A Systems-level Dynamic Model of Concussion

Elle Parks[1*], Erin Kenzie[1], & Wayne Wakeland[1]

[1]Systems Science Program, Portland State University, Portland, Oregon USA, *eparks@pdx.edu

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1 Aim

To construct a conceptual model, causal-loop diagram, and corresponding system dynamics model of concussion pathophysiology and recovery at the individual scale. These models will contribute to a greater understanding of the factors involved in concussion recovery and will inform the development of a new classification system for traumatic brain injury.

2 Problem

• Traumatic brain injury has been called "the most complicated disease of the most complex organ of the body" (Marklund and Hillered 2011).

• In the United States, at least 2.5 million people suffer a traumatic brain injury per year (CDC, 2016). Seventy to ninety percent of these cases are mild TBI, or concussion (Cassidy et al. 2004). Concussion is vastly underreported; one study found that at least 88% of cases might go unrecognized (Delaney et al. 2005).

• No single definition of concussion is accepted across disciplines, though several different definitions are available (Comper et al. 2005; Hawryluk & Manley 2015).

• Injury occurs in context. Traumatic biomechanical forces in the brain can occur from direct (to the head) or indirect (to the body) impact (e.g., sports, workplace accidents, violent trauma), fast acceleration or deceleration (e.g., whiplash, motor vehicle accidents), or intense changes in pressure (e.g., blast exposure) (Patterson & Holahan 2012).

• Following a concussion many people become symptom-free within a few weeks. However, an estimated 15% of people experience longer-term symptoms and deficits, although this number has been disputed (Zasler et al. 2007). Prolonged impairments can cause significant distress and debilitation.

• The medical field currently lacks reliable and accessible means of identifying individuals at risk for more prolonged or complicated recoveries from concussion.

• The current classification system for traumatic brain injury (mild, moderate, severe – based on the Glasgow Coma Scale) lacks precision and does not reliably predict recovery, especially concussion. The field is currently engaged in developing a new classification system.

• No clinically useful biomarkers or treatments have yet been approved for concussion, although several show promise.

• A wide variety of medical disciplines and specialties study and treat individuals with concussions. There is no shared explanatory framework for the pathophysiology of concussion and its recovery.

3 Methods

• Model development led by methodology team of systems scientists at Portland State University in cooperation with a large team of researchers and clinicians gathered by the Brain Trauma Evidence-Based Consortium (B-TEC).

• Conducted extensive review of relevant literature; interviewed many key researchers, clinicians, and athletic trainers; and conducted a focus group with young athletes experiencing prolonged recovery from concussion.

• Iterative model development with frequent review by experts.

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4 Concussion through a systems lens

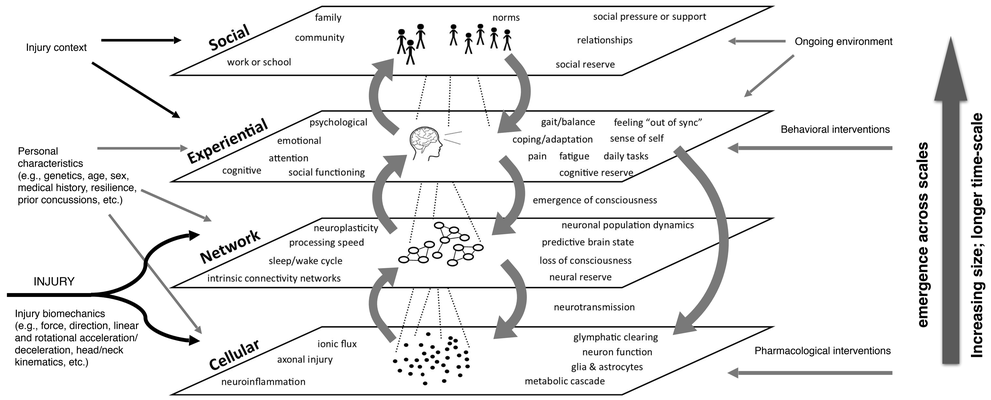
• Conceptual systems models can provide a way to synthesize relevant literature and expert knowledge and present it in a way that facilitates precise articulation of pathophysiology, identification of knowledge gaps, and communication across disciplinary lines.

• Many factors interact dynamically to influence an individual's recovery trajectory. The influence of these factors can differ across individuals, and can change over time.

• Traumatic brain injury is best characterized across four scales: *cellular*, *network*, *experiential*, and *social*. These scales are nested and show emergent properties. Feedback loops within and between scales can contribute to individual recovery trajectories and observed heterogeneity.

