looks at the inner working of behavior as cortical potentials associated the planning (Dirnberger *et al.,* 1998). Non-literal observation of planned motor activity is missing from clinical CMS measurement. Future CMS research informed by Dirnberger and collaborator's insight into planned motor activity might investigate the regulation of repetitive restrictive behaviors and the equilibrium at points critical to the sequential unfolding of repetitive restrictive, in sustained or cyclic repetitive patterns. Substituting anatomical positions for the competency based (goal-oriented metric) promotes a diagnostic research criteria absent from clinical CMS research. While CMS researchers maintain ability as a research objective future research might explore a taxonomy of repetitive restrictive behaviors under the skin or the functional regulation of repetitive behaviors within the time domain as micro-rhythms already discussed in the clinical CMS literature (Lewis *et al.*, 1984).

Diagnostic measurement of precise variability at highly granular time intervals might clarify the low variability hypothesis assigned by the neurological literature on CMS. To clarify the low variability hypothesis there is the proposition: *repetition is more than redundancy.* This view of repetition defines repetition as configurations in a granular dataset as an individual's movement transitions. These transitions appear through a methodical visualization system (Figure 18) where there are several neighborhoods: (1) sustained repetition or the next-step in a cyclic sequence.; (2) lateralized movement (ipsi-, bi-, contra-); and, (3) mapping behavioral plasticity as *turn-taking* in the transition of (*from- to*) distinct forms of lateralized movement.

Instrumental Design a Methodology

Since, Edward Muybridge's (1830-1904) photographic motion studies (if all feet leave the ground during a horse's gallop) motion capture technologies with markers (Pentland et al., 1998; Peikon et al., 2009; Rosenhan et al., 2006; Wren, 2005) or markerless (Mündermann et al., 2006; Rosenhan et al., 2006) remain on the surface of biological movement. *These motion capture techniques resort to frame analysis where granular movement (independent or coordinated) receive no asynchronous time processing within the frame*. To observe CMS anatomical behavior descriptions revise analytic criteria for future motion capture technologies based on transitions (from-, to-) in biological movement. Anatomical behavior descriptions supply motion capture with a

four-way observational criteria: anatomical (posture), behavior (postural engagement), descriptions (scenarios of engagement), and the combination of anatomical behavior descriptions (sequelae). A descriptive language of behavior markers (laterality, extension, flexion, independence, coordination, touching, etc.) registers transitions as a paired time-behavior function:

T'{t(from- behavior marker, time), t(to- behavior maker, time)}.

In the proposed motion capture protocol anatomical behavior descriptions index time-behaviors while bio-sensors capture independent interlimb activity and local time complexes within a network of biosensors. A spatial distribution of bioengineered sensors report on local time data, kinematic data (movement direction, skin innervation, and surface tension-pressure) modeled on Lowe (2011) in Bahn and Guest's (2011) report on the state of the art of biosensor development. Other sensor options include electronic skin sensors (Parasuraman & Wilson, 2008) would contribute to data collection of local directional movement, surface pressure (skin), and electrophysiological variables (EMG, EEG). The electronic skin sensors would require interfacing local time-behavior indexing data with the chronological biometric data from electronic skin sensors. Anatomical behavior descriptions act as time indexing process to keep pace with local patterns outside of the one-way chronological order of succession.

CMS functions as an expressive mobile boundary system and as a medium to further understand temporal dynamics of behavioral function under the skin. *A missing link in known motor wire modeling is behavior recording over the time course of rhythmic motor circuits.* The bridge between rhythmic motor circuits and repetitive restrictive behaviors points to an instrumental problem, without waiting for subject data. Research on CMS will study local time complexes in concurrent behavior markers (laterality, transitions, touching, and switching rates in behavioral plasticity) *en route* to the engagement and the allocation of resources in the time domain. Anatomical behavior descriptions provides observational criteria to observe visual evidence missing from current data collection of repetitive behaviors (Appendices F,G). Absence of visual evidence in motion capture techniques owes to seeing repetition as redundant, an absence of a rigorous model of behavior in the time domain, and an absence of a comprehensive "instrument model." Anatomical behavior descriptions formalizes guidelines on "where data comes from" in terms of instrument design and mathematical expectation to address the variability of the presentation of CMS.

Anatomical behavior descriptions as a behavior-time approach responds to the *low variability hypothesis* (Hadders-Algra, 2010; Prechtl, 1974, 1990, 2001) and the challenge to monitor variability in complex motor stereotypies (CMS). *The absence of high behavioral resolution in CMS reflects limitations in*

the observation of CMS rather than confirming low variation in CMS' structure and function. Three questions guide the development of an *instrumental proposition* to quantify CMS: (1) Is repetitive restrictive behavioral plasticity asymmetric (i.e., between series of forward-touch movement and backward-touch movement)? (2) Will time analysis support the association of ipsilateral movement with excitatory motor circuitry, contralateral movement inhibitory motor circuitry, and bilateral movement with excitatory/inhibitory motor circuitry? (3) How does the complexity of processing rates at several levels of behavioral resolution differentiate morphological timing and cellular processing? ... or, Does behavioral plasticity in high behavioral resolution yield a measure indicative of the allocation of resources in CMS between the morphological and the cellular? The instrumental proposition moves toward how to read visual evidence through motion capture at lower levels behavioral activity in CMS through time analysis.

Chronological time series are incomplete measures of CMS. Consider the visualization of a c. elegans' backward movement in Figure 5. Movement reflects more than the chronological order following time's arrow (one-way). Figure 5 visualizes a local time setting with flow patterns. To illustrate the flow of movement, the blue highlight suggests the step-by-step translation of engagement of side walls (the arc in orange reflects transitions in time along the length of the creature and is *not* a spatial displacement as the creature moves

posterior-to-anterior). Anatomical behavior descriptions serve a time-behavior protocol to monitor local microevents in CMS as more than a completion of chronological order.

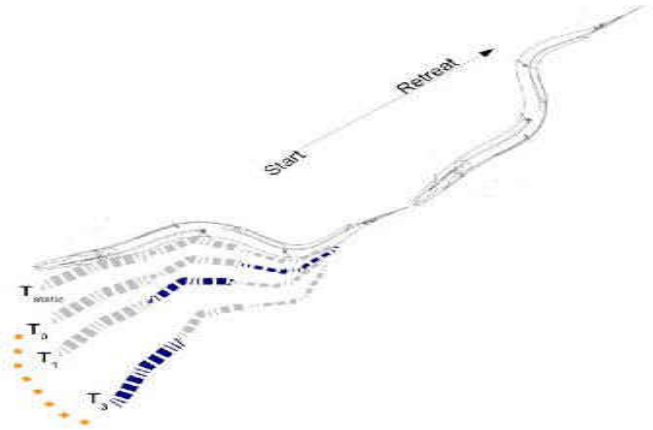


Figure 5 Visualization of local timing of posterior-to-anterior undulatory movement

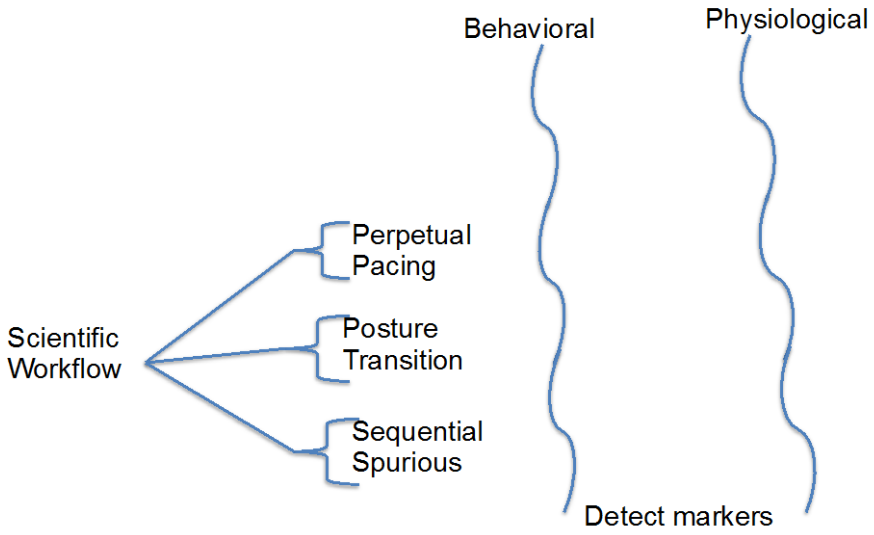


Figure 6 Basic detection model for complex motor stereotypies

Systematic indexing of time-behavior data in CMS, might differentiate sequelae's behavioral resolution. Indexing transitions (from-, to-). CMS as a boundary system with repetitions and perpetual sequelae patterns serve as a real-time conduit to study plasticity assigned to the central pattern generator (Briggman & Kristian, 2008; Marder, 2000; Marder & Calabrese, 1996; Selverston, 1980) and multi-stablity (Kelso, 2012) along morphological lines. This systematic observational protocol provides transition data to differentiate CMS repertoire or CMS sequelae.

Using natural observation of CMS is consistent with Siegler and Cowley's (1991) microgenetic protocol. Collecting data to measure general movement variability in CMS requires sufficient time to observe the behavior,

rather using an arbitrary observation duration. Sufficient observation duration would is a function of the depth of the repertoire to project the potential duration of the sequelae. To index time-behavior data there are several time variables in anatomical behavior descriptions: transition (from- evacuation of a posture, to- entry into a posture), switching rate in lateralized movement's phase, and regulation of sequelae transitions. Sensor distribution is central to acquire motion data within local neighborhoods (Figures 10, 11) absent in video analysis and motion capture with markers. A science of behavior markers registers local (micro-events) within the chronological order of a CMS sequence.

Local motion capture quantifies sequelae in several fractional series found during observation of intermediate transitions *en route* to completing the chronological order in a CMS sequelae. A fractional series of behavior markers CMS (Figure 8) details the chronological order of sequelae into a local measurement of from series (from*backward*, ipsilateral) or the forward series (to*forward* , ipsilateral). Observing CMS sequelae through recursion (Figures 10, 11) drill down into a broad (from-, to-) time-behavior pairing. Figure 10 illustrates behavior marker datasets through a local perspective within the chronological order: (from*backward*, to*backward*) or (from*backward*, skin innervation). Anatomical behavior descriptions taxonomy contributes to the study of *how* CMS *work* within a transitional time-complex. Observations on the low-

variation hypothesis confirm assessments as a complete time setting. But, to map time complexity within an interval, that is, local time neighborhoods observations will pursue a high behavior resolution model.

Instrumental-design builds upon Harel's claim, “Visual formalisms – diagrammatic displays with well-defined semantics for expressing relations” (as cited in Nardi & Zarmer, 1993). For computational enhancement a visual formalism renders increasing granularity (Figure 12), modular functions with varying controllability in multi-dimensional configurations (Figure 13), multi-resolution configuration (18,19), or short-lived local time relationships in a chronological sequence (Figures 12,13). Heightened visual symbolic expressivity takes on a functional role for algorithmic control of motion sensors' motion capture, scientific workflows in CMS research (Figure 15), or variability in heterogeneous datasets (Marder, 2011). As in video movement analysis the goal in instrument-design uncovers visual evidence but with increased research complexity, (e.g. formation of families of instruments).

Since Teitelbaum *et al.* (1998) researchers use video recording to differentiate repetitive behaviors. Visual evidence parsed through the lens of a strong visual semantics is a computational problem. CMS researchers progress with a logic to differentiate repetitive behaviors. The next step is logic-based differentiation of repetition. Table 6 based on Deleuze's (1994) *intensity of difference* outlines two granular series differentiate repetition *behavior markers*

in high behavioral resolution and *time markers* in behavioral plasticity. In both granular series appears criteria for motion capture or time series analysis within the anatomical behavior descriptions taxonomy (Table 7). Observing repetitive behaviors is a sequential-temporal problem as much a postural phenomenon documented in subject-design studies (Appendices A,B) using camera-based motion capture. Instrument-design introduces a computational layer absent from camera-based motion capture. No longer dependent on literal reading of visual evidence a biomedical knowledge base, MeSH taxonomy (curated at the United States National Medical Library) offers robust research evidence. The topic of regulation and metabolic process in this project is an outgrowth of cross-referencing metabolic aspects of movement disorders with psychological and neurological MeSH keywords (Appendix B) and the two groupings: (1) musculoskeletal and neural physiological phenomena; and, (2) nervous system and physiological phenomena (Appendix C). Anatomical behavior descriptions function as a computational protocol based on MeSH taxonomy to formalize motion capture. The anticipated result is a core CMS dataset with local timing data and time signatures (Figure 16) to replace clinical *assessment of ability* with the physiological and behavioral aspects of how CMS works in terms of a morphological regulatory measurement(Kelso *et al.,* 1981) and the trace of motor circuitry's multi-stability (Kelso, 2012).

This project proceeds with the need for mathematical hypothesis on time series analysis in biomedical research (Pincus & Goldberger, 1994). Visual formalism act as a conduit to apply computational literature: (1) biological dimensionality (Bellman, 1961); (2) regularity in time series (Deffeyes *et al.,* 2011; Pincus, 1991; Pincus & Goldberger, 1994); and, (3) fractal movement analysis (Chau, 2001; Hausdorff *et al.*, 1995, 1996,1997; Ihlen & Vereijken, 2013).

Toward a Science of Behavior Markers

A science of behavior markers points toward the exploratory rules based (taxonomy) and the local cross-section of chronological order. Rapin (1996) notes neurological assessments rely upon soft observations. A change in research objectives carries the eventuality to revise basic relationships on difference, repetition, and measurement.

Kohn *et al.,* (2006) molecular interaction mapping (MIM) diagram the complexity of pathways and networks in biological substrates occur under two conditions: (1) heuristic MIM possible interactions; or, (2) explicit MIM particular models from the possible interactions. The structure of the Kohn MIM resides in a "canonical map by deleting the molecules that are not expressed as well as the interactions that do not occur because of lack of colocalization." CMS a movement disorder without an etiological explanation

warrants the objective to map the regularity of the time series as a systematic behavioral markers (Figures 13,14) flowing (jerky or continuous) within local time series (backward or forward) and the allocation of resources over the time-course: onset (initial postural configuration), engagement (present), and replenishment (future) (Figure 17). Defining behavior as an engagement of resources extends Kohn and collaborators annotation of molecular interactions through absence or expression. A novel definition of CMS in the time domain follows:

Regularity in CMS is a problem of monitoring *high behavioral resolution* in the time domain and the *regulation of behavioral plasticity*. In all non-episodic CMS cases there is a perpetual pacing of a repetitive circuitry. CMS occur as whole-body *flow patterns*. To advance CMS motion capture anatomical behavior descriptions mark time-behavior pairing when using technologies with *direct biological interface* (wearable bio-sensors or nanoscience assays).

In CMS extension-flexion movements punctuate an extended duration marked by lateralized movement occurring as three behavioral markers (ipsilateral, bilateral, and contralateral). Diagramming the quantitative complexity of these categories of movement remains a systems biology question with specialized interest for CMS research (e.g., if ipsilateral (*uni-independence*

or *bi-independence*) movements differentiate bilateral/contralateral (*coordination*) movements in the time domain).

Detailing descriptions of morphological behaviors contribute time data leading to investigative questions: Are repetitive circuitry inhibitory or excitatory under lateralized conditions or sequelae patterns? How does ionic conductance function within sensorimotor transfer when ipsilateral conditions modify the time series in CMS sequelae? Do behavior-time pairings extend morphological measurement to trace a cellular allocation of resources within innervated skin? How do behavioral markers provide visual evidence of posture, skin, and time settings rippling within the whole body?

The study of pathological conditions and variability on mathematical grounds finds limited attention outside of Torres *et al.,* (2013) and Gowen and Hamliton (2013). Pincus (1991) develops a "preliminary mathematical development of a family of formulas and statistics, approximate entropy (ApEn), to quantify the concept of changing complexity. We ask three basic questions: (i) Can one certify chaos from a converged dimension (or entropy) calculation? (ii) If not, what are we trying to quantify, and what tools are available? (iii)" The clinical researcher's goal has less to do with developing a mathematical tool and more to do with a statistical reading of a behavior (CMS). Pincus recognizes "if we are trying to establish that a measure of

system complexity is changing, can we do so with far fewer data points needed, and more robustly than with currently available tools?" But Pincus' contribution requires a data collection protocol. The question of *Where does the data come from?* reappears in terms of the source data used to conduct time series analysis.

Behavioral markers bring to CMS precise measurement criteria with a working model to *mark intensity of difference.* The relationship of difference and repetition (Deleuze, 1994) brings a new standard for *designing target data in motion capture technology*, namely visual test to determine increasing levels of granularity (Figure 12) based upon a taxonomy (Figure 14). Increased resolution presents a granular dimensional data collection (sensorimotor) (Figure 13a) and differentiation of power process (regulation) during the sequence of repetitive restrictive behaviors (Figures 13, 18). The first method based on anatomical behavior descriptions would index time-behavior transitions to determine asymmetries in behavior plasticity and gradations of regularity CMS behaviors in the time domain.

Anatomical behavior descriptions introduce a universal standard. This descriptive system starts with a comprehensive measure (from-,to-) transitions. Science of behavior markers quantifies transitions through an *intensity of difference* (Deleuze, 1994) with increasing granular observations (Table 6). Deleuze (1994) proposes in *Difference and Repetition* the world is a fractional,

a 'remainder', and understood in terms of fractional or even incommensurable numbers. This claim anticipates repetition has additional differentiation:

> "Intensity is the form of difference so far as this is the reason of the sensible. *Every intensity is differential, by itself a difference.* Every intensity is E-E', where E itself refers to an e – e' , and e to ε – ε' etc. : each intensity is already a coupling (in which each element of the couple refers in turn to couples of elements of another order), thereby revealing the properly qualitative content of quantity." (Deleuze, 1994, p.222), (Table 6).

To translate this philosophical statement for quantitative researchers substitute *authenticity* (*fidelity with behavior*) for *sensible* clarifies the utility of intensity of difference as a series (Figure 12). Table 6 applies Deleuze's theory on difference and repetition to anatomical behavior descriptions and behavior markers used to observe high behavioral resolution and behavioral plasticity CMS.

Table 6 Intensity of Difference and Repetitive Restrictive Behaviors

Intensity (*E-E′*)	*Behavior Marker* (*High Behavioral Resolution*)	*Time Marker* (*Behavioral Plasticity*)
E refers to... *e – e′*	*laterality* → (ipsi-, bi-, contra-) >	*Transition* → t(from-, to-)>
	musculoskeletal → extension | flexion >	*repetition* → serial, cyclic>
	interlimb activity → independence | coordination >	*switching rate* → *en route*>
	geography touch fields → dorsal | ventral	*perpetuation* →local time
e refers to… *ε – ε′*	{(*ipsi-, bi-, contra-*)} → {(from- | to-)	*t*(*from-, to-*) → fractional series
	{*extension* | *flexion* } → sensorimotor transfer	*serial, cyclic* → excite | inhibit
	independence | coordination → backward |forward	*en route* → multi-function
	{ *dorsal* | *ventral* } → geography touch receptors	*local time* → flow patterns

Behavioral markers qualify repetition with greater quantitative detail (granularity) within a cascading series: (1) laterality; (2) (laterality → musculoskeletal); (3) (laterality → musculoskeletal → interlimb activity). Within each of these features there is a phase turning the feature into a detailed variable: laterality(ipsi-), laterality(bi-), laterality(contra-). In turn the grouping of {(laterality$_{\text{independence}}$,ipsi-)} contrasts with {(laterality$_{\text{coordinated}}$, bi-\| contra)}. An application in motion capture would implement a visual tests to differentiate {(laterality$_{\text{independence}}$,ipsi-)}. A researcher would want to look for contexts addressing how {(laterality$_{\text{coordinated}}$, bi-)} and

{(laterality coordinated, contra-)} occur in sequelae of varying severity for asymmetry or symmetry. An intensity of difference marks repetition allowing for differentiation of repertoire or sequelae in CMS in terms of inclusion or exclusion. To arrive at empirical findings this morphological differentiation contribute time data to neurobiological and motor circuitry *in vitro* studies is essential. The time-behavior pairing data evident through identification of intensities of difference starts as an observational criteria for motion capture.

