Research Statement

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Research Aims

My research aims to investigate sensorimotor processes in the context of goal directed movements. I am particularly interested in how the motor system integrates noisy multimodal sense data in uncertain environments. To focus my research, I investigate the difference between implicit and explicit learning processes in motor systems which developed my appreciation for embodied systems and movement in particular, specifically motor adaptation and control. In my research, I apply behavioural, neurophysiological paradigms, as well as computational modelling techniques to parse the contributions of the implicit and explicit components of motor adaptation and generalization in order to model the behaviour of an adaptive agent in a goal directed. From this research, I have developed a novel model of sensorimotor integration that may be applied to a variety of movement contexts. In addition to characterising the fundamental features of motor adaptation, I have employed this model in the applied setting of skilled motor experts, specifically expert minimally invasive surgeons. By investigating the key differences in motor learning capacities of expert minimally invasive surgeons in the context of of both surgery-specific and non-surgery-specific tasks, our model has provided a novel means by which to characterise expert-level difference in skilled motor performance. As a result, my research may be used to inform training protocols employed to train a wide variety of expert motor learners including surgeons, athletes, musicians, pilots, e-sports gamers, soldiers et cetera. Furthermore, our modelling results provide a novel means by which to correlate key motor processes to neural regions of interest in an effort to better understand the neural processes associated with motor-skill development.

Research Achievements

- Fourteen journal publications in peer-reviewed journals including *Scientific Reports*, *Human Movement Science* and *eNeuro*, across the domains of Pharmacology, Philosophy and Cognitive Neuroscience.
- A book chapter in *Neural mechanisms*, *Springer*.
- Presentations at international conferences including the *Cognitive Neuroscience Society* annual meeting, the *Society for Neuroscience* annual meeting, *Advances in Motor Learning Motor Control* conference, and the *Australasian Society for Philosophy and Psychology* annual meeting.

Previous Research

My research contributes to three key areas of scientific inquiry: (1) Parsing the fundamental components of sensorimotor learning and control, (2) Characterizing the key features of motor expertise and skilled performance, (3) Taxonomizing mechanistic explanation in the context of Bayesian models.

1. Parsing the fundamental components of sensorimotor learning and control

The principal component of PhD research investigated how each stage of the sensorimotor loop including planning, control, and learning contends with different sources of noise and uncertainty. The process of integrating sensory information during an ongoing movement and that of adapting motor plans over successive movements are both essential for accurate, flexible motor behavior. When sensory information indicates that an ongoing movement is errant, feedback control mechanisms update the descending motor commands to counter the sensed error. Two of my papers based on this research stand to have a considerable impact on the field of motor learning as we found some robust behavioural effects that “break” all dominant theoretical models of human sensorimotor learning under uncertainty. The results from three experiments indicate that sensory uncertainty influences feedforward adaptation that co-occurs with feedback integration in a fundamentally different way than it influences feedforward adaptation alone which indicates that sensory uncertainty inversely scales a bias term in the feedforward update that is independent of the experienced motor error. These results run counter to most previous studies which demonstrate inverse scaling of an error-dependent adaptive update and demand a rethinking of the dominant theoretical models of sensorimotor learning under uncertainty.

2. Characterizing the key features of motor expertise and skilled performance

The second component of my PhD applies our novel computational models of motor learning to the context fo expert minimally invasive surgeons. After critically reviewing the current literature on sensorimotor learning and performance in minimally invasive surgery I took a novel approach by viewing this literature from the well-developed theoretical perspectives of computational motor control and motor learning neuroscience. By drawing on insights from the field of motor learning, I was able to highlight how different aspects of technical surgical skills are underwritten by the operation of fundamentally different processes in the brain: one geared for motor execution and another geared for motor adaptation. As a result, I developed a standardized nomenclature and taxonomy by which to categorize the variety of perturbations experienced by expert laparoscopic surgeons. I then applied this novel taxonomy in a variety of behavioural experiments designed to map the contributions of specific motor components during the development of expert surgical skill.
The results of our first behavioural experiment provided evidence that endoscopic realignment imposes a reliable cost on performance across both naive controls and experienced surgeons. This finding clarifies an important ongoing discussion in the literature about the effects of camera realignment, which could inform the strategies that laparoscopic surgeons use in the operating room.
The results of our second experiment indicated that surgeons generalize to novel task contexts more broadly than non-experts which confirm that expert minimally invasive surgeons exhibit enhanced visuomotor learning and spatial generalization.
In combination, these results may be used to inform the development of novel training protocols and provide key insights into how expert surgeons gain technical proficiency.

3. Taxonomizing mechanistic explanation in the context of Bayesian models

In the co-authored book chapter, we investigate the varieties of constraints Bayesian models in neuroscience can apply on the mechanistic explanation of cognitive phenomena. Specifically, we respond to Colombo and Hartmann (2017) [1] who recently argued that Bayesian modelling in neuroscience can not only unify a diverse range of behavioural phenomena under a common mathematical framework, but can also place useful constraints on both mechanism discovery and confirmation among competing mechanistic models. After reviewing some reasons for decoupling unification and explanation, we raise two challenges for their view. First, although they attempt to distance themselves from the view that Bayesian models provide mechanistic explanations, to the extent that a given model successfully constrains the search space for possible mechanisms, it will convey at least some mechanistic information

Colombo, M., Hartmann, S. (2017). Bayesian cognitive science, unification, and explanation. *The British Journal for the Philosophy of Science*, 68(2), 451-484.

and therefore automatically qualify as a partial or incomplete mechanistic explanation. Second, according to their view, one widely used strategy to guide and constrain mechanism discovery involves assuming a mapping between features of a behaviorally confirmed Bayesian model and features of the neural mechanisms underlying the behavior. Using their own example of multisensory integration, we discuss how competing mechanistic models can be consistent with all available behavioral data and yet be inconsistent with each other. This tension reveals that there are exploitable degrees of freedom in the mapping relationship between models of behavioral phenomena and neural mechanisms, and points to the role that other background assumptions play including level-assumptions about the appropriate level at which the neural model should be specified (e.g., individual neuron or population level) and localization-assumptions about where in the system the underlying mechanism might occur. These considerations highlight the need for a more refined account of modelling constraints in neuroscience.

