THE UNIVERSITY OF
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Collective Workload: Human Performance in Competitive and Collaborative Tasks

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Bachelor of Psychology (Hons I)

Supervised by A Prof. Ami Eidels and Prof. Scott Brown
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for the degree of Doctor of Philosophy in Psychology

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Statements

- *Originality:* I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

- *Authorship:* I hereby certify that the work embodied in this thesis contains published paper/s/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.

- *Collaboration:* I hereby certify that the work embodied in this thesis has been done in collaboration with other researchers or carried out in other institutions. As part of the thesis, I have included a statement clearly outlining the extent of collaboration, with whom and under what auspices.

Signed:

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Date: 14/02/2023

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Acknowledgements

I begin by acknowledging the love, support, patience, and encouragement I have received from my family, friends, colleagues, and supervisors. I would particularly like to thank my amazing wife, Alice, for your courage always to try something different and to open yourself bravely to the unfamiliar. Your example is an inspiration that helps to build the people around you, especially me.

I would also like to thank my family of Bennetts and Buddens for their love and encouragement that began a long time before this Thesis did and will last much longer! I also thank the Scotts, the Browns, and the Mossels for providing a second home for Alice and me in your families. This academic endeavour is shared between us, and so are its accomplishments. As Alice and I move off into the next stage in our lives together, we look forward to returning to our homes at Lexington Park, Woodside Chase, or all across Newcastle to share our adventures with you.

To my friends and colleagues over the years, I thank you for the endless coffee walks and for providing a refreshing space away from the long hours of the lab. In particular, Max Katz-Barber, Nathan Tran, Joel Wolfgram, Laiton Hedley, and everyone in the Newcastle Cognition Lab! I would also like to single out Paul Garrett – your enthusiasm for science, curiosity, and interest in all things set a fine example in my early days as a researcher. Your approach to science and the people around you has left a lifelong impression that I regularly return to for inspiration.

Finally, I wish to acknowledge and thank both of my incredibly helpful, patient, and knowledgeable supervisors, Ami Eidels and Scott Brown. Your guidance and mentorship through my candidature were particularly useful for climbing this hill and an incredible template for how we can all aim to help encourage and support the people around us. The cognition lab that you built at Newcastle was an amazing space to grow and learn when I was there.

List of Publications

The work within this thesis has led to the following journal articles that are either currently published, submitted, or in preparation, which I have listed with the full bibliographic citations in the order in which they appear in the Thesis.

In order of reference:

1. **Bennett, M. S.**, Mullard, R., Adam, M. T., Steyvers, M., Brown, S., & Eidels, A. (2020). Going, going, gone: competitive decision-making in Dutch auctions. *Cognitive Research: Principles and Implications*, 5(1), 1-22.

2. **Bennett, M. S.**, Hedley, L., Love, J., Houpt, J. W., Brown, S. D. & Eidels, A. (2022; Under review). Human Performance in Competitive and Collaborative Human-Machine Teams. *Topics in Cognitive Science.*

3. Hedley, L., **Bennett, M. S.**, Love, J., Houpt, J. W., Brown, S. D. & Eidels, A. (2023; Under review). The Relationship Between Teaming Behaviours and Joint Capacity of Hybrid Human-Machine Teams. *Cognitive Science*

Additional Work

Listed are additional publications and presentations in which I have been involved during my candidature but are not included in this Thesis, or represent earlier iterations of included work.

1. Gronau, Q. F., **Bennett, M. S.**, Brown, S. D., Hawkins, G., & Eidels, A. (Under review) A Comparison of Discrete Choice and Rating Scale Experiments for Eliciting Preference Judgments. *Journal of Choice Modelling*.

2. John, A. R., Singh, A. K., Do, T. T. N., Eidels, A., Nalivaiko, E., Gavgani, A. M., Brown, S. D., **Bennett, M. S.**, Lal, S., Simpson, A. M., Gustin, S. M., Double, K., Walker, F. R., Kleitman, S., Morley, J., & Lin, C. T. (2022). Unravelling the Physiological Correlates of Mental Workload Variations in Tracking and Collision Prediction Tasks. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 30, 770-781.