Clinical researchers and neurologists agree repetitive restrictive behaviors occur as general movements without purpose. The activity in CMS may present sensory integration (touch and movement). Recently, Karch *et al.* (2012) call for objective descriptions in movement stereotypies and empirical measurement (Torres *et al.,* 2013). What remains unclear is the consequence of a universal description for CMS data collection? Three potential areas of develop include: (1) a taxonomy handle descriptive applications; (2) symbolic systems to recursive. A recursive implementation of anatomical behavior descriptions reveals a series where one description (computable) leads to a series of laterality related events:

Several cases describe *how CMS work* in a behavioral recording. In CMS when a lateral movement occurs there is a transition (from-, to-). When there is a lateral movement there is an interlimb activity (coordinated,

independent). When a transition occurs there is a switching rate. Within the setting of CMS there is additional time data: repetition, perpetuation, transitions, and switching rates. Anatomical behavior descriptions of laterality act as a taxonomy of behavioral resolution and reveals a degree of recursion in CMS behavioral plasticity (e.g. backward, forward movements) to measure severity of CMS.

Anatomical behavior descriptions use lateralized conditions (ipsi-, bi-, and contra-) to identify observational criteria for motion capture of CMS and to trace the regulation of sequential patterns. Looking for local neighborhoods in CMS or the rates at which local neighborhoods vanish assist in quantifying sequelae regulation. Following such a standard of measurement revises the low variability hypothesis in the developmental neurological literature (Hadders-Algra, 2010; Prechtl, 1990, 2001; Touwen, 1978, 1979, 1993) by arguing each CMS repertoire or sequelae exhibits a kind of optimality : (1) decomposes into a differentiated behavior-time relationships within a personalized space; (2) local optimality characterized by a behavior marker or time marker; (3) differentiating point more toward exclusion, that is, poorly differentiated transitions; or, (4) randomness in marking intensity of difference.. Anatomical behavior descriptions approach measures the regulation and regularity in CMS sequential patterns. A decision-tree (Figure 14) maps mathematical expectation to document sequelae in CMS. Behavioral markers qualify repetition with

greater quantitative detail (granularity). An intensity of difference marks repetition allowing for differentiation of repertoire or sequelae in CMS.

Table 7 Anatomical Behavior Descriptions Taxonomy

CMS Visual Evidence >
- *rules* >
  - *observational* >
    - > *kinematic (non-spinning) rule:* movement → counter movement
    - > cinematic *rule:* (sequelae) sustained series | next-step cyclic
    - > dynamic *rule:* perpetual repetition | repetitive pace
    - > filtration *rule:* asymmetric (non-commutative) | symmetric

- *CMS high behavioral resolution* >
  - *time markers*
    - > fractional series (local)
    - > repetition > sustained series | next-step cyclic
  - *behavior markers*
    - > laterality phases (ipsi-, bi-, contra-)
    - > musculoskeletal (extension | flexion)
    - > interlimb activity (independence | coordination
    - > geography touch fields (skin innervation)

- *CMS behavioral plasticity* (t*ime domain*) >
  - *supply-side* >
    - > allocation of resources
    - > regulation
  - > severity (regularity)

- *multi-stability* >
  - > transition (sequelae)
  - > switching (transition)
  - > excitatory | inhibitory circuitry (switching rate)
  - > laterality phases (*en route*)

CMS occur as a repetitive stream of sensorimotor movements of the whole body occurring in 3-D space. CMS functions as a boundary system with phases marked by lateral movement at three levels: (1) descriptive on the regulation of movement; (2) quantitative measurement and pathology on regularity of repetitive movement; and, (3) visualization system. First, behavior markers describe movement with granularity: behavioral resolution (laterality, extension/flexion, touch patterns, skin innervation, and geography of touch fields); and, behavioral plasticity (transitions in laterality, switching rates in

sequelae, independence/coordination interlimb activity; depth repertoire/sequelae). Next, there is the quantitative measurement and pathology a mathematical protocol frames regularity in time series to define variability under pathological conditions. Finally, in Figures 13a,13d, and 18 a visualization system maintains fidelity with the source behavior by approximating the reconstruction of the source behavior by isolating local neighborhoods and displaying engagement/inactive units during whole body movement. The visualization system in Figure 18 reconstructs the original behavior used during motion capture in a static version or an animated version. The engagement of resources in the repetitive stream has temporal complexity. The following proposes observational criteria for motion capture.

Table 8 Anatomical Behavior Descriptions Protocols and Scientific Workflows

Protocols >
> motion capture
> flow patterns
> recursion
> severity (regularity)

Tools >
visual formalisms
> multi-dimensional
> mathematical expectation
> multi-resolution display

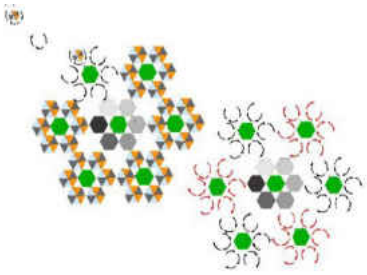
Tools > graphing
> time series analysis > multi-resolution
> comparison & differentiation > local neighborhoods

Tools > visualization
> analysis
> sequelae > transition complexity
> fractal > local optimality
>heterogeneous > local neighborhoods

Neurobiology & Plasticity >
> cross-reference
> c. elegans wiring (behavioral plasticity)
> bending leeches (lateralization & motor circuitry (inhibitory | excitatory)
> laterality phases
> multi-functional pattern architecture
> central pattern generator (rhythmic circuitry, neuronal oscillators, synaptic strength

Behavioral recording applies the resvised definition of CMS. Along with rules for observation (Table 7) and computation practices (Table 8) to conduct data collection in terms of cross-referencing neuroscience knowledge on motor function (Table 9) and MeSH taxonomy (Tables 18-21). Modularity and configurability of visual formalisms (Figures 13-14) visualize local neighborhoods in CMS with levels of behavioral resolution (local, chronological) depending on the severity of the CMS. The selection of observational criteria cross-references what neuroscience knows about motor

function (Tables 9-12). Cross-referencing known neurobiology (Table 9) and the medical MeSH taxonomy (Tables 18-21) the taxonomy in Table 4 has a scientific basis. The indexing of time-behavior data is a systems problem addressed through several visual formalisms (Figures 13a, 14, 18). *Behavioral plasticity* from c. elegans research since Chalfie *et al.* (1985) further supports differentiation of repetitive movement as asymmetric (e.g., backward and forward movement) (Ardiel & Rankin, 2008; Chronis et al. 2007; Kawano et al.,2011; Larsch et al., 2013; Nagy et al.,2011; Salvador et al., 2014; Wen et al., 2012). These researchers use nanoscience microfluidic channels to improve accuracy in data collection and purity of test environments. Behavioral plasticity in CMS to specify behavioral engagement in motion capture technology in terms of under the skin dynamics (bio-engineered for wearable sensors or nanoscience tools).



	Ipsi-	Bi-	Contra-
Ipsi-	1/3	0	0
Bi-	0	1/3	0
Contra-	0	0	1/3

Figure 7 Measuring laterality (graphing system or weight system)

Table 9 Anatomical Behavior Descriptions and Research Antecedents

Low variation hypothesis in CMS (Prechtl, 1990, 2001)	High behavioral resolution	Configuration and filtration of input data during biological movement
Repertoire, Sequelae (Hadders-Algra, 2010; Prechtl, 1990, 2001; Touwen 1978, 1979, 1993)	Behavior markers	Visual evidence (time domain) 1. Indexing biological movement, transitions, sequential types;
	Behavioral plasticity	2. Data collection: rates, switching
		3. Populates a lateralized movement multi-dimensional grid (punnett square)
Reflex arc (interneuron, motor neuron, proprioceptive neuron)	Extended reflex arc (Repetitive Restrictive Behavior)	Visual evidence (morphological) 1. Pairing {time, (behavior → circuit)}
Cortical potentials pre-motor Planning (Dirnberger et al., 1998; Hallett, 2007, 2010; Houdayer et al., 2013; Shibasaki & Hallet, 2006)	CMS a boundary system and behavioral plasticity	Visual formalisms (data capture) 1. Regulation (lateralized movement, extension/flexion)
		2. Regularity (fractal, self-similarity)
Multi-functional architecture (Briggman & Kristan, 2008; Kelso, 2012)	Enumeration (sequential, transition *from-to*)	Visual formalisms (visualization) 1. Sequential comparison
		2. Granular analysis
Sensory information in motor function (Salinas & Abbott, 1995)	Geography of touch fields; sub-sec dissipative data	Local time 1. second-behavior pathways
		2. sub-second-behavior pathways
		3. sub-second dissipative-behavior pathways

Behavioral recording applied to motion capture observes the following: behavioral resolution, transitions (from-, to-), sequential repetitions (sustained or next-step in a cycle), and switching rates (independence/coordination or lateral conditions). Observing CMS investigates the presence of additional gradations within sequelae (e.g., behavior-time patterns in bilateral and

contralateral conditions defining *coordinated engagement* with separate conductances: (1) bilateral limb interactivity (visually tested by *separated* limb movement); or (2) contralateral limb interactivity (visually tested by *overlapping* limb movement). Anatomical behavior descriptions in this case is a preliminary workbench requiring *in vitro* experimentation.

Table 10 Multifunctional Circuits and Anatomical Behavior Description Terminology

ABD Terminology	*Taxonomy Unit*	*Briggman & Kristan (2008)*	*Studies*
biological boundary systems	neural network generates multiple output patterns	Circuit reconfiguration/fusion ← external inputs	(Bem et al. 2005)
		Switch between multiple states ← modifying circuit's elemental intrinsic properties	
behavioral plasticity	multistability	biophysical mechanisms by which a single network can generate multiple output patterns	(Kelso, 2012)

Anatomical behavior descriptions provide a taxonomy to characterize behavior-time pairing CMS presentation with multifunctional circuitry (Table 25). Briggman and Kristan (2008) discuss a variety of animal models with "multifunctional circuit architectures, including unifunctional and multifunctional neuron pools, uni/multifunctional muscle groups, behavioral modules, and muscle synergies. Inputs coordinating behaviors include sensory input, proprioception, neuromodulation, and command inputs."

Table 11 Anatomical Behavior Descriptions and Neuroscience

ABD Terminology	*Briggman & Kristan (2008)*	*Observation Conditions*	*Studies*
taxonomy of motor behaviors	behavior plasticity	behavior selection can involve a behavioral hierarchy, in which decisions are sequentially made, resulting in the selection of a motor program.	(Kristan & Gillette, 2007)
high behavioral resolution and granularity	multifunctional architecture	putting together all the pieces—the influence of sensory pathways, descending commands, and multifunctional circuit pattern selection—is necessary to elucidate further the complex mechanisms of behavioral choice.	(Bem & Rinzel 2004, Chow & Kopell 2000, Lewis & Rinzel 2003, Pfeuty et al. 2003, Wang & Rinzel 1992)

Cross-referencing known neurobiology (Tables 11) and the medical MeSH taxonomy provides a systematic basis extend indexing of behaviors in time as descriptive expressions of the anatomical behavior descriptions taxonomy, symbolic transformation of descriptions into formalisms (e.g., recursive), or graphs for time series analysis.

Table 12 New Motor Circuitry Techniques and Anatomical Behavior

ABD Terminology	*Briggman & Kristan (2008)*	*Practice*	*Studies*
conditions leading to behavioral plasticity	new approaches to neural circuit reconstruction will help identify these elements	recent development population-imaging techniques (bulk loading of calcium indicators and voltage-sensitive dyes), characterize a population is multifunctional	(Briggman & Denk 2006) (Bonnot *et al*. 2005, O'Donovan *et al*. 2005).
transitional pathway asymmetric	motor circuitry and lateralized movement	ability to excite and inhibit many specific neurons simultaneously may be the crucial step toward identifying the mechanisms of multifunctionality in larger nervous systems	(Zhang *et al*. 2007).

As a descriptive system emergence of new techniques (Table 12) might further support instances where cross-scale studies between time-behavior pairs in CMS and neurobiology. Identify barriers where subtle events hard to decipher (e.g. Luo and collaborators report on transient inputs without change in biophysical properties (as cited in Briggman and Kristan, 2008) form part of a list of exceptions).

Implementing anatomical behavior descriptions includes visual formalism (Figures 13a, 14) to communicate the complexity of behavior markers for visualization of local neighborhoods (Figures 12, 13) within the framework of a taxonomy (Table 7). Visual formalisms contribute to collecting granular datasets (Figures 13, 14). While as a generative taxonomy (anatomical behavior descriptions) with rule-based components offer the prospect to frame

relationship for symbolic computing or graphing local neighborhoods. A systematic description launches quantitative research and enlarges the instrumental proposition by organizing a *en route* relationships, local relationships, or interactivity for the purposes of motion capture or time series analysis.

Symbolic Computation in CMS Research

The computational accuracy of a diagnostic instrument's capacity to sense the complexity of a hyperkinetic movement requires equal modeling of a computational layer in a taxonomy. The flexibility of a taxonomy enables the filtration, zoom-in capacity as local neighborhoods might further render diagnostic data. A diagnostic instrument's design with increased sensitivity attempts to conduct motion capture of hyperkinetic movement's behavioral plasticity within an organism's biological system. Quantitative measurement shifts from *eye-witnessing* behaviors to define the diagnostic mapping the *potential configurations* populated by the ensemble of engaged/non-engaged resources. *To develop a computational layer the design of diagnostic instruments point-set data is less viable to a taxonomical methodology* (*Table 7*) *where a formalism is capable of anticipating descriptive expressions* (*combinatorial or multi-resolutional complexity to analyze modularity and configurability*)*, a functional taxonomy to process depth of markers* (*behavioral or temporal*)*, or a generative taxonomy* (*rule system producing observation*

criteria for motion capture). Cross-referencing biological knowledge with a taxonomy (Tables 9-12, 26) formalizes observation criteria enabling modularity and configurability for systematic CMS data collection.

From Descriptive to Symbolic Quantitative Research

Implementation of anatomical behavior descriptions function on a descriptive or symbolic basis as transitions in behavior markers relate to multi-function architecture in rhythmic circuitry during CMS. Rule-based quantitative research anticipates grounds for diagrammatic analysis (Figure 2) and visual formalisms (Figure 13) to identify if sequelae patterns or lateralized movement might reveal neighborhoods with patterns (self-similarity or fractal analysis). Anatomical behavior description fulfill several functions: (1) documenting behaviors, (2) quantifying time-behavior pairings in sequelae, and, (3) monitor neighborhood relationships in each behavior's granular components.

Multi-stability:

behavior resolution > movement > phase

repetitive behavior > lateral move > ipsi-, bi-, contra-

lateral move > extension, flexion

lateral move > touch (toward release)

plasticity > sequelae > transition

sequelae > transition pattern > ipsi-, bi-, contra-

sequelae > switching > phase

sequelae > switching rate > excitatory, inhibitory

sequelae > whole body > coordination, independence

The motion capture would include monitoring classes of variables: (1) temporal (onset, duration, exit); (2) local position (dorsal, ventral); (3) posture (ipsilateral, bilateral, contralateral); and, (4) equilibrium (thermal). It is beyond the scope of this project to discuss the implementation of thermal and under the skin dynamics. Visual formalisms play a role in translational practices where scientific workflows locate: self-similarity, heterogeneity, and local optimality.

Motion capture:

repetitive behavior> *extended reflex arc*

rules > visual evidence > phase

visual evidence > movement, counter movement; non-spinning

visual evidence > repetitions (sustained serial, next-step cyclic)

visual evidence > perpetual pace (sequelae)

visual evidence > transitions asymmetric (non-commutative)

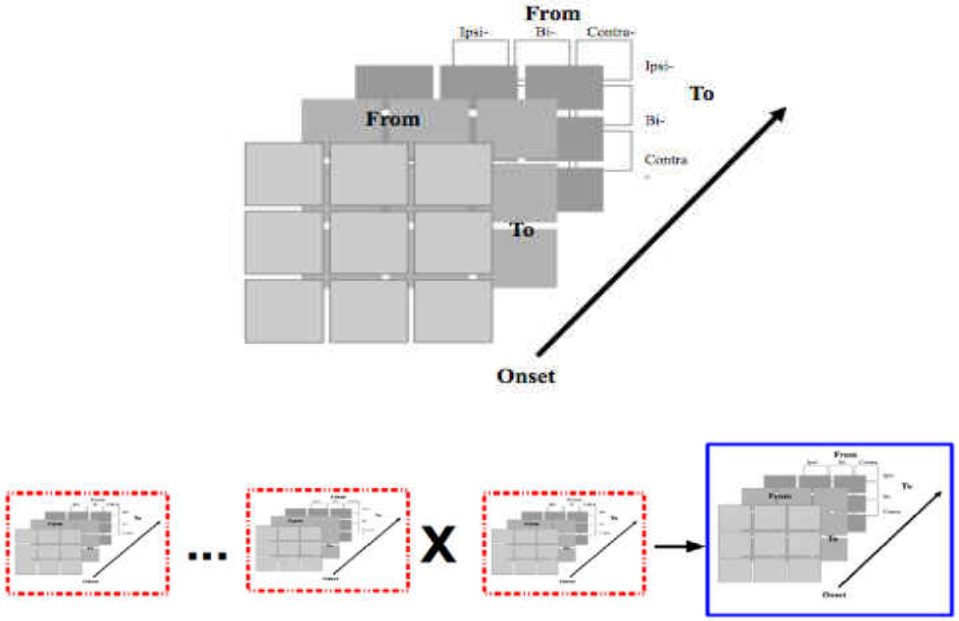


Figure 8 Transition of laterality (ipsi-, bi-, contra-) in sequelae.(Top) Chronological order of lateral transitions. (Bottom) Grouping of local pathways (red boxes) approximate the chronological lateral transitions.

The combination of high behavioral resolution and behavioral plasticity offer observation criteria to organize analysis of behavior markers within a multi-resolution display encoded using Figures 13d).

The transitions in lateral movement differentiate timing across the whole body and local neighborhoods pinpointing neighborhoods between sequelae. A model of (from-, to-) transitions based upon anatomical behavior descriptions occur within a sequelae. Punctuated by extension/flexion and touch patterns behavior-time patterns occur. A single transition has three layers of timing: (1) three time scales for local neighborhood activity in (from-, evacuation) in orange; (2) three time scales for local neighborhood activity in (to-, entry) in blue; and, (3) whole body time scale in black. Below indentation reflect timing and parallel events. Each block of time-events represents a re-framing and reformation of the organism's resources.

time (onset, local) > seconds

strata 1 (from-, lateral state)

time (episodic, local neighborhood) < sub-second

sub-strata 1a (continuous-motor... dissipative-touch)

sub-strata 1a' (continuous-motor... extension...flexion)

time (planning/pre-reengage, local neighborhood) < sub-second

sub-strata 1b (sustain repetition, next-step repetition)

sub-strata 1b (strength next-step repetition) | sub-strata 1 (strength sustain repetition)

time (offset, local neighborhood)

time (duration, whole-body)

strata 2 (inclusion, next-step) | strata 2 (exclusion-off state)

time (onset, local neighborhood)

strata 3 (to-, lateral state)

time (episodic, local neighborhood) < sub-second

sub-strata 3a (continuous-motor... dissipative-touch)

sub-strata 3a' (continuous-motor... extension...flexion)

time (planning/pre-reengage, local neighborhood)

sub-strata 3 (sustain repetition, next repetition)

sub-strata 3 (strength next repetition) | sub-strata 3 (strength sustain repetition)

time (offset, local neighborhood)

time (duration, whole-body)

strata 4 (inclusion, next-step) | strata 4 (exclusion, off-state)

Comparing chronological time and local time functions in a transition (from-, to-) provides a global (chronological) and cross-section (local) view of sequelae. Observing CMS cycles through facets while precise fractional series replace chronological order. In the anatomical behavior description taxonomy CMS are a repetitive environment staging recursion.