Future Research

In addition to my work in detailing the interactions between feedforward and feedback processes in goal-directed movements, I intend to employ a series of paradigms that provide a means by which to further investigate the features of implicit and explicit motor adaptation and control. In particular, the use of pre-movement reporting and error-clamp paradigms, as well as multi-factorial state-space models will provide the means by which to characterize the confluence of these motor processes in the unique context of sensory uncertainty. Results from these experiments have the capacity to bridge the gap between neurophysiological, behavioral, and theoretical models of motor control and will inform fundamental models of sensorimotor control such as Bayesian integration and predictive processing. I have also designed novel training protocols that employ visuomotor adaptation paradigms to train novice motor learning in a variety of tasks associated with surgical skills. By employing these paradigms that are uniquely designed to emulate the perturbation dynamics experienced in minimally invasive surgical procedures we will be able to track the learning and retention rates of motor learners trained on these protocols and compare them to standard surgical training protocols employed by the industry standard (FLS) protocols.

Publications

[1] Hewitson, C. L., Whiting, M. J., Barbara, J., & Mangoni, A. A. (2007). Acute effects of haemodialysis on biochemical modulators of endothelial function [Publisher: Wiley Online Library]. *Journal of internal medicine*, *262*(5), 571–580.

[2] Mangoni, A. A., Hewitson, C. L., Woodman, R. J., Whiting, M. J., McAteer-Carr, B., & Barbara, J. A. (2008). Symmetric dimethylarginine is an independent predictor of intradialytic hypotension [Publisher: Oxford University Press]. *American journal of hypertension*, *21*(8), 955–959.

[3] Paul, B., Hewitson, C. L., Woodman, R. J., & Mangoni, A. A. (2009). Analysis of short-term reproducibility of arterial vasoreactivity by pulse-wave analysis after pharmacological challenge [Publisher: Wiley Online Library]. *Clinical and Experimental Pharmacology and Physiology*, *36*(1), 49–54.

[4] Bouteldja, N., Woodman, R., Hewitson, C. L., Domingo, E., Barbara, J., & Mangoni, A. (2012). P86Methylated arginines and nitric oxide in end-stage renal disease: Relationship with inflammatory and oxidative status. *Cardiovascular Research*, *93*(supplementary 1).

[5] Bouteldja, N., Woodman, R. J., Hewitson, C. L., Domingo, E., Barbara, J. A., & Mangoni, A. A. (2013). Methylated arginines and nitric oxide in end-stage renal disease: Impact of inflammation, oxidative stress and haemodialysis [Publisher: Taylor & Francis]. *Biomarkers*, *18*(4), 357–364.

[6] Hewitson, C. L., Kaplan, D. M., & Sutton, J. (2018). Yesterday the earwig, today man, tomorrow the earwig? *Comparative Cognition & Behavior Reviews*, *13*.

[7] Hewitson, C. L., Sowman, P. F., & Kaplan, D. M. (2018). Interlimb Generalization of Learned Bayesian Visuomotor Prior Occurs in Extrinsic Coordinates [Publisher: Society for Neuroscience]. *Eneuro*, *5*(4).

[8] Hewitson, C. L., Crossley, M. J., & Kaplan, D. M. (2020). Enhanced visuomotor learning and generalization in expert surgeons [Publisher: Elsevier]. *Human Movement Science*, *71*, 102621.

[9] Kaplan, D. M., & Hewitson, C. L. (2021). Modelling Bayesian computation in the brain: Unification, explanation, and constraints. *Neural Mechanisms* (pp. 11–33). Springer.

[10] Crossley, M. J., Hewitson, C. L., Cartmill, J., & Kaplan, D. M. (2021). Motor adaptation: An underappreciated aspect of technical surgical skill [Publisher: Wiley Online Library]. *ANZ Journal of Surgery*, *91*(4), 489–490.

[11] Hewitson, C. L., Crossley, M. J., & Kaplan, D. M. (2021). Effects of visuomotor perturbations on motor performance in minimally invasive surgery: A theoretically-oriented review [Publisher: Lippincott Williams and Wilkins]. *Annals of Surgery*.

[12] Gillett, A., Whyte, C., Hewitson, C. L., & Kaplan, D. M. (2021). Defending the viability of the mutual manipulability criterion in the extended cognition debate:: A reply to Baumgartner et al. [Publisher: Routledge, Taylor and Francis Group]. *Philosophical Psychology*.

[13] Hewitson, C. L., Shukur, S. T., Cartmill, J., Crossley, M., & Kaplan, D. M. (2021). Camera counter-rotation imposes a cost on laparoscopic performance [Publisher: Springer, Springer Nature]. *Scientific Reports*, *11*(17634).

[14] Hewitson, C. L., Kaplan, D. M., & Crossley, M. J. (2021). Feedback integration alters how sensory uncertainty modulates feedforward adaptation. *In review*.

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