3. Gavgani, A. M., **Bennett, M. S.**, Eidels, A., Brown, S. D., Whelan, T., Baxter-Menzies, E., Walker, F. R., John, A. R., Singh, A. K., Do, T. T. N, Lal, S., Simpson, A. M., Gustin, S. M., Double, K., Kleitman, S., Morley, J., Lin, C. T., & Nalivaiko E. (In preparation). An Investigation into the Potential of Cardiovascular Parameters to Index Cognitive Load.

4. Garrett, P. M., **Bennett, M. S.**, Hsieh, Y. T., Howard, Z. L., Yang, C. T., Little, D. R., & Eidels, A. (2022). Wheel of fortune: A cross-cultural examination of how expertise shapes the mental representations of familiar and unfamiliar numerals. *Computational Brain & Behavior*, 5(1), 45-59.

Statement of Contribution

Below I have included a statement outlining my contribution, and the involvement of others, in each chapter where the research performed involved collaboration. This addresses the requirements of the *statement of Collaboration* and *Statement of Authorship*. My primary supervisor, Ami Eidels, has endorsed the below statement.

Chapter Contributions

- *Chapter 2*: My contribution to the work included in this Chapter involved programming the experiment, collecting data, and performing and interpreting the analyses. Others involved in this work include Jonathon Love, who aided with programming the experiment, Rachel Mullard, who aided with data collection; Marc Adam, who helped develop the research design, Mark Steyvers, who provided expertise on group performance research; and Ami Eidels and Scott Brown who supervised the project.

- *Chapter 3*: My contribution to the work included in this Chapter involved developing the model, computational simulations and data analyses, and interpreting all included analyses. Others involved in this work included Scott Brown, who helped develop the model and provided expertise on computational models and project supervision, and Ami Eidels, who provided project supervision.

- *Chapter 4*: My contribution to the work included in this Chapter involved designing the research, programming the experiment, collecting data, performing the included analyses, and interpreting all included analyses. Others included in this work were Rebecca Wise, who helped with pilot data collection; Callum McGoldrick and Laiton Hedley, who aided with pilot data collection and preliminary data analysis, Jonathon Love, who assisted with the online deployment of the experiment; and Ami Eidels, who aided in project supervision and provided expertise on the application of systems factorial technology.

- *Chapter 5*: My contribution to the work included in this Chapter involved developing and conducting the analysis included in this Chapter and interpreting

all included analyses. Others involved in this work included Laiton Hedley, who aided in the data collection and analysis of the final publication material, and Ami Eidels and Scott Brown, who provided project supervision.

By signing below, I, Ami Eidels, confirm that Murray Bennett led or made major contributions to the papers and publications "Publications" section above. These contributions include experimental design and programming, coordination and collection of data, data analysis, computational simulation and design of models, and manuscript preparation. Murray also served as a lead author on two manuscripts and co-author on a third manuscript.

Signature of Supervisor:

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Date: 14/02/2023

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Abstract

Individuals combine to form groups in many domains to improve safety and quality, increase production, or reduce errors. The distinct benefit of group performance occurs through the additional resources provided by group members and the ability to divide labour amongst the group. However, completing tasks as a group requires additional work to allow the group to function, such as communication, predicting the needs of, or providing assistance to, group members. The trade-off between additional resources and teamwork can make evaluating group performance difficult, particularly in dynamic tasks. Furthermore, different group conditions, such as competition or collaboration, require different intra-group processes that may differentially affect group performance. The primary aim of this Thesis is to examine how competitive and collaborative group conditions affect task and cognitive performance in dynamic tasks.

I address this aim by developing a series of novel group performance platforms and adapting quantitative and cognitive process models to examine the cognitive processes and behavioural strategies used within these dynamic group conditions. I design a competitive group performance platform using a "Dutch auction" task to examine the effects of competition on group performance. I present an iterative adaptation of Prospect theory to account for the behavioural trends observed within the competitive Dutch auction context. I then examine performance in competitive and collaborative groups using a dynamic multiplayer task "Team Spirit". I quantify and characterise efficient team performance on this task using workload capacity analysis. Finally, I adapt and implement a series of advanced behavioural pattern analyses to identify group strategies and their relationship with performance within these group conditions. This thesis presents novel methods, experimental platforms, and analysis techniques that provide new insight on the examination and measurement of group performance.