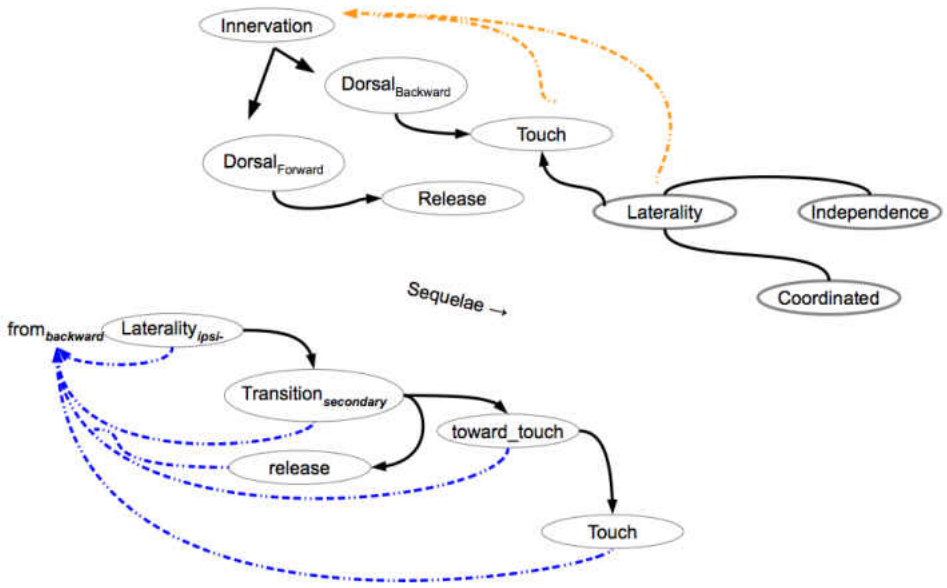


Figure 9 Retrospective models of sequelae.

Interlimb activity from backward and recursive model of skin innervation.

Quantifying the sequelae occurs in several fractional series. Each series has a primary facet (to*forward*, ipsilateral) or (from*backward*, ipsilateral) and secondary facets (secondary transition, sensorimotor process: toward_touch$_{ventral}$, touch$_{ventral\ |\ dorsal}$, release$_{ventral\ |\ dorsal}$). Each behavioral-time pairings are non-zero (fractional). A fractional series of behavior-time pairings evaluates descriptive

facets (high behavioral resolution or behavioral plasticity). Anatomical behavior descriptions facilitate a recursive assessment of CMS as local timings within a primacy facet and neighboring secondary facets. Observing a CMS sequelae recursions from multiple viewpoints drills down into a broad behavioral-time pairings or the reversal of a very brief behavior-time pairing. A precise model of CMS captures patterns in time series under several conditions: (1) when an unexpected strength occurs during the *gearing down* of sub-second micro-events (e.g. touching) as a motor hiccup (burst);(2) the bi-directional perspective of a facet taking a primary role followed by secondary facets; or, (3) anomalous behavior-time patterns in switching or whole-body events (independence or coordination). Framed by an onset-completion interval observations for low-variation hypothesis but within onset-completion interval there is a transitional complexity in CMS.

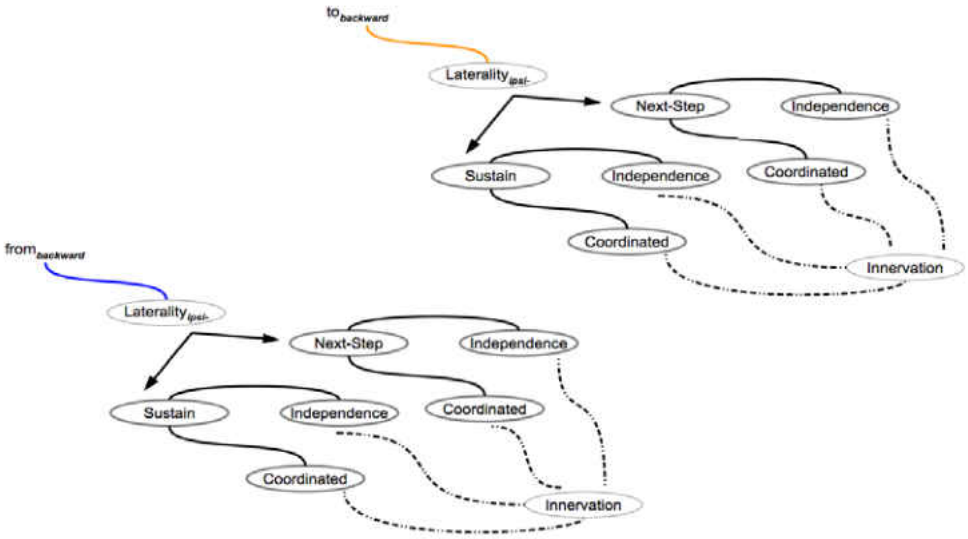


Figure 10 Recursive expansion of pair (from-, to-)

In Figure 10 is the backward time series detailing behavior options: repetition (sustain, next-step), whole body movement (independence, coordinated), skin innervation (dorsal, ventral).

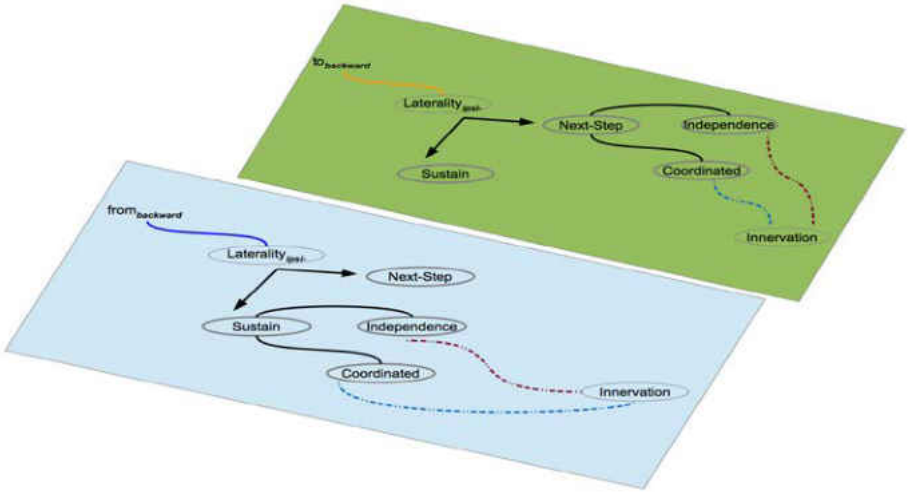


Figure 11 Example of an expansion of a recursion pairing (from-, to-).

In Figure 11 (top) is the next-step pathway in green and in the bottom is the sustained pathway in blue.

Symbolic to Graphing Formalisms

Graphing the CMS monitors lateral movement with variations in interlimb activity, touch patterns, extension/flexion patterns. Figure 18 documents CMS as each movement in the sequelae marks a plane a shape with a color (indicating timing onset while the cycling through hexagons show movement in time) in a hexagon cycling in a clockwise manner depending on the sequelae's complexity and the depth of the repertoire. A repetitive sequence becomes like a sundial revealing visual evidence (posture), time variables (transition patterns or switching) within the course of regulation of movement rippling across the whole-body. This process marks *interrelationships* in the configurability of the visualization pointing and marks the CMS *modularity* as *compartmentalization* of neighborhoods at larger shapes in a complex CMS. A field of differentiated shapes with the same color indicates coordinated movements. A field of adjacent shapes in distinct clusters of hexagons indicates independent movements (same time with distinct interlimb activity). The sparse or serialized sustained repetition remain expressive through what is not engaged, that is, what is not marked. Configuration and modularity appear in the visualization of the CMS point toward the ingredients for compiling the core CMS dataset. The visualization system monitors behavior resolution (phase

transitions) and flow of plasticity while assigning repetitive restrictive behavior to the following variables: behavior-time pairing, interlimb activity engaged, touch patterns, and details of behavioral plasticity (switching in transitions, switching rates, coordination/independence patterns) in Figure 18 motion capture data yields a jagged contour. Analysis of the jagged contours found in the populated visualization system define: regulation, regularity, intensity of pathology, the repertoire of behavior markers, innervation patterns, generalized sequelae, and the combination of spurious movements plus the generalized sequelae.

Table 13 Visualization and Progression of Shape Encoding in 3 Time-Series

Time-Scale	*Region*	*Measure*	*Local Transition Pattern*
1st	trapezoid (0)	rate movement between states (laterality: ipsi-, bi, contra-)	(from-,) (to-,) - sustained series (no change) - next step
2nd	Hexagon (0)	duration	(forward, backward)
3rd	Transition (0)		
1st	Trapezoid (1)	rate movement between states (laterality: ipsi-, bi, contra-)	(from-,) (to-,) - sustained series (no change) - next step
2nd	Hexagon (1)	duration	(forward, backward)
3rd	Transition (1)		
1st	Trapezoid (5)	rate movement between states (laterality: ipsi-, bi, contra-)	(from-,) (to-,) - sustained series (no change) - next step paired l

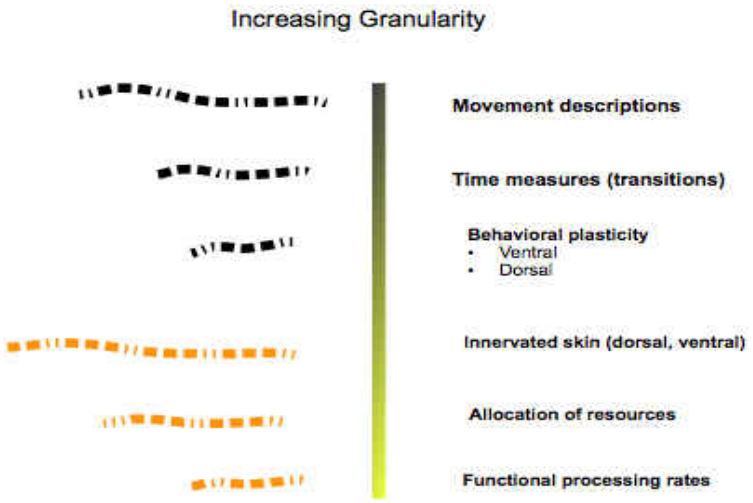


Figure 12 Increasing granularity (morphological and cellular)

CHAPTER TWO LITERATURE REVIEW & TRANSLATIONAL REPORT

The low variability hypothesis (Hadders-Algra, 2010; Prechtl, 1990, 2001) contributes to diagnostic assessments without precise assessment. Support for this claim appears when reviewing data from a CMS research study. CMS research provides insufficient information to reconstruct the whole body movement (independent and coordinated). The absence of a methodology to quantify CMS and the reliance on narrative descriptions support the need for computational analysis to capture variability in CMS.

A review targeting the quantitative methodologies in CMS research is a gateway to develop instrumental design. CMS merits a rigorous model to identify *how CMS works* rather than *how individual's with CMS work*. Instrument design in CMS research would investigate CMS the problem of registering complex behaviors rather producing an accounting system to measure performance competency for sub-groups of CMS, typical vs. atypical individuals presenting CMS (Appendices A,B), or CMS compared with another hyperkinetic motor dysfunction. The absence of time data and prospect of defining a core dataset would supply clinical researchers with an indexing system consistent with MeSH taxonomy (NLM, 2015) and application of wearable bioengineered sensory technology or *in vitro* assays for precise time analysis. Video analysis provides clinical CMS researchers with coarse

processing of visual evidence. Coarseness in clinical CMS research in this project occurs based on three observations: (1) inability to reconstruct CMS with current research data; (2) absence of a model of variables to capture a core dataset during the presentation of CMS; and, (3) absence of time data characterizing: (i) behavioral plasticity, (ii) sustained repetitive sequences and cyclic repetitive sequences in CMS, or, (iii) the network of engaged/non-engaged resources in a CMS repertoire/CMS sequelae.

Advanced technologies grounded in nanoscience and bioengineering clarify aspects of the clinical CMS literature where video analysis shape quantitative research leaving out biological systems. This review discusses diagnostic criteria (DSM) and definitions of movement disorders. Researchers Van Beveren and Hoogendijk (2011) offer a revision of diagnostic criteria on biomedical grounds and point to weakness in the DSM regarding mental disorders. Van Beveren and Hoogendijk's research is a recent consequence of the NIH's (NAMHC, 2009) call for new a translation field of study: *translational developmental neuroscience*. The implementation of biosensors in mental disorders in Bahn and Guest's (2011) comprehensive review anticipates the use of next-generation diagnostic instruments for diagnostic measurements with biomedical grounding. Lowe's (2011) prediction on the future of biosensors in mental and psychiatric disorders informs the translational criteria used in this project. A literature review on quantitative measurement in clinical

CMS would be incomplete without discussion of the new call to revise diagnostic measurement standards on bio-molecular grounds (NAMHC, 2009).

The clinical CMS literature cites an APA DSM without further exploration of the disorder's definition or researching diagnostic criteria (Appendices A, B). But, the clinical CMS literature gives negligible account for the absence of an etiological explanation when discussing the DSM criteria and a definition of CMS. The objective of this review informs an audience of clinicians and bioengineers how scientific literature might integrate diagnostic criteria within a poorly understood disorder. Translational discussion of diagnostic instrumentation and definitions of movement disorders (hyperkinetic) bring to this literature review *direct biological interface* in nanoscience and bioengineering. But these advanced technologies require their own quantitative research methods. Otherwise, a watering down of the potential of advanced technologies would occur. New tools applied under the assumptions of old questions underestimate the challenge to isolate a phenomena poorly understood (Table 2). Direct biological interface might promote discovery of diagnostic criteria and empirical relations to reduce etiological uncertainty. Novel tools carry along with a quantitative potency a need for advanced methodologies to reconcile instrumentation with novel phenomena.

Literature Review Procedures

This literature review argues quantitative research methods function on two levels: generalized and specialized. The historical general methods on subject design psychometric in Fechner-Weber, behavior by Watson and Skinner,or phenomenological Lewis and Bodfish (1998) guide specialized methodology clinical-pathology (ASD and developmental neurology) stereotypies research (Appendices A,B). For a more systematic review of human knowledge on CMS there is the MeSH browser rather than the chronological development of isolated bibliographical citations. The MeSH Browser encapsulates an interdisciplinary research taxonomy developed at National Institutes of Health National U.S. Library of Medicine (NLM). A complex knowledge base MeSH is a taxonomy with drill-down capacity. Systematic drill-down biological knowledge clarifies concurrent and potential interactions underestimated by clinical researchers on biomedical grounds and biological researchers on behavioral grounds. The introduction of cross-scale methods (morphological and cellular) might serve as a corrective procedure to maintain details evident when drilling down the MeSH taxonomy (Tables 16-18).

In this project a search procedure used several keyword pairings to identify methods rather than behavioral findings. In the initial search (Google Scholar) preliminary keyword selection inquired into the following: Is there a

presence or absence of time data on CMS? Does CMS research reflect the assignment of time variables to measure repetitive restrictive behaviors? How close is CMS research to defining a core dataset for repetitive restrictive behaviors within several pairings: (1) oscillatory behaviors and video analysis; (2) neuronal network and repetitive restrictive behaviors; (3) "motor stereotypies" and sequence analysis; (4) “repetitive restrictive behaviors” and postural control; and (5)“repetitive restrictive behaviors” and time analysis? These cases would offer time data contributing to a core dataset.

Multi-Dimensional Keyword Search

A multi-dimensional keyword search organizes the conjecture on the absence of time data in clinical research on CMS. Surveying definitions related with CMS the literature breaks down into the following: (1) neurological definitions of CMS (Maurer & Damasio, 1979, 1982); (2) diagnostic terminology on hyperkinetic movements in early childhood by a national task force (Sanger *et al.,*2008); and, (3) the reliance of current specialized research (CMS) using generalized quantitative methods dating back to Weber (1795-1878) and Fechner (1795-1878). CMS-centric definitions do not incorporate *direct biological interface tools* found in nanoscience research (Ardiel & Rankin, 2008; Chronis *et al.* 2007; Das *et al.,* 2006; Kawano *et al.,*2011; Larsch *et al.,* 2013; Nagy *et al.,*2011; Salvador *et al.,* 2014; Smith *et al.* 2013, 2014; Sung *et al.,* 201; Wen *et al.,* 2012) or neurobiology (Arber, 2012; Ugolini,

2010). Clinical definitions of CMS remain limited by subject-design protocols without addressing variability at work in the biophysical regulation (Kelso *et al.,* 1981) and equilibrium registered under Kelso's multistability theory (2012). Bellman (1961) offers a mathematical foundation to guide a systematic investigative framework to consider restrictive repetitive behaviors in terms of sensorimotor integration and the regulation of supporting process.

Table 14 Multi-Dimensional Keyword Search with Zero Search Results

Search Keywords	*Parameter Generalized*	*Parameter Specialized*	*Parameter Subdivision*	*Parameter Instancy*
Instrument & "time analysis"	Dystonia, dyskinesias, bradykinesia	rates of severity in "motor stereotypies"	"oscillatory patterns" in severity of rates in "motor stereotypies"	"oscillatory onset patterns" motor stereotypies
Instrument & "time analysis"	in "motor stereotypies"	rates of severity in "motor stereotypies"	"repetitive circuit"	"cellular repetitive circuit"
"time data"	in "motor stereotypies"	"repetitive circuit"	"central pattern generator"	"central pattern generator" timing in touch patterns
"video analysis"	timing in "motor stereotypies"	synchronism in "motor stereotypies"	time series in "motor stereotypies"	time frames in "motor stereotypies"
"video analysis"	periodicity in "motor stereotypies"	oscillatory behaviors in "motor stereotypies"	time frames in "motor stereotypies"	asymmetry in backward and forward series in repetitive circuitry

The absence of results in the keyword search (Table 14) in the CMS literature suggest future time domain study would investigate several issues: (1) *local optimality:* How do repetitive restrictive behaviors work within

personalized time signatures? Are time signatures in CMS differentiated as a potential indicator of CMS severity?; (2) *regulation:* Does the transitional complexity present in CMS characterize a time signature?; (3) *differentiation of severity in CMS:* Do lateralization patterns differentiate the severity of sequelae patterns in CMS? This line of inquiry follows up on Kelso *et al.'s* (1981) physical models of movement analysis. Literature relevant to studying *behavior in time* appear in neurobiological studies on multistability during the switching of function in repetitive motor function (Briggman & Kelso, 2008). Table 19 from the MeSH browser taxonomy supports the credibility of cross-referencing several biological units in CMS research: (1) psychological phenomena and process [F02]; (2) musculoskeletal and neural physiological phenomena [G11]; and, (3) nervous system physiological phenomena [Gll.561]. This MeSH cross-reference would provide a biological model on repetitive behavior within several levels of a biological system's laterality.

