Notice of the Final Oral Examination for the Degree of Doctor of Philosophy of

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“Cognitive Control Modulates Pain During Effortful Goal-Directed Behaviour”

Department of Psychology

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Remote Defence

Supervisory Committee:
Dr. Clay Holroyd, Department of Psychology, University of Victoria (Supervisor)
Dr. Jim Tanaka, Department of Psychology, UVic (Member)
Dr. Alona Fyshe, Department of Computer Science, UVic (Outside Member)

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Dr. Laura Arbour, Division of Medical Sciences, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract

Many theories of decision-making consider pain, monetary loss, and other forms of punishment to be interchangeable quantities that are processed by the same neural system. For example, standard reinforcement learning models utilize a single reinforcement term to represent both monetary losses and pain signals. By contrast, I propose that 1) pain signals present unique computational challenges, 2) these challenges are addressed in humans and other animals by anterior cingulate cortex (ACC), and 3) pain is regulated by cognitive control during goal-directed tasks, using principles of the hierarchical reinforcement learning model of the ACC (HRL-ACC). To show this, I conducted an electrophysiological study to investigate the effect of task goals on event related brain potentials (ERPs) during conditions where pain and reward are used. Specifically, I intended to see whether feedback stimuli predicting forthcoming pain would elicit more positive-going ERPs than feedback stimuli predicting no-pain when the goal of the task is to find electrical shocks. Contrary to my predictions, changing task goals did not affect ERPs in the pain condition similar to negative feedback (e.g. no reward) in other standard RL tasks which are observed to be modulated by higher level task goals. Results suggested that pain and monetary loss are processed differently, so I investigated this difference further in a series of behavioural tasks. In that experiment I calculated the subjective costs of mild electrical shocks and equated them with monetary losses for each individual participant. I then had the participants execute a sequential choice task that required them to withstand immediate punishments in order to attain long-term rewards. As predicted, participants’ choice behaviour and response times differed for sequences involving pain vs monetary loss, even when these punishments were equated according to their subjective values. Results demonstrated that the costs associated with pain and monetary losses differ in more than just magnitude. To explain these results, I developed an extension to an existing computational framework of the ACC, the HRL-ACC model. The present model provides insight into choice behaviour in the pain and monetary loss (ML) conditions by showing that cognitive control levels converge to an
average level across trials. The high-level control system receives feedback at the end of each trial which determines whether performance is good or not. In the ML condition, control is not needed for good performance, so the high-level system decreases control until the end of the task. In the pain condition, control remains at a high level, because decreasing it after several trials with positive outcome brings control to such a low level that would not be enough to overcome subsequent painful trials. Therefore, in the pain condition the model overcomes pain by maintaining good performance (sustain average reward values across trials). These findings are in line with psychological approaches to pain treatment and provide neuro-cognitive explanations that underlie their mechanisms. In line with the HRL-ACC theory, I propose that the ACC regulates pain by motivating good performance in the face of physical punishments (but not monetary losses) in order to achieve long-term goals that are produced by ACC.