• Here we present two conceptual systems science diagrams to help elucidate the variables most critical to concussion and their causal interrelationships.

Figure 1: Multi-scale framework of concussion.



5 Next steps

• Finalize multi-scale framework and causal-loop diagram in collaboration with investigator team.

• Acquire reference behavior data (recovery trajectories at the individual level for key indicators).

• Develop system dynamics computational model based on causal-loop diagram that will generate estimated recovery trajectories based on individual inputs for key parameters.

• Together, the goal of these systems science models will be to assist in the development of a new classification system for TBI, identify research gaps, aid in the design of successful clinical trials (especially appropriate inclusion/ exclusion criteria), and promote collaboration among experts.

• Concussion is a pressing public health issue. Researchers and clinicians across disciplines need a shared explanatory framework for understanding the pathophysiology underlying concussion and its recovery.

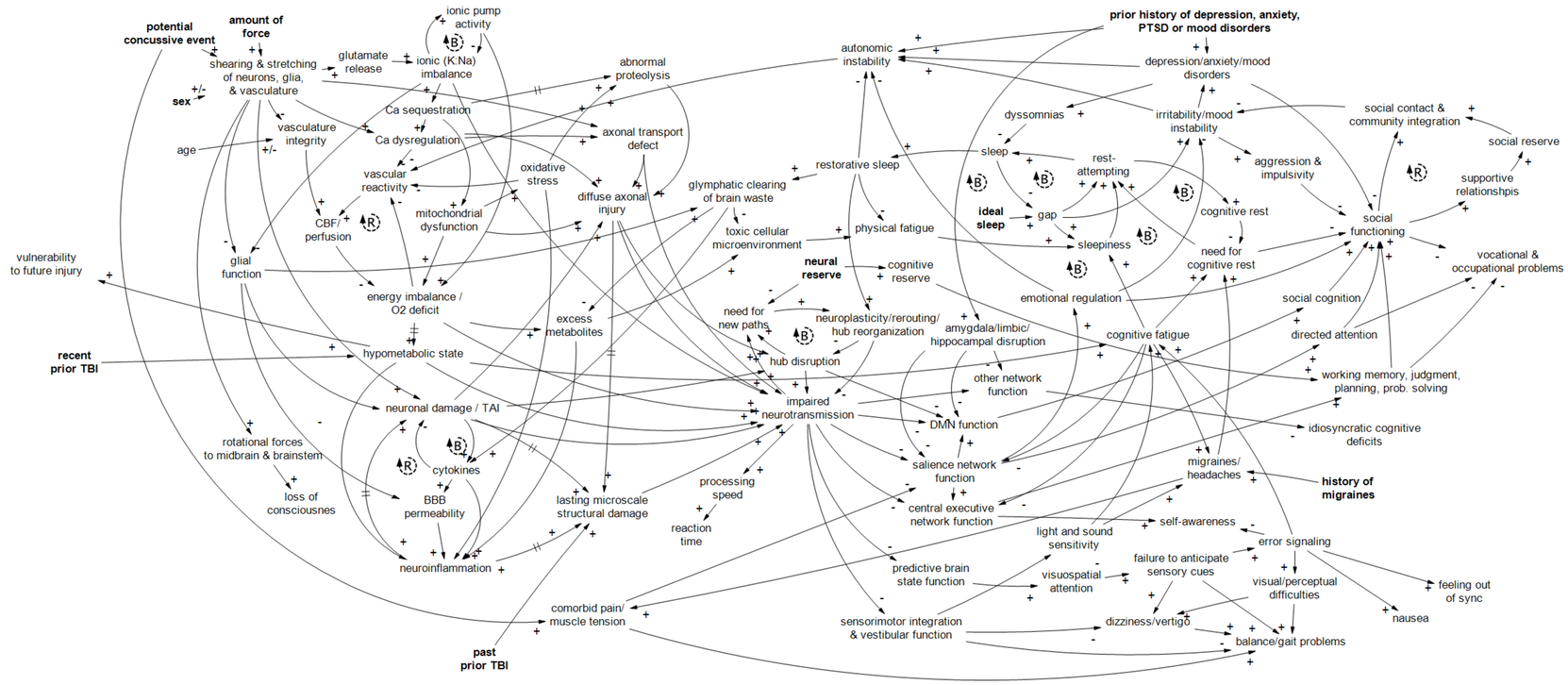



Figure 2: DRAFT causal-loop diagram of concussion. (Created in MapSys.)