Describing CMS as a sequence of (from-, to-) transitions is a point of interest for tracing cross-scale measurement of morphological transition and multifunctional exchanges in the CPG during repetitive sequences. The combination of morphological transitions and multi-functional switching represent a merging of research topics. Quantifying transitional complexity in CMS sequelae might combine quantitative research within an observational metric (from-, to-) and several neurobiological resources: (1) multifunctionality

in pattern-generating circuitry (Briggman & Kristan, 2008); and, (2) CPG research (Marder, 2000; Marder & Buchner, 2001, 2007; Marder & Calabrese, 1996; Selverston, 1980). The cell recording practices discussed in Marder and Calabrese's (1996) review on CPG leave unspecified a taxonomy of behavioral variability within the multi-functional patterns in CPG. The central pattern generator is one part of the timing mechanisms to monitor the switching in rhythmic circuitry or repetitive behavioral sequences? Along with substrates active in cellular switching there is the architecture useful instrumental design, that is, the multifunctional architecture in motor activity.

Involuntary movements in CMS remain unrecorded. Kelso *et al.'s* (1981) presentation of several physical models (linear, non-linear, homoeostasis, and feed-back) to characterize information and power process. Central to CMS the biophysical context is the neurobiological research on the central pattern generator

Evidence on the Absence of Time Data in CMS Research

A clinical view of repetition maintains a psychological perspective of compulsion. The evaluation of repetitive patterns as a compulsion reduces the behavior to a statistical measure of frequency. The psychological explanation of CMS contributes less to a physical visualization of the behaviors having at least two positions (fron-, to-). Otherwise the movement would be a continuous

movement circling perpetually. Any non-spinning repetitive behavior has a *to* and a *fro* component. The coarseness in clinical CMS research starts with the failure to recognize subdivisions within a realistic model of repetitive movement. The observation by Lewis and Bodfish (1998) on repetitive restrictive movements results in an absence of precise timekeeping data on CMS in clinical CMS research. The construct *behavior in time* (Deffeyes *et al.,* 2011) reflects point for further CMS research. The absence of time-data on CMS occurs in part due to clinical research on prevalence of CMS and the definition of CMS as repetitive restrictive behavior, that is, a *rigidity with a formal representation* (Figures 13, 14).

Ross *et al.* (1998) measure repetitive restrictive behavior as rhythmicity without applying precise temporal regularity. "Periodic behavior occurs at fixed intervals...successive occurrences are constant. Average rate of behavior constant if the interval is constant. But, constant rates do not imply constant intervals." In another time related study Campbell *et al.* (1990) studied stereotypies using the Timed Stereotypies Rating Scale and dyskinesia Abnormal Involuntary Movement Scale. Some researchers come close to gathering temporal data (Bodfish *et al.,* 2000). Ross *et al.* (1998) maintain partial accuracies in the measurement of periodicity. Lewis *et al.* (1984) study using spectral methods but this only addresses the rocking body without studying the whole-body. Each of these studies provide no standard for the

measurement of time function in CMS. Other studies stray from precise time data collection in CMS studies. There is the Lewis *et al.* (1984) study on correlating repetitive behaviors with cardiac function. In this case the time data maintains a coarse treatment without the ability to reconstruct the complexity of the movement from the research data.

Despite the objectives to design instruments designed for automation (Goodwin *et al.,* 2014; Gonclaves *et al.,* 2012) or improvement universal data characterization Karch *et al.,* 2011) these studies remain weak in their collection of precise time data collection. These three studies recognize the need to map transitions and establish sequential pattern recognition using a classifier system dynamic time warping (Sankoff & Kruskal, 1983) in the Gonclaves and Karch studies or the classifier in the Goodwin study. Given the measurement of sequential patterns the opportunity to measure timing in the transition contributes to quantifying the repetitive restrictive behavior and motion capture of a core CMS dataset. Monitoring evidence on regulation and repetitive sequence in the time domain offers a chance to establish how repetitive movements work with varying levels of severity in motor stereotypic behavior.

Clinical researchers analyze the severity of CMS based on ability rather than how CMS works empirically. Richler *et al.* (2007) recognize repetition as common in a child's early reading behavior. These researchers consider repetitive behaviors as common to individuals with developmental or

psychiatric disorders. Following a common practice Richler and collaborators base their research assumptions on repetitive motor mannerisms, inflexible tics, or routines (rituals) found in the DSM. Diagnostic assessments based on CMS establish a basis for Richler and collaborators to investigate methods to: (1) examine individual restrictive repetitive behaviors in very young children with ASD in addition to consider repetitive restrictive behaviors as a category; (2) determine the rates of different repetitive restrictive behaviors in a sample of children with broadly defined ASD in order to obtain a clearer picture of repetitive restrictive behaviors in ASD across a range of abilities and to compare subgroups of children with ASD. These research topics overlook the presentation of the physiology (touch, motor activity, and the cyclic or sustained sequential patterns) as an extended case of the reflex arc's architecture (interneuron, proprioceptive sensory neuron, and motoneuron). Some form of goal-oriented measurement of ability is a common metric in clinical research on CMS (Appendices A, B). An individual's ability is the central research question in clinical CMS research and results in the absence of time data in CMS research especially in terms of power process, that is, the regulation of repetitive behaviors.

Clinical Research on CMS

A systematic discussion of behavior and quantitative measure of complex motor stereotypies appear as two options: computational approaches

and diagnostics inventory related with performance competency. Existing motor assessment tools appear in Jongmans *et al.* (1997) Touwen's examination of the child with minor neurological dysfunction and the movement Assessment Battery for Children (movement ABC: 8 items sample manual dexterity, ball skills, and balance). The diagnostic contribution of developmental neurologists (Hadders-Algra 2000, 2007, 2010; Hadders-Algra *et al.,* 1997) and Touwen (1978, 1979, 1993) include posture, balance, balance of trunk, fine manipulative ability, dyskinesia/kinesia, gross motor functions, quality of motility, and associated movements.

A move away from imprecise surveys appears in the recent research (Gowen & Hamilton, 2013; Torres *et al.,* 2013). These researchers argues in favor of empirical practices based on computational practices (Todorov, 2004; Wolpert & Ghahramani, 2000) to replace the surveys found in clinical movement research.

Clinical studies use several methods: (1) retrospective video analysis to conduct assessments for early diagnosis and early trajectories (Baranek, 1997; Lord, 1995; Lord *et al.*, 2012); (2) use multiple settings (conversational, waiting, TV, lego play) to study self-stimulatory behaviors (Smith &Van Houten, 1996); (3) stereotypies as pathological and physiological (Mahone *et al.* (2004); (4) comparative studies on CMS appear in Lewis and Bodfish (1998); and, (5) biomedical review differentiates stereotypies in typical and atypically developing children (Muthugovindan & Singer, 2009). In a routine CMS assessment descriptive qualifiers of CMS occur under a 5-minute under conditions to assess gross/fine motor activity or obvious/subtle behavior. While empirical studies of sensory-motor function (Appendix B) might reveal potential behavioral markers of autism. Studies close to addressing sensory integration (Smith & Van Houten, 1996) fall short of discussing the reflex arc with its combination of sensory neurons, motorneurons, and the organizing neurons in the central nervous system. An extensive review of the literature on behavior and quantitative measurement remains a daunting challenge beyond the scope of this project.

In clinical CMS research at best temporal evaluation occur within a fixed framework. Campbell (1985) added timed stereotypies rating scale , 30 sec intervals one or more stereotypies observed in 10-minute period while studying haloperidol-related dyskinesias. Campbell's implementation of a time

scale offers little insight into the complexity of repetitive movement discussed by Mahone *et al.* (2004). Mahone and collaborators conduct descriptive comparison of tics (abrupt movements that involve either a cluster of simple motor tics or more coordinated sequence of movements) and stereotypies. A review of the Mahone study suggests a lack of time data to differentiate repetitive or sequential patterns. Loh *et al.*(2007) in a pilot study on stereotypies use posture (dyskinesia, etc), competency, functional movement, and time characterization criteria flexion/extension. Other researchers pursue measurement standards of motor activity as in De Kieviet et al.'s (2009) meta-analysis compares several measures: Alberta Infant Motor Scale, Peabody Developmental Motor Scale, Griffiths Test, Bayley Scales of Infant Development version II, Bruinsky-Oseretsky Test for Motor Proficiency. The ingredients to measure CMS in the time domain appear as a next step following Memari *et al.* (2013) study of postural sway defined as "postural stability ability to maintain and keep projected center of mass (COM)." A methodical study Poizner (1990) develops a visual motion capture system meeting several objectives: (1) spatial temporal accuracy in skilled movement; (2) extend this accuracy to general movement; (3) two-camera setup; (4) spatial orientation camera; and, (5) arm movement illustrations.

To improve current literature on CMS equal interest in the ability to quantify the severity of CMS in the time domain would extend the focus on

subject-design discussed in the literature: (1) typical and atypical repetitive behaviors (Richler *et al,* 2007); (2) age and the onset of repetitive behaviors (MacDonald *et al.,* 2007); (3) ability and repetitive behavior (Lewis, 1984); (4) comparison individuals with stereotypies and dyskinesias (Bodfish *et al.,* 2001); (5) stereotypies behaviors humans and other species (Thelen, 1979); and, (6) postural control and sway (Memari *et al.,* 2013). These research topics emerge from subject-design without raising further insight into diagnostic designation. Meanwhile these empirically inspired CMS research provide few methodologies outside of subject-design protocols to increase empirical research standards (Gowen & Hamilton, 2013; Torres *et al.,* 2013). Even biomedical researchers (Mahone *et al.,* 2004; Muthugovindan & Singer, 2009) revert to clinical terminology of typical and atypical in the categorization of motor stereotypies. When Gao and Singer (2013) propose a CMS neurobiological research agenda using the corticostriatal-thalamocortical pathway there is no methodology to examine a behavioral component in a neurobiological research agenda.

Definitions on Hyperkinetic Movements and Taxonomical Foundations of Diagnostic Observations

Along with the NIH Taskforce on Childhood Movement Disorders there are similar international reports from World Health Organization (2002) defined the (International Classification of Function) and the National Center for Medical Rehabilitation Research (NCMRR) established a hierarchy of chronic diseases (Campbell, 1996). These two frameworks contribute to systematic

diagnosis prior to the formation of the Taskforce on Childhood Movement Disorders. The Sanger and collaborators' review differentiates two or more classes of motor dysfunction with a focus on behavioral observations or to conduct studies as behavioral observation maximize biological models. Already, NCMRR has proposed a framework for chronic diseases including interactions between health condition, body functions and structure, activity, and participation provide their own criteria for motor terminology the NCMRR maintain (1) pathophysiology (underlying disease process), (2) impairment (clinically observable signs and symptoms), (3) functional ability (effect on task performance), (4) disability (effect on daily activities), and (5) societal participation (effect on lifetime opportunities). These definitions leave additional room for behaviorally oriented characterizations of hyperkinetic movements. Along with a consolidation of terminology there is the need of a taxonomy with a systematic biological overview of motor function, e.g. MeSH.

Observations of motor dysfunction within clinical-behavioral methodologies characterize without musculoskeletal details cross-referenced within relevant branches of the MeSH taxonomy. Clinical differentiation of two presentations of motor dysfunction (Rhett's syndrome and autism disorders) studies occur in Goldman and Temudo (2012). The MeSH taxonomy offers a cross-referencing and drill-down characterization of biological phenomena beyond a purely behavioral assessment. A protocol with musculoskeletal

phenomena provides additional precision to differentiate the characterization of CMS and Tourette syndrome (Singer, 2013) using three motor circuits in cortical-straital pathways. Coarse behavioral observations do not minimize biological factors. Goldman and Temudo's methodology relies upon ‘‘hand-washing’’ stereotypies, “as girls with Rhett's syndrome have many other stereotypies, like flapping and pacing, observed in children with autism disorders. Conversely, hand stereotypies are, in fact, far from specific to Rhett's, as they can be observed rather often in children with AD.” In another study Singer (2013) employs a study on motor control within cortical-striatal-thalamo-cortical interactions during goal-directed and habitual behavior. The introduction of musculoskeletal levels of observation might improve motor observation in clinical CMS research as in the Canales and Graybiel (2000) study. Currently, clinical CMS research behavioral observations of visual evidence overshadow exploration of hidden (under the skin) evidence supplied by the MeSH taxonomy (e.g. metabolic regulation) to develop an empirical model of hyperkinetic movements in early childhood.

The hyperkinetic terminology in Sanger *et al.* (2010) establish pathological descriptions with varying degrees of success to formalize behavioral and biophysical underlying factors. Such clinical readings of motor activity address the presentation of CMS and clues on the pathology in a motor dysfunction. Definitions of hyperkinetic movement disorders in Sanger and

collaborators' review provide computational parameters for systematic observation of hyperkinetic movements in childhood.

Applying a taxonomy to hyperkinetic movements might further organize clinical terminology. A sensitive diagnostic instrument might capture expressivity of biological systems. The immediate display of data in hyperkinetic movement partially records the complexity of hyperkinetic behaviors. Several terminological catalogues (NCMRR, WHO, and Taskforce on Childhood Movement Disorders) devise signs and symptoms on childhood movement disorders without a taxonomy to translate descriptive relationships into spatial, temporal, or biological formalisms. Sanger and collaborators establish a formal model without arriving at a functional taxonomy capable of manipulation along with the variability of biological system in hyperkinetic movements. To summarize the consensus found in Sanger and collaborators on childhood motor dysfunctions suggest observations for CMS within a hierarchy of motor dysfunction: (1) musculature miscues; (2) posture shaping; and, (3) functional miscues (e.g. repetitive). Integration of these factors in CMS research or each hyperkinetic movement in a systematic taxonomy might provide an expressivity of biological systems (e.g. multistability evident in motor activity).

Biomedical Terminology for Hyperkinetic Movements

Descriptions of hyperkinetic childhood movements occur as individuated pathologies in Sanger *et al.* (2010). A systematic comparison would monitor insertions (posture, movement, muscle configurations) and degrees of temporal patterns or temporal irregularities. Characterization of dystonia, chorea, athetosis, tremors, and tics contribute to a more informed modeling of CMS research. Consistent terminology on hyperkinetic movement discussed by (Sanger *et al.,* 2010) provides a reference point to estimate assumptions on CMS within the time domain. This taskforce of clinicians and researchers address CMS as a subset of hyperkinetic movements in terms of signs and symptoms. A reading of Sanger and collaborator's review leads to a line of inquiry: Instrumental design provides addition insight on the basis of improvement in diagnostic data collection.

Sanger and collaborators' definitions of hyperkinetic movements support measurements of temporal relationships: (1) phenomenologically: duration, speed, amplitude, jerkiness,repeatability, or stereotyped quality, and identifiable movements or postures; and (2) time-course: rhythmicity, intermittent with intervening normal movement, presence of discrete sub-movements or movement fragments or whether the movement appears to be continuously flowing. The taskforce's review definitions arecompatible with time analysis. Comparisons between *athetosis* and *chorea* is a first step toward establishing

metrics within the temporal domain for stereotypies. Sanger and collaborators maintain chorea is distinguished from athetosis by the ability to identify discrete movements or movement fragments within the ongoing sequence of chorea movement fragments in chorea are brief and often appear jerky.

In the Sanger *et al.* (2010) report their consensus for the definition of hyperkinetic movement disorders using spatial analytic terms (overflow, postural combinations, inserted postures) and functional activity (descriptive postural dystonic, voluntary). Definitions on dystonia illustrate how the clinical CMS research literature (Appendices A,B) might refine CMS diagnostic criteria. Sanger and collaborators repoert a dystonia occurs in the presence of abnormal postures. These postures superimpose upon or substitute for voluntary movements. The Sanger and collaborators review claims at a given point in time, dystonic postures in each child repeat as particular patterns or postures. Along with behavioral description in the Sanger review a physiological characterization introduces grounds for quantitative measure. Sanger and collaborators point out there is a behavior, unnecessary co-contractions, and maintenance of a stable posture in two cases (voluntary postures or dystonic postures). In dystonia the Sanger review maintains muscles activated are different from those normally appropriate for a goal-directed action.

The dystonic characterization in Sanger and collaborators' review introduces the *overflow* triggering a dystonic posture by a voluntary movement

despite an absence of data to support the relation between overflow and postures in dystonia. An illustration of the overflow attempts to move hands may lead to neck extension suggesting an ‘‘overflow’’ from the muscles of the forearm to the posterior cervical muscles. Overflow provides an observational criteria to guide observation of a movement disorder at a lower level.

The collection of hyperkinetic movements in Sanger and collaborators' report presents guidelines for observing behavioral biomarkers beyond the intuitive (eye-witness) observations of hyperkinetic movement. Sanger and collaborators define athetosis, a hyperkinetic movement, as: (1) slow, continuous, involuntary writhing movement without maintaining a stable posture; (2) continuous smooth movements, appearing random and without recognizable sub-movements or movement fragments; and, (3) same regions of the body are repeatedly involved. A sustained repetitive movement in athetosis act as behavioral markers within configurations of the whole body and to quantify time patterns in local neighborhoods.

Systematic Time Measure and Complex Motor Stereotypies Regulation

Indexing CMS motion capture might replace low variance hypothesis with time patterns between the engaged limbs and inactive limbs while configuring time signature classifiers. The systematic analysis of transitions between sequences would monitor in a repetitive restrictive:

{time variable, (behavioral condition, motor circuitry → inhibitory, excitatory}.

This model replaces a single sequence with a behavioral condition (a backward series and a forward series).

Mapping "behavior with time" brings CMS research closer to combining morphological transitions (repetitive restrictive behaviors) with cell function (innervation dorsal,ventral) anticipated in (Chalfie *et al.,* 1985; Forssberg & Hirschfeld, 1994; Hadders-Algra *et al.,*1997; Kristan, 1982; Kristan *et al.,* 2005, 2007; Kristan & Gillette, 2007).

Table 15 Core CMS Dataset and Computation

Protocol	*Measure*	*Visual Formalism*	*Standard*
Morphological Characterization	behavioral resolution	Decision tree (onset, next-step)	depth of local neighborhoods number adjacent orbits at higher resolution
	sequelae to repertoire	Punnett square multidimensional	survey lateralized movement; touch-movement patterns; geography of touch fields & distribution of touch
	behavioral plasticity	Fractal display (multi-resolution)	quality of transitions (sustained/cyclic; independent/coordinated)
Metabolic Regulation	behavioral plasticity	Fractal display Figure 12	independent/coordinated
	sequelae	Graph (from, to) Figure 7	multi-resolution
	behavioral resolution	Transitional complexity Figure 8	

The core CMS dataset (Tables 15,17) appears as a multi-dimensional configuration of time data, morphological characterization, and cellular function. Although there are data point-sets found in motion capture the core CMS dataset is a hierarchy of variables with specific motion capture routines (Tables 8, 16).

Table 16 Taxonomy Motion Capture Routines

Core CMS Dataset			*1st Test-Set* (motion-capture) *Data Capture*	*2nd Test-Set* (post motion-capture) *Repurposing*
Routine	*Data Collection*	*Observation Target*		
Recording	*Summary*	behavioral plasticity check (fractal encoded | reconstructive)		enumeration
	1st Zoom-in	sustained repetitions | cyclic(Next-Step)	Visual	
	2nd Zoom-in	whole body movement (engaged limbs, inactive limbs)	Visual	enumeration; time
	3rd Zoom-in	whole body movement (lateral, lateral-touch, lateral...)	Visual	enumeration; time
Post-Recording	*Summary*	switching in sequence		
	1st Zoom-in	transition (occupy-from, evacuate-from| occupy-to, evacuate-to)	Visual	enumeration
	2nd Zoom-in	regulation_independent (ipsi-)		Time
	3rd Zoom-in	regulation_coordination (bi-) | (contra-)		Time
	4th Zoom-in	regulation ← [transition (inhibitory), transition excitatory)]		Time

Table 17 Visual Atlas Core CMS Dataset

Routine	*Visualization Protocol*	*Behavioral Measures*
Record-Keeping (whole body)	local neighborhood & enumeration	lateralized states (ipsi-, bi-, contra-)
	behavioral plasticity (nesting)	behavioral characterization * lateralized sequences (independent, coordinated) * lateralized movements (sensory integration) touch ← Reflex arc
	anatomical disposition	* geography of touch fields * touch-movement patterns
Time-Keeping	duration (from, to) sequential analysis in transition (from, to) *turn-taking* in the transition *from-* to (lateralized movement)	

The core CMS dataset includes empirical modeling within skin innervation (dorsal or ventral) and the time transitions (from, to) within sustained (serial) repetition or cyclic (next-step) repetition. The case of sustained sequences requires precise monitoring since repetitive movements have a sub-division unless there is a perpetual circling movement. Sustained repetitive movements warrant additional monitoring to identify complementary whole body movements (independent or coordinated) suggesting subtle

transitions in the unfolding of sequential data. The core CMS dataset accumulates sequential transitions (from-, to-) between lateralized movement and the timing of sequential patterns found while mapping whole body movement. The precision of core CMS dataset in the time domain extends the documenting oscillatory movements, phases of a behaviors, micro-rhythms, and sequential mappings. Along with precise time data there are accompanying morphological characterizations as visual evidence of skin innervation in several parameters (ventral/dorsal, anterior/posterior) supply a researchers with time-data. Finally, the morphological characterization of skin innervation in movement with time-data points toward cellular functions: switching, central pattern generator, and other multifunctional architecture in repetitive restrictive behaviors. The assembly of motion capture forms a core CMS dataset in preparation to assign time signatures for whole body regulation of repetitive movements derived from data based upon (Figures 14, 17) and visualization of time-flow patterns (Figure 13, 18) as local neighborhoods define aspects of the behavioral plasticity (Figures 13 bottom, 18 left; Table 13) in the CMS sequential transitions.

Promoting empirical CMS research follows the theme of direct biological interface. Canales and Graybiel (2000) conduct striated muscle fiber to identify a relationship between striatal function and stereotypies. But, Canales and Graybiel's chemically induced study is less likely to maintain a

consistent model of time data within CMS. Wearable sensors and *in vitro* cellular studies in CMS research would follow Loewi's pioneering experiment establishing electrical and chemical responses within neurobiological function. Wearable biosensors and *in vitro* assays offer a less invasive environment to conduct precise motion capture of time data.

Table 18 MeSH Keywords Mental Disorders

Mental Disorders [F03]

Mental Disorders Diagnosed in Childhood [F03.550]

Sub-levels (...500...)	dev disabilities 550.362	motor skill disorders 550.650	stereotypic movement disorders 550.787	tic disorders 550.825

Table 19 MeSH Keywords on Psychological and Neural Physiology Phenomena

Psychological Phenomena and Processes [F02]
Psychophysiology [F02.830]

1st Sub-levels (...830...)	Cerebral dominance 830.297

2nd Sub-levels (...830.297.)	Functional laterality 830.297.425
Annotation	restrict to neurological & psychological sense; sidedness or laterality of disease, index the disease with / pathology (MeSH qualifier data) or / physiopathology (MeSH qualifier data); for unilateral or bilateral surgery, index the surgical technique with/ methods (MeSH qualifier data) if pertinent
Entry terms	Laterality motor function behavioral laterality handedness, etc .

Cross-Ref [G11] See below	Functional laterality G11.561.225.425
Ref [E04]	Split brain procedure
	E04.525.770

Musculoskeletal and Neural Physiological Phenomena [G11]

Nervous System Physiological Phenomena [G11.561]

1st Sub-Levels	Cerebral dominance
2nd Sub-level	Functional laterality G11.561.225.425

MeSH Taxonomy Implementation for Reading Biomarkers Selection

Quantitative measurement and behavioral analysis conduct data collection to make predictions useful in the diagnosis, explanation, or comparison of individuals. But the criteria for making observation has no governing hierarchical rationale to support using one data feature over another in psychometric measurement other than the researcher's expertise, measurement facility in available instruments, or prior trends in data analysis in prior research.

The MeSH taxonomy functions as a repository of thematic variables rather that associating variability with data points. The measurement of the thematic variables occurs within the norms of biological research. The MeSH taxonomy presents variability on biological terms and composition of the black-box evident in clinical research (Fischer *et al.,* 2010). In the simple example of Table 18 are constructs on mental disorder. A practical use of the MeSH would map mental disorders (Table 18) followed by psychological phenomena and neurological physiology (Table 19), metabolic and chemical phenomena (Table 20), and musculoskeletal phenomena (Table 21). Tables 18-20 suggest the expressivity of the MeSH taxonomy for developing diagnostic constructs and components related with involuntary movement.

Moving from observable data features in a psychometric methodology to data provided by biomarkers in a biologically-inspired methodology a basic question persists: What criteria promotes a systematic overview in quantitative measurement and behavioral analysis? A cross-referenced measurement criteria in the MeSH taxonomy would replace current observational data collection where there is no auto-monitoring (internal check) and computational check outside of an initial observation of visual evidence. To improve data collection a multi-level and multi-scale data selection the research starts with a hierarchy (Figures 13-15, 17).

Table 20 MeSH Keywords Phenomena: Metabolic and Chemical

Metabolic Phenomena [G03]

Brain Chemistry G03.200

1st Sub-levels (...200...)	Brain Chemistry	
	200.000	
Annotation	differentiate from BRAIN / metab; consider also / chem with specific parts of the brain but probably as NIM with BRAIN CHEMISTRY (IM) if site is merely locational & illustrative	
Cross-Ref [G02.111.100	Brain Chemistry	
1st Sub-levels (...495...)	Metabolism (descriptive)	Metabolic networks and pathways
	495.000	495.553

Chemical Phenomena [G02]

Biochemical Phenomena G02.111

1st Sub-levels (...111...)	Brain Chemistry
	111.100

Table 21 MeSH Keywords Musculoskeletal

Musculoskeletal and Neural Physiological Phenomena G11]				
Musculoskeletal Physiological Phenomena [G11.427]				
1st Sub-levels (...427...)	musculoskeletal physiological process 427.590	motor skill disorders 427.650	stereotypic movement disorders 427.787	tic disorders 427.825

2nd Sub-levels (...427.590...)	movement 427.590.530	muscle contraction 427.590.540	musculoskeletal 427.590.560	
[redacted]				
Nervous System Physiological Phenomena ([G11.561]				
1st Sub-levels (...561...)	Evoked potentials 561.270	Membrane potentials 561.570	Nervous system physiological processes 561.600	Psychomotor performance 561.623	Reaction time 561.677

Shifting Behavior into Measurement Standards

Behavior and quantitative measurement have been subjects of investigation while contributing to human performance, education theory, and developmental science. Further specialization in behavioral and quantitative measurement includes analysis of severity of biological movement in the time domain (time series).

Quantifying variability on biological grounds includes the plasticity evident in multifunctional motor activity discussed in (Briggman & Kristan,

2008). Meanwhile, variability in clinical research confines quantitative measurement to data points in a sample population. *Rather than assembling data points to deduce variables in quantitative research measurement standards in behavioral research might shift measurement of variables to a pre-existing biological taxonomy* (*MeSH*).

CHAPTER THREE DESIGN AND METHODS

A universal observational standard in CMS research establishes a four-way measurement protocol using: anatomical (posture), behavior (postural control), descriptions (expression of paired transitions: to-, from-), and anatomical behavior descriptions while recording a temporal complex in *real-time*: {onset; engagement of resources (present); and replenishment of resources (future)}. In CMS research systematic observation practices remain an instrument problem. While an indexing protocol would define three aspects of CMS: scoring lateralized movement (time-behavior pairings), classifying sequelae, and cross-referencing behavior (e.g., sustained serialized repetition/next-step cyclic repetitions; independence/coordinated movements; touch-movement (sensorimotor information)/regulation of sequelae (ipsi-, bi-, contra-). Already, Kohn *et al.* (2006) implement diagraming to monitor the universe of biological pathways (actual and potential) in molecular interactions.

Anatomical behavior descriptions function as a novel observation standard for motion capture using the capacity of advanced technologies (nanoscience and wearable bioengineered sensors). Anatomical behavior descriptions define protocols for signal monitoring within whole body movement with guaranteed approximation of an original behavior. To implement a reconstruction protocol hexagonal porous-solid-fractals (Bobbitt,

2002; Perrier *et al.,* 2000, 2002) and content addressable memory (Kohonen, 1989) (Figure 7d) encode motion capture data.

In addition to chronological time series there are local temporal conditions found within a recursive treatment of minute series of micro-events (e.g., to **backward** ,lateralized phase) and (from **backward**, lateralized phase). A recursive treatment of anatomical behavior descriptions records transitions in 3-d space, switching in behavior plasticity, and multi-functional allocation of motor activity within high behavior resolution. Given the precision of direct biological interface through wearable bioengineered sensors (Lowe, 2011), nanoscience assays used in wiring studies of repetitive restrictive behaviors in c. elegans (Ardiel & Rankin, 2008; Chronis *et al.* 2007; Kamano *et al.,*2011; Larsch *et al.,* 2013; Nagy *et al.,*2011; Salvador *et al.,* 2014; Wen *et al.,* 2012), *in vitro* nanoscience assays (Das *et al.,* 2006; Smith *et al.,* 2013); and, brain chip interfacing (Fromherz, 2006; Pais-Vieira *et al.,* 2013). Video analysis offer coarse and incomplete treatment of visual evidence without capturing neurobiological plasticity (behavioral or cellular), the dynamics of central pattern generator, the interleaving architecture of motor function (2012), multi-functional pattern architecture (Brigmann & Kristian, 2008).

Visual Formalisms and Behavior Recording

Design. To a present taxonomy for CMS two formalisms map multi-dimensional scale (Figure 13a) and a decision tree maps transitions (from-, to-) in Figure 8. Several observational rules guide the formation of the multi-dimensional mapping in Figure 13a and the decision tree in Figure 14. The formation of a descriptive taxonomy for CMS relies on several observational rules: (1) every movement has a counter movement (non-spinning) to conduct a repetitive behavior; (2) repetitions appear as sustained or next-step in a cycle; and, (3) transitions in a repetition are asymmetric (non-commutative) repetitive cycles are perpetual. Data capture for CMS research relies upon observational rules and analysis. The analytic foundation for the symbolic system examines regularity in a time series (approximate entropy), self-similarity in local neighborhoods (fractal analysis), and evidence of local optimality. The literature pointing to the origins of the symbolic system appears in Tables 10-12. Figures 8-19 introduce a novel of symbolic system for translational development of motion capture in CMS research.

Listed below is a catalogue of the working parts of a proposed protocol: to provide adequate variability to design visual test for motion capture (high behavioral resolution and behavioral plasticity), characterize behavior-time pairings, and to analyze dynamics of CMS (behavioral plasticity) in the temporal domain. Measurement of how CMS work leads to a methodical

measurement of flow patterns (Figure 12) absent from the clinical literature on CMS. How the symbolic system works graphs variability to measure local optimality of local neighborhoods within each presentation of CMS across levels of behavioral resolution. The novelty of heterogeneity in variability motor circuitry (Marder, 2011) suggest the need of a symbolic system to visually graph the potential of varying parameter combinations to produce similar behaviors. Future CMS research would benefit from quantifying flow patterns in CMS.

Behavioral markers in CMS leads to symbolic representations and visual formalisms. The behavioral markers (lateralized movement) occur at distinct timings measured at time scales. A multi-resolution display (Figure 18) reports on linear time (within any hexagon) or side-by-side measurement in a collection of sequences (clusters of hexagons, (Figure 13d) when backward/forward movement and laterality in the display system act as content addressed memory (Kohonen, 1989) in Figure 13d. Fidelity with CMS in the multi-resolution display movement encode CMS movements as jagged contours representing time signatures to differentiate behaviors. The jagged contour shows behavioral markers as either an active conditions of lateralized movement (Figure 13d) or the proliferation of a hexagon due to absent conditions of lateralized movement. A multi-resolution display system acts as a mechanism to conduct comparisons within universal descriptions to differentiate behaviors.

Fidelity with the original behavior records: independence/coordinated movements, laterality, touch patterns, extension/flexion patterns, and switching/transition in sequelae. Figure 13 encodes lateral conditions (ipsi-, bi-, contra-) in two trapezoids representing forward movement and backward movement. Given non-spinning movement all CMS have a minimum of two phases (e.g. forward and backward movement). The expressivity of monitoring repertoire in a series of sheets (Figure 13a) and the sequelae as behavior-time pairings (color coded) appears in Figure 18 based on Figures 13d-13f.

The configuration of shapes (hexagon, trapezoid, hourglass, parallelogram, equilateral triangle) graph CMS at a granular level. An enhanced visual semantics supports monitoring flow of plasticity by differentiating active limb-by-limb scoring: transition patterns in Figure 13a; intensity of timing, switching rates in transitions (color coded) in Figure 18. Configurability in a hexagonal symbolic system (Figures 13, 18) expresses several hexagonal pairings: (1) trapezoid (backward movement, forward movement); (2) hourglass (cross-reference laterality in backward series and laterality in a forward series); (3) adjacent equilateral triangles postural transitions (backward movement, forward movement); and, (4) parallelogram (backward movement, forward movement).

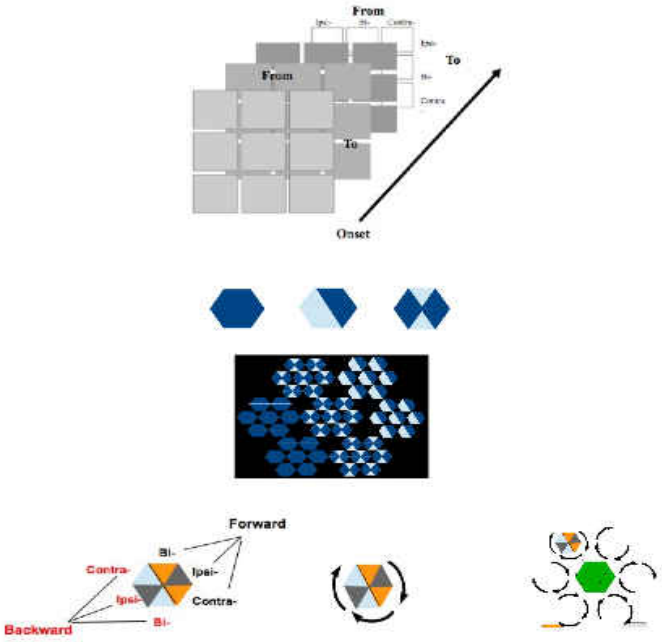


Figure 13 Visual formalisms for motion capture.

In Figure 13 is memory and reconstruction using three levels of transition mapping (from-, to) for time-behavior pairings Figure 13a (Top) Multi-dimensional to quantify variability in sequential patterns in CMS. Figure 13d (Middle Top) Simple pathways of movement (one-way phase, two-way phase, three-way phase). Figure 13c (Middle Bottom) Module for granular pathways for movements with complex phases. Figure 13d (Bottom Left) Shape and address of lateral movements. Figure 13e (Bottom Center) Sequence of forward-backward movement. Figure 13f (Bottom Right) Flow of sequelae.

Structure. Figure 13a records the sequelae (sustained repetition or next-step in repetitive cycle). Multi-dimensional scaling of transitions in sequelae

appear as a feature (from-, to-). To document the features in a sequelae's transition there are ordered lists and asymmetric intervals appear in (Figure 20). Figure 13d visualizes an instance of the sequelae in Figure 13a. Fidelity with the original behavior occurs based upon recording flow patterns (Figures 13c, 13d) and the expansion of Figure 13 into a graphing and visualization system (Figure 18, Table 13). Flow diagramming in Figure 18 occurs on multiple levels: subject of repetitive movement (forward, backward); unfolding of the sequelae; and the unfolding of cyclic patterns of the sequelae over time. Encoded in Figure 13d and Figure 18 are flow patterns occurring at levels of behavioral resolution in anatomical behavior descriptions measured showing switching rates, rates of lateralized conditions, and unfolding of sequelae/cycles.

Automation. An animated version of Figures 13d, 18 approximate the original movement patterns while parsing movement in classified neighborhoods based upon encoding in Figure 13d. *Application.* Based on the punnett square allelic discovery continuous/jerky behavioral phenotype in twins or families with a tendency toward CMS and autism.

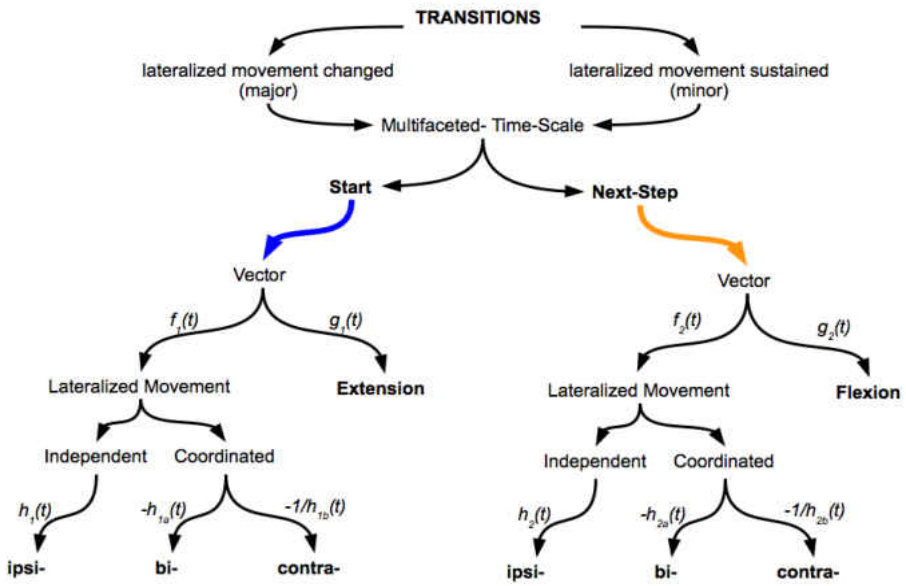


Figure 14 Mathematical expectation in complex motor stereotypies sequelae.

Mathematical expectation of lateralized movement and extension/flexion patterns

Structure. Figure 14 organizes complexity in behavior-time pairing in a sequelae as an onset moving toward an extension and the next-step moving toward a flexion. Details of the decision-tree present a mathematical expectation of CMS: lateralized movement, behavioral plasticity (independent, coordinated), and association of excitatory/inhibitory underpinning in lateralized movement condition. *Application.* Mapping of time series data for sequelae analysis and comparison. Brings additional behavioral mapping of time series for approximate entropy analysis. Scientific workflow found in Figure 15 relies on motion capture data organized in Figure 13.

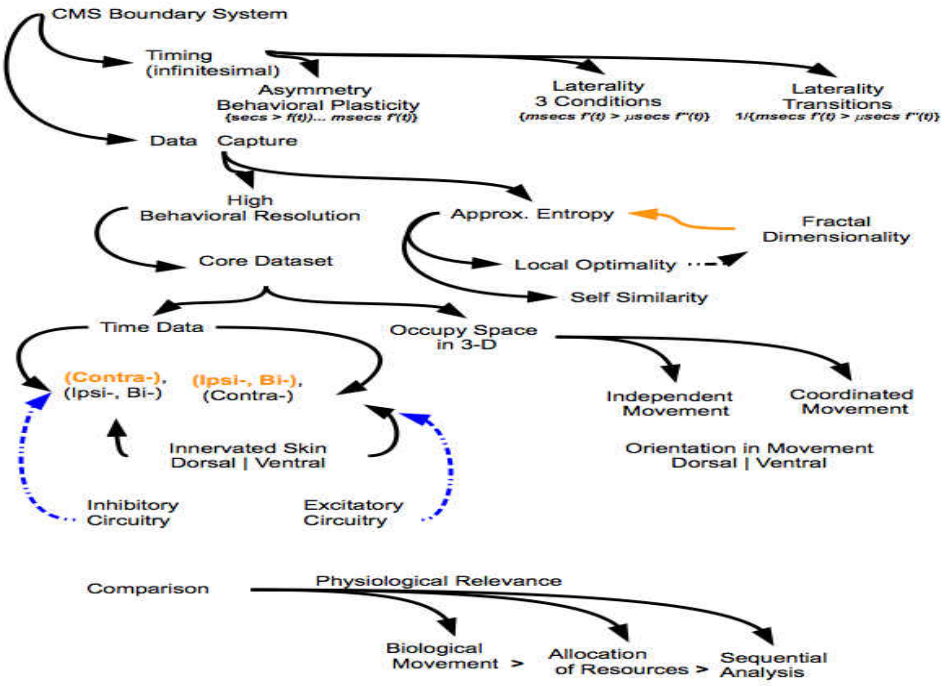


Figure 15 Complex motor stereotypies as a boundary system.

Several scientific workflows emerge to examine CMS as a boundary system.

Structure. Figure 15 summarizes CMS as a boundary system. When observing visual evidence in CMS there are several methods to assess CMS: (1) anatomical behavior descriptions; (2) quantifying the complexity of CMS; (3) compartmentalizing CMS into time data and occupying 3-D space; and, (4) comparisons of behavioral recording through physiological relevancy.

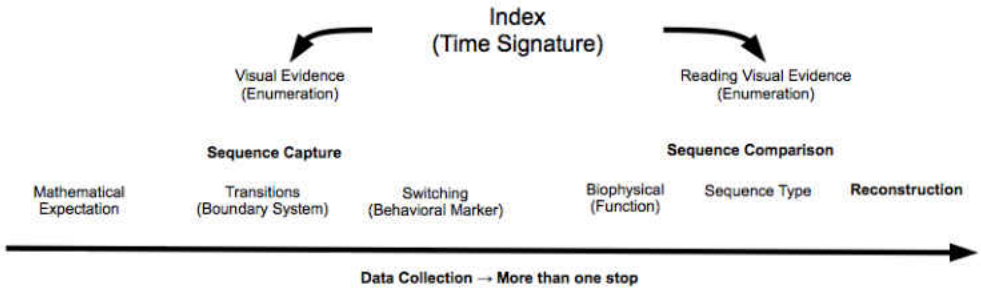


Figure 16 Time signatures and complex motor stereotypies.
Time signature assembly from data collection and data analysis.

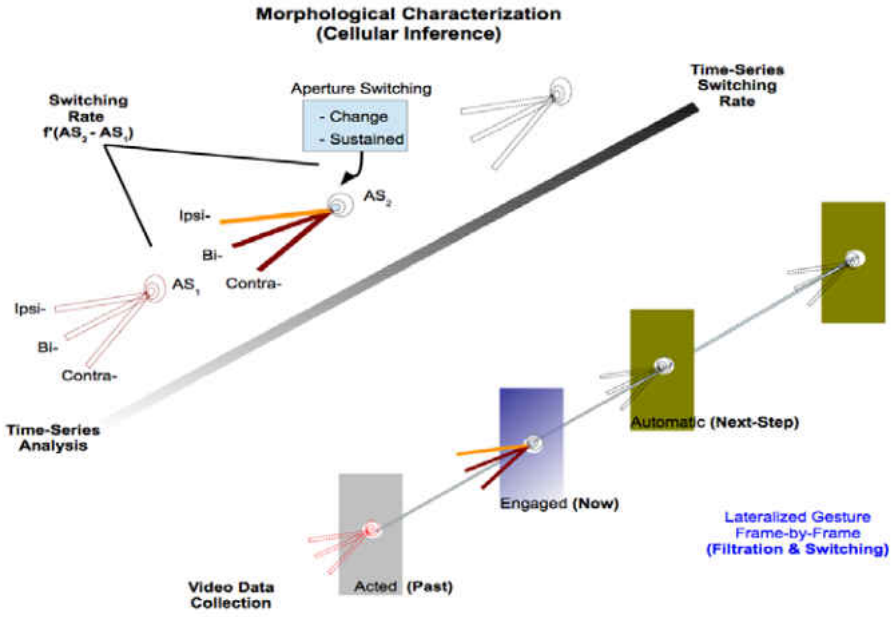


Figure 17 Temporal complexity in CMS morphology

Porous-solid-fractals provide a framework to compare and compute CMS (time signatures, sequelae, transitions) in local neighborhoods, cyclic patterns, and multi-loops of the CMS sequelae. The engagement of lateral movement

during forward or backward phase appear as a shaped contour leaving the excluded lateral movements colorless/unlined. This produces a jagged shape contour at each instance of the sequelae. Reading a geometry of hexagons (porous-solid-fractals) anatomical behavior descriptions (Figure 13d). The individualize movements appear as articulated intervals of planes and nested configurations at multiple resolution. The rotation within nested rings define the actual time sequence with color coding each instance of movement to indicate numerical duration (intensity) and sequential order rotating (clockwise) to document limb activity, interlimb activity, or a region in the individual's anatomy.

Starting with innervation (Figure 18a left) measurement of rotation (Figure 12c right) occurs within a ring of hexagons as an arc in a clockwise movement. Facets of lateralized movement appear as shaped subdivisions of the hexagon (Figure 13d, Table 13). The transition of sequelae appear as a ring of hexagons (Figure 18 left). For management purposes a center hexagon (Figure 18 center) maintains location and general numerical data for each ring (Figure 18a right). The configuration of shapes facilitate the analysis of transitions (rotation Figure 18a right) or parallel comparison of recurrence of movement within a position within the sequelae via side-by-side comparison (Figure 18a center). This configuration (Figures 13d, 18a, 18b) follows in defining sets of

higher resolution. When Figure 18a center acts as a facet in a higher resolution pattern.

The graphing capacity of the visualization system conducts comparisons with high behavioral resolution of interlimb activity or time signatures between multiple cases of CMS. There are several applications of this visualization system: (1) plotting transitions using ApEn where (from-, to-_intervals replace point-by-point graphing; (2) parallel analysis of facets in the same position in sequelae overtime; and, (3) parallel analysis of clusters of facets to compare time variation between CMS with ipsilateral or contralateral tendency.

The visualization system serves as a preliminary assessment tool for conducting ApEn analysis. Future research will implement ApEn using the visualization system. Using shape analysis of time-behavior pairings in repetitive movement conducts analysis with increased granularity while maintaining zoom-in and zoom-out view of sequelae.

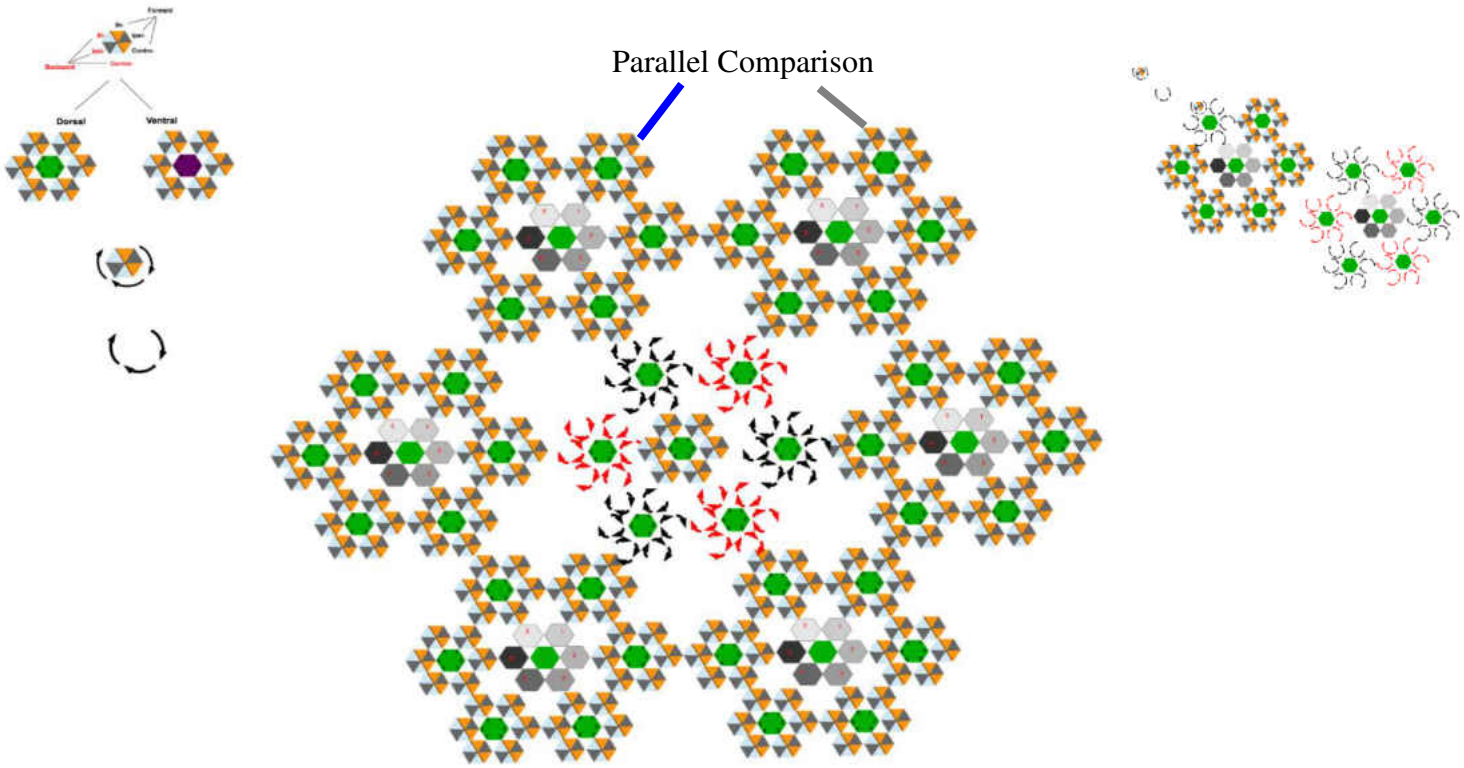


Figure 18 Porous-solid-fractal visualization system

(Left) systematic encoding forward/backward, ventral/dorsal, and clockwise flow; (Center) multi-resolution mapping of flow patterns and synchronization in CMS; (Right) mapping flow patterns in CMS time analysis. Key components (1) content-encoding and processing components (formatted shapes representing morphological characterization); (2) data collection component (outer shell of nested hexagons); (3) local optimality and transitions component (inner core of hexagons representing cycling time-events; (4) animated record-keeping sequencing component (clockwise representation of micro-events and transitions).

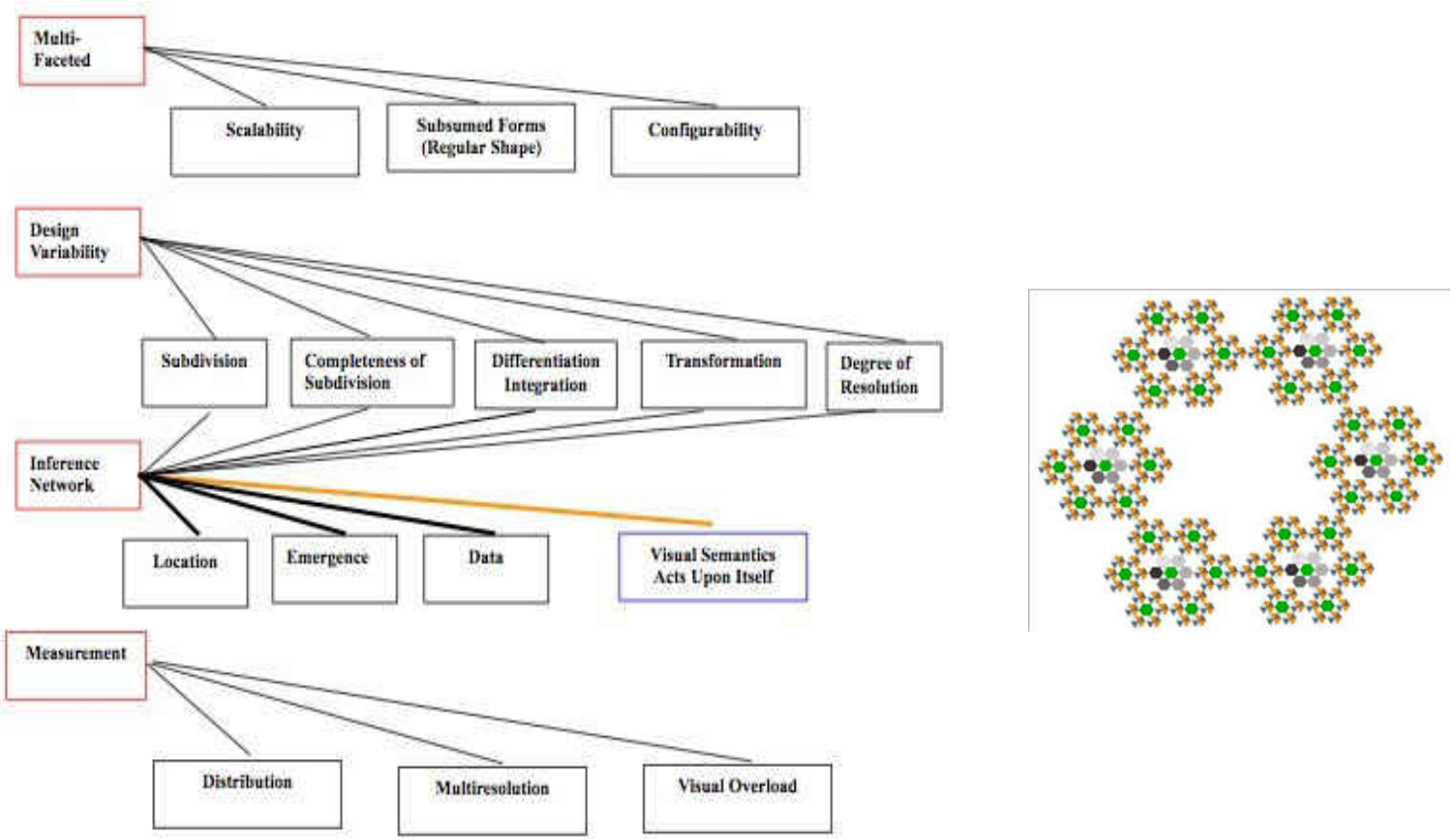


Figure 19 Porous-solid-fractal visualization framework from Bobbitt (2002)

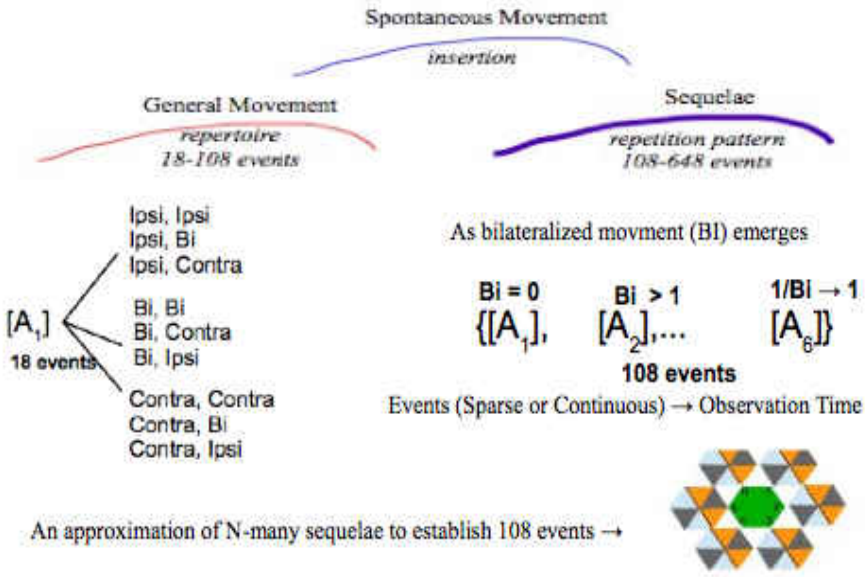


Figure 20 Approximate observation duration for motion capture

Structure. Figure 14 organizes lists of potential events in CMS: (1) repertoire complexity (micro-rhythms) as a matrix of 18 events with 6 matrices yielding 108 events; (2) sequelae complexity with 108-648 events. *Application.* Population models for numerical simulation of CMS and sensory information transfer (Salinas & Abbott, 1995).

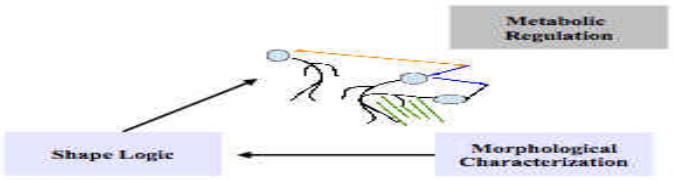


Figure 21 Three conditions for the observation of CMS

Mathematical Origins of Anatomical Behavior Descriptions

The streams of behaviors in CMS lend themselves to a mathematical description. Motion capture of repetitive restrictive behaviors is consistent with the presence of motor-touch engagement, oscillatory patterns, and recurrent patterns. Mathematical grounding of a descriptive taxonomy (anatomical behavior descriptions) provides a mechanism to methodically explore a disorder without an etiological explanation. Lewis and Bodfish (1998) characterize repetitive research in terms of prevalence and a psychological oriented construct (e.g., compulsion). Clinical CMS researchers work from the vantage point of what leads to an intervention at the expense of empirically defined research frameworks. Appraising repetitive regularity in CMS starts with how well a research practice maintains fidelity with the CMS in the time domain and whole-body movements within an increasing granularity (Figure 6). There is a mathematical complexity when quantifying CMS in terms of the expression of repetitions in sensorimotor scenario punctuated by a touch or extension/flexion pattern, the articulation of a sequence (series of transitions) supplied by a motor circuitry in lateralized movement, the isolation of behavioral resolution and behavioral plasticity during motion capture. Observational variables define the instrument while identifying performance variables (behavior-time pairings). Anatomical behavior descriptions is a protocol where mathematical tools define instrument design and scientific workflows to quantify performance variables in CMS.

Mathematical tools support the capacity to drill-down into behavioral levels (descriptions, time measurements, and behavioral plasticity) and the cellular level (innervated skin, allocation of resources, and functional processing/switching rates). Using several questions related with diagnostic assessment the mathematical complexity in CMS becomes clearer. (1) Is there an asymmetric differentiation between (ipsi-, bi-, contra-) in the time patterns in phases (forward-touch induced movement, backward-touch-induced movement) in a sequelae?; (2) Does the synchronized time of independent (ipsilateral) movement or coordinated (contra-) movement differentiate severity in sequelae?; (3) What configuration of lateralized movement in the repertoire of CMS serve as indicators of severity of CMS?; and, (4) Does coordinated lateralized movement in bi- or contra- maintain a common time signature? These questions pursue a progressive observation and analysis with increasing granularity to differentiate between behavior and sequence, phases in the behavior, a level of behavioral plasticity. In anatomical behavior descriptions mathematical norm follows a pursuit of difference in repetition.

As a boundary system CMS with membrane dynamics and interlimb activity anatomical behavior descriptions investigates quantitative measurement within several mathematical frameworks: fractal, heterogeneous, and biological mathematics in the time domain. Before discussing biological phenomena relevant to CMS mathematical observations inform the analysis of repetition as

a product of a pathological condition and the impact of pathological conditions on motor systems.

The mathematical origins of anatomical behavior descriptions draw upon several collections of research: (1) time series analysis used to define regularity within a pathological condition; (2) advances in empirical (neurobiological) research on variability; and, (3) the absence of behavioral recording in neuronal recording techniques. To conduct an analysis of the severity of CMS a mathematically grounded methodology contributes to the formation of a core CMS dataset and scientific workflows for collaborative research. A schematic mapping of a functional behavior (CMS) describes, quantifies, and visualizes neighborhoods of interrelationship. Clarifying local neighborhoods is a mathematical symbolic problem when considering the heterogeneous space as membranes, sensorimotor circuits, and networks occur with plasticity. Mathematical principles act as a framework where repetition and plasticity function in a sequential expression.

Mathematical Concepts for Anatomical Behavior Descriptions

Increasing behavioral fidelity in motion capture warrants mathematical tools to model data collection. From an instrumental standpoint the closer anatomical behavior descriptions come to differentiating sequelae and repertoire in CMS the more a mathematical basis will become apparent. The mathematical origin for anatomical behavior descriptions constructs observational practices to target two aspects of CMS: the *regulation* of transitions in CMS and *regularity*

of behavior-time pairings in CMS. Marking differences in a time varying assembly implements a visual indexing of streams of sensorimotor information and the regulation of the transition (from-, to-) in sequential patterns would contribute to a mathematical basis. Behavior-timing pairs will need to differentiate circuitry plasticity (synaptic and interneuron transform/coordination), network plasticity (circuitry partnerships, switching-complexes, compensation, modulation), and innervation geography (touch fields, motoneurons). Looking at behavioral ensembles present in the CMS functions as a reduced network with physiological, a repertoire of engaged/excluded interlimb activity, and touch movement. The timing regime in the anatomical behavior descriptions taxonomy opens the opportunity to arrive at neighborhoods approximating variability within a heterogeneous dynamic. Self-similarity and heterogeneous complexity are central to detection of features and behavioral phenotypes within a biological-behavioral setting. The alternative approach conducts diagnostic readings within a biological black-box. Improvements in direct biological interface support maximizing behavioral regulation and minimizing biological uncertainty. Marder and Calabrese (1996) provide evidence on central pattern generator relating single neuron oscillators, motor circuitry, and networks relating rhythmic circuitry in a physiological expression of behaviors.

Anatomical behavior descriptions serve as a system further explore Hadders-Algra model of repertoire and sequelae to quantify. Motor circuitry's

engagement, inhibition, and exclusion from a repetitive sequence have their place in a mathematical model. Application of a mathematical basis improves computational capacity using known neurophysiological relationships. Comparing levels of severity in CMS mathematical concepts of *self-similarity, heterogeneity,* and *multi-resolution* extend the use of biological mathematics and fractal analysis.

Regularity is central to the low variability hypothesis on CMS. How visual evidence functions in defining regularity in CMS prompts a mathematical formalism building upon several topics: (1) novel forms of analysis (self-similarity, heterogeneity, and multi-resolution) based fractal analysis (Chau, 2001; Hausdorff *et al.*, 1995, 1996, 1997; Ihlen & Vereijken, 2013); (2) experimental research with a stronger general mathematical protocol to envision bio-medical measurement (Chau, 2001; Deffeyes *et* al., 2011; Pincus & Goldberger, 1994); and, (3) a novel visual graphing of multi-resolution. A granular display (Figures 7,12) facilitates visualizing side-by-side and rotation through nested steps quantifying degrees of local optimality (in sequelae transitions) anticipates marking difference to compare levels of severity. A system of planar relationships (Figure 7b) and a detailed behavior fidelity (timing, interlimb descriptions, and sensorimotor engagement) is in a position to identify potential pre-conditions or pre-requisites as types of lateral movement patterns.

The application of ApEn serves as an example to standardize repetitive behavior research. Pincus argues ApEn functions as an indicator of pathology across a range variables (complex, randomness, and chaotic). There are a number of medical fields with the investigative use of ApEn (cardiology, endocrinology, anesthesiology, traumatic brain injury, Parkinson's disease, and orthopedics) (Deffeyes *et al.,* 2011). Examination of research on ApEn further establishes the role of novel scientific workflows in motor research. The long-range correlations through fractal analysis (Hausdorff *et al.,* 1995, 1996, 1997) illustrate variability measure to differentiate CMS repertoire and sequelae in CMS (Figures 7,8, 9). The utility of ApEn is the measurement of oscillatory or repetitive movement.

ApEn is an alternative mathematical model to statistical mean and variance in time series analysis. Used as an analytic tool ApEn defines regularity in a behavior under pathological conditions through a time series analysis. Pincus and Goldberger (1994) use ApEn to investigate "compromised physiology" in many systems with more regular and normative physiology with greater irregularity (randomness, complexity). In a study on infant movement and cerebral palsy Deffeyes et al. (2011) apply ApEn. Deffeyes and collaborators experimentally compare data from infant movements and physical simulations (single pendulum periodic activity and double pendulum chaotic activity) using an ApEn assessment of regularity. Deffeyes and collaborators' research investigates the lack of regularity for a dynamic system considering

two hypotheses on complexity in pathology. First, complexity in an organism will decrease with increase pathology in the loss of complexity hypothesis. Second, optimal movement variability hypothesis complexity my increase or decrease from an intermediate optimal value. This argues a pathological condition with regularity can maintain complex or chaotic characterization.

Self-similarity is a measurement criterion and measures details in variability. Chau's (2001) review on gait analysis includes fractal dynamics. The fractal dimension quantifies self-similarity Chau considers two reasons for the significance of self-similarity in physiological analysis. Chau maintains fractal dimension reveals deeply embedded correlations (self-similarities) and heterogeneities (dissimilarities) in signals. This claim according to Chau argues information undetected through standard statistical analysis when signal fluctuations usually assumed to be random. Second, knowledge of the correlation structure informs physiological mechanisms generated by observed signals. In a review on computational gait analysis Chau (2001) fractal analysis characterizes gait over long-range correlations in human gait fluctuations (Hausdorff *et al.,* 1995, 1996, 1997) produces a "new characteristic feature of normal gait patterns can be exploited in the quantitative diagnosis of neurological pathologies." The utility of fractal analysis in gait research appears to assist "a new breed of correlated central pattern generators endowed with memory." Observing general movement using self-similarity through a

taxonomy of movement (anatomical behavior descriptions) opens the possibility of granular differentiation in repetitive behavior.

Two theories on motor control and variability: (1) component-oriented as specific sources and underlying mechanisms of the motor control system movement pattern and the environmental context in which the movement appears; or, (2) interaction-oriented variability to be evidence of a self-organized and meta-stable motor control system common across all movement patterns and environmental contexts (Ihlen & Vereijken, 2013). Computational neuroscience promises to conduct an ability to generate accurate and appropriate motor behavior relies on tailoring our motor commands to the prevailing context movement. Torres *et al.* (2013) define non-stationary stochastic patterns of minute fluctuations (micro-movements) as patterns of behavioral variability with re-entrant sensory feedback's contribution to motor output with autonomous regulation and coordination. Operational practice used by Torres and collaborators detect changes in micro-movements aligned with kinesthetic re-afference in tandem with stimuli variations. A component based motor behavior method governs research on empirical standards discussed in psychological discussions of performance ability found in ASD (Gowen & Hamilton, 2013; Torres *et al.,* 2013).

Optimal control theory models autonomy and generality defines motor activity as tasks defining behavior (Wolpert, 1995; Wolpert & Ghaharmani, 2000). Optimal control theory's challenge predicts a nonlinear dynamics is

useful to observe a new task (Todorov, 2004). Replacing surveys used in clinical CMS research Torres et al., (2013) introduce aspects of computational neuroscience in clinical research on CMS in ASD. Computational neuroscience research relies upon numerical computations to organize an optimal control theory. Optimal control theory mimics motor activity. Torres (2011) holds understanding the statistical properties of physical movements using a probabilistic framework. What is the point of departure for mapping physical movements: performance parameters or anatomical-physiological parameters?

Neuroscience research on rhythmic circuitry (Marder, 2011) has mathematical implications. Advancing personalization or heterogeneity would have intermediate steps related with biological evidence. Brown (1914) proposes rhythmic movements are centrally generated and alternation between functional antagonists depends on reciprocal inhibition between flexors and extensors (as cited in Marder, 2000) introduces an extensive study of central pattern generation to understand rhythmic circuits. The dynamic interplay between central and sensory mechanisms in the generation of adaptive movements is seen in all preparations. In some preparations, sensory information may be used primarily to initiate or terminate ongoing movements or to modulate cycle period and amplitude in a graded fashion. In others sensory information provides critical timing cues (Marder & Calabrese, 1996). This translational research avoids layering advanced technologies upon conventional research methods. Claims on a signature unique to each individual to address

the heterogeneity of ASD (Torres, 2011). This suggests the need to formalize heterogeneity and uniqueness are mutually exclusive. Heterogeneity opens one state to many conditions or many states to many conditions.

The rhythmic study of motor circuitry in Marder's laboratory attempted to tune models of the STG motor circuitry. Out of Marder's neurobiology laboratory emerged studies on the lobster model STG research reviewed (Marder, 2011) examine the pyloric rhythm a tri-phasic motor pattern according to three neuron types (pyloric dilator, lateral pyloric, and pyloric neurons) appear in a stereotyped and repeating sequence. Disparate parameters produce the same network of pyloric rhythms. Marder's laboratory contribution to neurobiology of motor function proposes variability in known parameters result in a pyloric rhythm. Recording neuronal membrane conductances (K^+, Na^+) and spike bursts lead to measurement based upon variability, compensation, and modulation. Quantitative research using populations of models is essential to capture the variability in motor function. Compensation in the dynamics of motor circuitry in STG Marder's research points to "similar changes in network performance can result from changes in different network parameters." Modulation in motor circuitry in Marder suggests "perturbations that will differentiate among circuits with different sets of underlying parameters even if they produce similar behaviors." Granularity in neurobiological research leads to a novel form of analysis where heterogeneity requires a systematic trapping of relationships foregoing one-to-one relationships. There is a heterogeneity

motor circuitry captured through additional interactivity in terms of compensation and modulation that further define variability.

Following the conjecture on sequelae measurement through paired transitions research on ApEn (Pincus, 1991) serves as a mathematical starting point for the use of anatomical behavior descriptions. Also, the conjecture on lateralized movement follows motor circuitry (excitatory, inhibitory) has a *cross-scale* (morphological and cellular) mathematical formalization of central pattern generator (Forssberg & Hirschfield, 1994) in addition to evidence from animal model studies. The biological evidence on cellular function aligned with repetitive motor circuitry (central pattern generator) and the prospect of behavioral study on how CMS works find in mathematical protocols the prospect to define scientific workflows.

Anatomical behavior descriptions present levels of observation within the setting of CMS. To differentiate repertoire or sequelae mathematical tools revisits diagnostic assessment solely on the basis of low variation. Mathematical tools (ApEn and fractal analysis) combined with anatomical behavior descriptions (sequential transitions, local neighborhoods in motion capture data, sustained/next-step repetition, and pacing perpetual sequencing). Classifying subtypes in CMS clarifies the low variation hypothesis by pursuing a multi-resolution conjecture on CMS severity (repertoire or sequelae).

Establishing protocols with advanced mathematics supports porting visual evidence into translational scientific workflows. Already, Marder's

(2011) research on rhythmic circuitry illustrates variability in parameters generate the same network of tri-phase oscillatory patterns in pyloric rhythm. Marder and Taylor (2011) discuss the importance for research practices using families of models for quantitative research to keep pace with heterogeneity in rhythmic circuitry. A mathematical foundation for quantitative research would equally investigate scientific workflows (tunability and families of models) as well as phenomena poorly understood. CMS research based on mathematical techniques is in a position to arrive at data capture practices where the presence of CMS in heterogeneity and multi-resolution avoid generalization. The reduction of CMS' functional complexity appears in two cases: (1) absence of touch and skin innervation data reduces the possibility to quantify sensorimotor dynamics, behavioral plasticity, and whole-body activity; and, (2) quantifying perpetuation of repetitive restrictive behaviors within sequential analysis. Observations informed by Kelso's (2012) multi-stability contributes to data collection supported by physiological and neurobiological evidence.

A diagnostic methodology uses mathematical complexity to promote the identification of configurations across behaviors (postures and musculoskeletal), switching (during the unfolding sequence), and perpetuations (maintaining a cycle). Based upon description, quantitative measurement and pathological conditions anatomical behavior descriptions addresses a biological function multi-functionality plasticity, that is, transformation of the same unit for re-purposing. Re-purposing occurs on a literal level when comparing variability of

the presentation of CMS during shifts in lateralized movement patterns in each individual's sequelae. Re-purposing on a neurobiological level monitors the switching and regulation patterns during interlimb activity within an individual's sequelae. Anatomical behavior descriptions consider mathematical complexity within the context of three levels of observation: behavioral, diagrammatic, and neurophysiology. The instrumental investigation of CMS stands for a mathematical inquiry to analyze behavioral transitions in a time series (ApEn), diagrammatic organization of behavior-time pairings using multi-resolution display (shape logic) and self-similarity fractal analysis of sequential transitions, and the neurophysiology of lateralized movement's plasticity in the interleaving organization of motor function (Arber, 2011), multi-functional pattern architecture of musculoskeletal motor function (Briggman & Kristan, 2008), and literature on central pattern generator (Marder 2000, 2011; Marder & Calabrese, 1996; Marder & Taylor, 2011; Selverston, 1980).

The strength of observation for motion capture would benefit by descriptions capable of quantitative and biological expressivity. Mechanistic models of movement would benefit from the observation of several layers as Arber's (2012).

Identifying a network contributes to a visualizing more of the complexity within biological movement. Additionally, the tools used to quantify repetitive movement will compute while observing layers of variability in the description of visual evidence in repetitive restrictive movement as an

expression of probability over time framed within a self-expressing framework of repetition. Repetitive movement may serve as an anchor to identify network complexity by analyzing the recurrence in repetitive movement. Taking visual evidence into a mathematical organization is central for anatomical behavior descriptions to explore how an individual occupies 3-D space and the distribution of whole-

CHAPTER FOUR DISCUSSION

In this project scientific workflows are more than *ad hoc* investigative tools. The scientific workflows (e.g. motion capture) help to cross-reference biological knowledge (Table 22) and empirical observational criteria (rules). Gauging direct biological interface through scientific workflows replace the acquisition of datasets, that is, an interactive paradigm replaces the component-paradigm found in psychometric methodology.

Table 22 Observation criteria to visualize CMS

Morphological Characterization Criteria	*Antecedent*	*Relevant Research*
Innervation pattern →	Multi-cell recording (somatosensory)	Nicolelis *et al.,* (1995, 1997)
	Spinal circuits in motor function	Barbeau *et al.* (1999)
Ipsilateral movement →	Contralateral movement	Kristan, 1982; Marin-Burgin *et al.,* 2005, 2008
Integrated cell types →	Touch-induced movement	Chalfie *et al.* (1985)
Forward circuitry | backward circuitry →	Behavioral plasticity in c. elegans	Ardiel and Rankin (2008), Chalfie *et al.* (1985), Kawano *et al.* (2011)
Dorsal/ventral touch-movement data →	Innervation pattern, behavioral plasticity, touch-induced movement pattern	Sequelae time series analysis, unknown
Independence in movement →	Ipsilateral movement, behavioral plasticity	Sequelae time series analysis, unknown

The proposed instrumental design methodology reflects several investigative perspectives: (1) a translational shift in research agenda (NAMCH, 2009; Roco & Bainbridge, 2003; Shonkoff & Levitt, 2010); (2) families of tools

to monitor heterogeneous complexity in biological phenomena (Marder, 2011; Marder & Taylor, 2011); and, (3) platforms to regulate high throughput instrument analysis.

Calls for translational research agenda lead to a renewal of instrument design. The NAMCH's (2009) report set an agenda for advanced research validated (e.g., contextual fear conditioning, face processing, object recognition) across multiple levels of analysis to develop and validate new tools and procedures, including imaging tools, that can be used in multiple species and across all developmental stages. The National Science Foundation- Department of Commerce report organized by Roco and Bainbridge (2003) calls for the integration of converging technologies (nanoscience, biotechnology, computer sciience, and cognitive science). Shonkoff and Levitt (2010) argue in favor of integrated research as stress-factors appear during early stages of development and biomolecular evidence. The development of *families of instruments* provides an alternative quantitative research methodology to conduct analysis of heterogeneous complexity in three-phase pyloric rhythmic circuitry (Marder 2011, Marder & Taylor, 2011). Researchers have implemented a tool development strategy by quantifying biological movement through high-throughput.

High throughput assays reflects one aspect of the renewal of instrument design. Examples of novel tool development strategies include: (1) bioinformatics and imaging tools to identify behavioral phenotypes along side c.

elegans' biological movement (Feng *et al.,* 2004; Brown & Schafer, 2013; Schafer, 2011); (2) computational spatial analysis in biophysical studies of c. elegans' undulatory movement (Stephens *et al.,* 2008, 2009, 2011); and, (3) nananosciene use of tiny channel systems (microfluidics) to register motor behavior (Ardiel & Rankin, 2008; Chronis *et al.* 2007; Kawano *et al.,* 2011; Larsch *et al.,* 2013; Nagy *et al.,*2011; Salvador *et al.,* 2014; Wen *et al.,* 2012).

But to implement high-throughput studies increased granularity in observation criteria. Processing a taxonomy (anatomical behavior descriptions) provide systematic descriptions to conduct motion capture across multiple scales. Already, behavior research documents neurobiological evidence in bending leeches (Kristan 1982; Langen *et al.,* 2011, 2011a; Lockery & Kristan, 1990; Murin-Burgin *et al.,* 2005, 2007) and the developmental study of swimming zebra fish (Drapeau *et al.,* 2002). Meanwhile, clinical researchers replace self-reporting surveys with empirical and stochastic analysis in autism research (Guigon & Hamilton, 2008; Torres et al., 2013).

Instrumental-based research in this project removes high level motor programs or component models of motor function (Gowen & Hamilton, 2013; Torres *et al.,* 2013; Todorov, 2004 ; Wolpert, 1995; Wolpert & Ghaharmani, 2000) given the pathology in CMS and temporal complexity discussed in this project. A pointing gesture discussed through experimental research lacks the temporal and sequential complexity of CMS. This project proposes methods to monitor the cascading, repetitive, and perpetuated movements in CMS.

Research on *how* CMS *works* uses an instrument-based methodology. It is anticipated empirical observation and a rules system to support precise motion capture and data collection. Otherwise, variability in CMS at local levels (temporal) and granular levels (behavioral) will remain hidden from view in chronological time series analysis. An instrument design using a rules-taxonomy interface attempts to keep pace with granularity and potential heterogeneous complexity in repetitive behaviors.

How does a dysfunction work within an individualized biological context? This line of inquiry leads to a series of questions: (1) degree of severity of the dysfunction; (2) specialized data collection in the spatio-temporal domain; and, (3) behavioral assessments of the allocation of sensorimotor resources. These topics establish new forms of scientific workflows while investigating a population with motor dysfunction and *How is* a dysfunction *locally-optimal*? Visual formalism used to compute fractional series might provide a metric to identify local optimality, that is, how the sequelae works for each individual's equilibrium.

CMS research in this project introduces instrumental-design to configure diagnostic assessment methods. A set of rules (empirical observation) provides observational criteria to guide programming motion capture tools (e.g. postural transitions (from-, to-) to differentiate lateralized movement in a sequence). A neighborhood of sensors register interlimb activity through anatomical behavior descriptions programmed in a motion capture system. The combination of

observational criteria and descriptive markers of CMS activity (anatomical behavior description) generate data collection instruments (motion capture). The protocol (anatomical behavior descriptions) anticipates an instrumental standard for measurement in complex motor stereotypies (CMS) research.

A novel quantitative research reconciles interactive modeling where local neighborhoods of movement mark musculoskeletal dimensions and skin innervation registered during direct biological interface. Literature on biological psychiatry (Bahn & Guest, 2011) and the bioengineering pharmacological sensor development (Patel, 2012) suggest a systematic integration of technology with system biology.

Anatomical behavior descriptions suggest new criteria to identify signatures in CMS based on variation during sequential analysis, that is, the differentiation of phases of lateralized movement. This leads to several key time based questions:

1. *Is behavioral plasticity in CMS asymmetric (forward-touch induced movement, backward-touch-induced movement)*
2. *Will time analysis support the association of ipsilateral movement with excitatory motor circuitry, contralateral movement inhibitory motor circuitry, and bilateral movement with excitatory/inhibitory motor circuitry?*
3. *How does the complexity of processing rates at local levels of behavioral resolution differentiate morphological timing and cellular*

processing? Does this yield a measure indicative of the allocation of resources between the morphological and the cellular?

These questions arise from taking undulating movement in animal models and the purposeless repetitive restrictive movement.

CMS severity measurement would compare time-behavior pairings in sequential transition patterns (from-, to-). This would yield a standardized measurement and diagnostic classifiers to monitor behavioral plasticity to detect pre-conditions or prerequisites for levels of CMS severity. *The absence of high behavioral resolution in CMS reflects limitations in the observation of CMS rather than confirming low variation in CMS' structure and function*. Anatomical behavior descriptions bridge a gap between behavioral measurement and the instruments to conduct behavioral observation.

To quantify variability in CMS quantitative research, one might pursue a generative taxonomy to detect variability at granular levels of *behaviors in time*. Positioning quantitative research within a descriptive taxonomy with rules on the observation of repetition parallels a linguistic formalization of a generative taxonomy and rules to analyze language families. Measurement of CMS is a quantitative measurement challenge to: detect time-behavior data, time characterization of regulation of repetitive behaviors, and conduct motion capture without losing sight of the “physiological relevancy” in motor behavior. Physiological relevancy is a construct to validate a nanoscience tool's behavioral authenticity. Physiological relevancy attempts to further define a behavior

within *in vitro* or brain chip interfacing (Fromhertz, 2006). Implementation of a generative taxonomy in motion capture derives from advancement in instrumental protocols: *in vitro* nano tools (Das *et al.,* 2006); brain-to-brain interface (Pais-Vieira *et al.,*2013); brain chip interface (Fromhertz, 2006). These advanced tools frames behaviors in time at levels of granularity hard to capture through camera-based observation.

Barriers to direct biological interface have been broken using levels of material manipulation: (1) chemically synthesized genome (Gibson et al., 2010); (2) novel behavioral experimentation brain-to- brain (Pais-Vieira et al.,2013); and, (3) computation and olfactory circuits (Rhodes, 2008; Rhodes & Anderson, 2012). Methodologies guide a researcher to conduct innovative tool-use (e.g. olfaction research by Buck and Axel (1991)). Coarse data collection remains a problem when considering a condition without an etiological explanation (e.g., complex motor stereotypies). Such a claim differentiates the prior inability to chemically synthesis a genome and the J. Craig Venture Institute breakthrough on the manufacturing of genome in Gibson et al. (2010).The brain-to-brain shared real- time work in Pais- Vieira et al., (2013) illustrates a form of empirical research improving upon conventional behavioral standards precision and interface. *Setting aside behavior as we know it there is the supply-side view of behavior, that is, the manner each individual allocates their resources: biologically and temporally.* Advanced methodologies and novel toolkits revise what behavior encompasses.

The call for insights in challenging pathologies (autism) requires instrumental solutions for neuroscience and nanoscience to keep pace with computational complexity in living systems. Methodologies for direct biological interface prompt a methodical definition of diagnostic instrument design in cases where etiological explanations are weak. Diagnostic assessment of CMS in the time domain might report on behaviors in time, the perpetuation and pacing of repetitive sequences to compute and replace the coarse characterization (jerky and continuous) of hyperkinetic motor disorders in children discussed in Sanger *et al.* (2010).

Outside Readers and Next Steps

Outside readers for this project include multiple disciplines: kinesiology, behavioral neuroscience, infant behavior, neuroscience, and biomedical pharmacology. A methodical assessment of anatomical behavior descriptions will need to evaluate the empirical basis (4 rules used to characterize data collection). Factor analysis might assess variables and system integrity but several methodical improvements would be overlooked (Figure 22). A comparison between wearable sensors used within an interactive paradigm (direct biological interface) and wearable sensors within a component paradigm is a substitute for factor analysis. The comparison of between each wearable sensor methodology would focus on a rubric to analyze the steps reproduce behavioral fidelity. A neurobiological assessment of the anatomical behavior protocol using cellular preparations is a long term objective.

Figure 22 Configuration to compare CMS research methodologies

A comprehensive analysis of distributed sensor network based on anatomical behavior descriptions and wearable markers (data collection in a psychometric methodology) might contribute to assessing gains in data collection from a translational perspective. Assessing anatomical behavior descriptions would evaluate several topics: (1) the quality of investigative questions raised. due to a novel methodology; (2) scientific workflows designed to promote direct biological interface; and (3) symbolic-visual formalisms used to address heterogeneous complexity.

Future research will present algorithms for motion capture: (1) local timing; (2) regulation of sequelae; and, (3) visual tests for data collection of high behavior resolution. A set-logic is essential to formalize the visual logic introduced in this project in Figures 13, 14. The application of the anatomical behavior descriptions taxonomy in time series analysis using ApEn and fractal analysis would contribute to the proposed methodology. Using a mathematical

formalism would examine CMS within an interactive paradigm, that is, to advance direct biological interface within two levels of research: rhythmic circuitry and repetitive circuitry when examined using nanoscience tools and *in vitro* preparations.

To develop the architecture and symbolic system for next generation biological machines CMS movement analysis might provide spin-off technology. First, applying the scientific workflows presented in this project model Bellman's dimensional problem to study sensory integration and regulation of repetitive sequences as a power process. Second, conducting research on transitional complexity study Kelso's multistability (repurposing of motor circuitry). Finally, CMS data functions as an engine for the proposed visualization system. The engagement of repetitive movements functions as an animated display showing repetition as flow patterns defined by lateralized movement..

Unconventional Computation

CMS appears to be a conduit to advance direct biological interface due to the perpetual repetition evident in CMS. CMS as a boundary system serves as a model for biological computational machines. Increasing behavior fidelity in a quantitative methodology requires side-by-side (juxtaposed) local neighborhoods. A universal description of a time varying behavior (CMS) has consequences in developing observation criteria for motion capture or framing time series analysis.

Anatomical behavior descriptions taxonomy is in a primitive stage. A formal presentation would document anatomical behavior descriptions as a taxonomy with *descriptive* precision to conduct comparative analysis, *functional* measure of variability, and a *generative* system to define observational criteria. Establishing the syntax (set-theory) for visual formalisms in transition complexity would model high resolution behaviors or model the interactivity of behavioral plasticity in CMS.

APPENDIX A CLINICAL STUDIES REALTED WITH MOTOR STEREOTYPIES FROM AUTISM RESEARCH

Table 23 Clinical Studies Related with Motor Stereotypies from Autism Research

Type of Study	Methodology	Study
Systematic	Systematic Study (atypical repetitive behaviors)	Bodfish *et al.* (2000)
	Review of Methodology (repetitive behaviors in autism)	Lewis & Bodfish (1998)
Typical Dev.	Self-Stimulatory Behaviors (video recording at home)	Smith & Van Houten (1996)
	Neurological Assessments (Case Studies)	Tan *et al.* (1997)
	Video recording	Thelen (1979)
Young Children Atypical Dev	Neurological Assessment (primary stereotypies TD, secondary stereotypies ASD etc.) Neural Circuitry & Neurotransmitters	Multhugovindan & Singer (2009)
	Biomedical Clinical Assessment	Campbell *et al.*(1990)
	Behavioral Assessment of Repetitive Motor Behaviors. Video recording (manual encoding of based upon Thelen (1979).	Loh *et al.* (2007)
	Direct Observation (play behavior, stereotypies) Continuous duration measurement (real-time measurement method Miltenberger (1999). 30 minute assessments, used 5 min. sample free-play, 5 min. sample assessment trials (NECC Early Core Skills)	MacDonald *et al.* (2007)
	Parental Report (Autism Diagnostic Interview-Revised) Repetitive Restricted Behaviors (Repetitive sensory motor, Insistence on sameness). Factor Analysis- Repetitive Restricted Behaviors: (Prevalence, Severity: ASD, TD). Determine if behaviors that cluster show similar patterns (prevalence or severity) in ASD, TD young children.	Richler *et al.* (2006) (Part of longitudinal study)
Pre-term Infants	Literature Review (early motor development, spectrum of major motor disabilities)	Bracewell & Marlow (2002)
	Meta-Analysis (pre-term and low birth weight)	de Kieviet *et al.* (2009)
	Touwen Examination of the Child with Minor Neurological Dysfunction,	Jongmans *et al.*(1997)
Early on-set ASD	Retrospective Video Analysis (sensory-motor and social behaviors)	Baranek (1999)
	Microgenetic Observation	Lord *et al.* (2012)

APPENDIX B EMPIRICAL DESIGN ON MOTOR STEREOTYPIES FROM AUTISM SPECTRUM DISORDERS

Table 24 Empirical Studies on Repetitive Behaviors

Stereotypies / Other	Instrumentation	Modeling System
Memari *et al.,* (2013)	Bertec force plate records the ground reaction forces by an individual	Postural sway, directional oscillations in each axis separately: anteroposterior (AP) or mediolateral (ML) and composite measures; mean velocity in AP, ML composite measures; range in AP and ML directions, mean frequency and sway area Measures postural sway parameters; root mean square, numerical computations Excel macros.
Karch *et al.* (2012).	Electromagnetic tracking system, dynamic warp timing pattern (sequence comparison)	Representation of lower as well as the upper limb in all degrees of freedom of the corresponding joints Numerical computation algorithm for biological movement
Lamoth *et al.,* (2009)	Accelerometer	Postural sway patterns of three populations that differ with respect to their athletic skill level. Stochastic-dynamical analyses of body sway acceleration signals can discriminate the postural sway patterns
Bodfish *et al.* (2001)	Formal dynamic analysis of movement	Drug-induced dyskinesia in postural task (goal oriented); dyskinesia vs. stereotypies; postural dynamics (anterior-posterior, side-to-side, vertical directions) Measures (amp, freq of motion); organizational properties periodicity and complexity characterizing motion changes in time and space. Postural stability frequent adjustments of center of pressure through sequential low amplitude whole-body postural movement
Ross *et al.,* (1998)	Video recording (home, school, or workshop)	Definition of periodicity in stereotypies instead of rhythmicity. Spectral analysis
Yamada (1995)	Accelerometer,Mathematica	Self-determined finger tapping. Variation in stereotyped human movement cannot be modeled as Brownian motion or noise separated from a deterministic movement system
Lewis *et al.* (1984)	Accelerometer (Frequency domain analysis)FFT Tukey-Hanning window	Cyclical properties: stereotypied body-rocking (rhythmic/repetitive patterns),cardiac activity (ECG) Numerical analysis of physiological and behavioral data (coupled oscillatory systems: heartbeat and sway); Spectral Analysis (time series) variance decomposition/partitioning

APPENDIX C MEASURES ON THE SEVERITY ON MOTOR STEREOTYPIES (1967-2010)

Table 25 Measures on the Severity of Motor Stereotypies

Assessment Tool	Reference	Measurement & Psychometric Measures
Bayley Scales of Infant Development III	Albers & Grieves (2007) Bayley (1993)	Fine motor subtest 66 items, Gross motor subtest 72 items in an infant toddler developmental battery of subtests
Movement Assessment Battery for Children	Henderson et al. (1992)	Children (ages 3-6,7-10, 11-16) eight tasks are grouped under three headings: manual dexterity, aiming and catching, and balance
Bruininks-Osevetsky Test of Motor Proficiency	Bruininks & Oseretsky (1978)	Measures fine and gross motor skills of children age 4-21. Characterizes motor performance, specifically in the areas of fine manual control, manual coordination, body coordination, and strength and agility
Examination of the Child with Minor Neurological Dysfunction	Touwen (1979)	Development assessment of sitting, standing, walking, and lying
Developmental Test of Visual-Motor Integration	Bernstein (2010) Wuang & Su (2009)	standardized form-copying examination of integration visual and motor abilities 3-17 years
Beery-Buktenica Developmental Test of Visual-Motor Integration	Beery & Buktenica (1967)	
Rutter Scales	Elander & Rutter (1996)	Rutter scales are a pair of short questionnaires for collecting information from parents and teachers about the behaviour of children aged about nine to thirteen years.

		They focus on emotional and conduct disorders and were designed as screening instruments for ...
Timed Stereotypies Rating-Scale	Campbell et al. (1985)	Isolated measure of timing of stereotypic behaviors
Abnormal Involuntary Movement Scale	Guy (1976)	4 point rating scale of movements: facial/oral, extremity, trunk, and global judgments
Repetitive Behavior Scale Revised	Miller et al. (2006)	4 point rating scale of movements
Vineland Adaptive Behavior Scale	Matson et al. (1997)	Measures Communication, Daily Living Skills, Socialization, Motor Skills, and Maladaptive Behavior domains.
Alberta Infant Motor Scale	Schemer & Sexton (1991)	Measures gross motor maturation of infants from birth through the age of independent walking within neuromaturational concept and the dynamical systems theory
Peabody Development Motor Scales	Folio & Fewell (1974) Wang et al. (2006)	six subtests (reflexes, stationary, locomotion, object manipulation, grasping, visual motor integration) that measure interrelated abilities in early motor development. It was designed to assess gross and fine motor skills in children from birth through five years of age.

APPENDIX D EVIDENCE FROM MUTLIFUNCTIONAL CIRCUITS

Table 26 Evidence from Multifunctional Circuits

Thesis Terminology	Briggman & Kristan (2008)	Evidence on Motor Circuits
Switching variability in motor behaviors	Neuronal network function and selective engagement of motor circuits	Truly independent neurons within a defined circuit are those that are active, either hyperpolarized or depolarized, during one behavior and inactive during other related behaviors (Selverston, 1980)
Cross-scale morphological and cellular	Behavior module generates multiple behaviors	Behavioral module refers to single neurons or groups of neurons that coordinate a particular muscle synergy (Briggman & Kristan, 2008).
Independence		Remarkably, short-term adaptation of the right or left leg does not gen eralize between forward and backward stepping (Briggman & Kristan, 2008).
		This lack of generalization implies that the networks underlying walking are both leg and direction specific, consistent with the idea of discrete behavioral modules (Choi & Bastian 2007).
Sustained repetitive restrictive behavior	Phase-locked ineterneuron and motorneuron	Modules can be either movement specific (phase-locked to a movement used in multiple behaviors) or behavior specific (phase-shifted depending on the behavioral context). Neurons in the turtle spinal cord during three forms of hindlimb scratching are often phase-locked (e.g., to hip flexion), regardless of changes in motor neuron coordination (Berkowitz, 2001, 2005).
	Behavior specific, movement specific	Despite shared-phase relationship, different neurons elicit two closure phases, again indicating behavior-specific modules (Jing et al. 2004).
		Biting and swallowing are similar ingestive patterns; both require a closure of the food grasper, the radula, during the retraction phase of both behaviors. Despite this shared-phase relationship, different neurons elicit two closure phases, again indicating behavior-specific modules (Xin et al. 1996, 2000).
Granularity in switching behavior	Switching behind motor circuits	(a) sensory or projection neurons providing input from the periphery or via descending and ascending inputs from higher-level networks
		(b) the effects of neuromodulatory substances on intrinsic membrane properties and synapses
		(c) biomechanical constraints imposed by the body, detected by sensory feedback as the body moves. (Briggman & Kristan, 2008)
	Neuromodulation (monoamines)	Studies on the neuromodulation of in vitro vertebrate nervous systems use bath application of modulatory cocktails to elicit behaviors (Whelan et al. 2000).
	Contex-Sensitive Muscles	Biomechanical proper- ties of musculature and joints and the transformation of motor neuron spikes into muscle con- tractions further constrain the behaviors that these patterns generate (Chiel & Beer 1997).
		Nonlinear properties of individual muscles and variability between ani- mals, predicting behavioral responses from mo- tor neuron (Hooper et al. 2006, Hooper & Weaver 2000). spike trains is difficult
	Development of quantitative models	How neurons control muscles is necessary ultimately to determine the behavioral relevance of patterns produced by multifunctional circuits (Brezina et al. 2000, Brezina & Weiss 2000).

APPENDIX E CROSS-REFERENCING MULTI-FUNCTIONAL CIRCUITRY FOR BEHAVIORAL RESEARCH

Table 27 Cross-Referencing Behaviors and Multifunctional Architecture

ABD Terminology	Briggman & Kristan (2008)	Research Topics
Behavioral fidelity	Versatility: (1) central nervous systems → producing and modifying behaviors.	Neuronal level showed combination of the synaptic connectivity and intrinsic membrane properties generates → activity patterns in multifunctional circuits (Kristan et al. 2005, Marder & Bucher 2001, Marder & Calabrese 1996).
		Activity level of descending interneurons in the goldfish spinal cord can modulate the strength of escape behavior in goldfish and zebrafish (Bhatt et al. 2007; Fetcho 1992).
(Versatility)	(2) reconfigure anatomically defined circuits into many distinct functional circuit	Number of recruited interneurons increases the strength of escape behaviors in fish and frogs (McLean et al. 2007, Sillar & Roberts 1993).
		Richer set of capabilities can be captured by viewing the neural activity as a dynamical system in a phase space diagram (Briggman & Kristan, 2008).
	Multifunctional networks → generate discrete behaviors	Circuit capable of generating more than one stable pattern is termed multistable, which is one form of multifunctionality (Briggman & Kristan, 2008).
Behavioral markers	Behavioral phases (flexion, extension)	Phase space diagram captures both the dimen- sionality of stable patterns (indicating which parameters must be measured) as well as the dynamics of the system in response to stimuli (Briggman & Kristan, 2008).
Transition and switching	Switching	Phase space plots can also indicate when transitions between stable states occur at different time scales, from abrupt transitions (Figure 1) to the slow evolution of one pattern into another (Briggman & Kristan, 2008).
Precision (visual formalism)	Phase space diagram	Phases of some rhythmic behaviors are generated by a distributed network of neurons oscillating in unison (Grillner 2006).
Visual formalism	Phase space plot	Series of basic building blocks, made of neuronal pools dedicated to coordinating the activity of a muscle group (Briggman & Kristan, 2008).
	Phase in rhythmic behaviors	Motor primitives can be combined to generate spatially and temporally precise force fields and the corresponding body and limb movements, for example, reaching, grasping, or kicking (Flash & Hochner 2005).
Morphological characterizations	Behavioral modules	Multifunctional circuits implementing this architecture can potentially drive unifunctional muscles to generate two or more behaviors simultaneously, as in the crab STG (Bucher et al. 2006; Weimann et al. 1991).
	Multifunctional architectures	Multifunctional circuits may drive a common set of multifunctional muscles reconfigure to drive a variety of different inspiratory and expiratory rhythms and two forms of locomotion in the leech (Lieske et al. 2000).
	Multifunctional architecture	Swimming and crawling, are controlled by a multifunctional circuit activating multi- functional muscles (Briggman & Kristan 2006).
	(Example respiratory circuits in mammals)	Many of the behaviors generated using this architecture are mutually exclusive—a leech can- not both swim and crawl at the same time
		Behaviors driven primarily by multifunctional circuits can also include apparently dedicated neurons (Berkowitz 2002; Briggman & Kristan 2006).
	Exclusion	Characterizing the activity of single neurons and relating their activity to two or more behaviors can lead to new insights about their multiple functions, knowing the complete anatomical circuit is invaluable(Hooper & DiCaprio 2004, Marder & Bucher 2007)
		Switching the roles of neurons to support multiple simultaneous rhythms produces important behavioral consequences (Clemens et al. 1998, Heinzel et al. 1993, Thuma et al. 2003).

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