



Face Perception and Cognition Using Motor Representations A Computational Approach

by Jonathan Vitale



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University of Technology Sydney
Faculty of Engineering and Information Technology

This dissertation is submitted for the degree of
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Certificate of Original Authorship

I, Jonathan Vitale declare that this thesis, submitted in fulfilment of the requirements for the award of a Doctor of Philosophy degree, in the Faculty of Engineering and Information Technology (School of Software) at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Jonathan Vitale

Date: 24/01/2018

I want to dedicate this dissertation to all the people who gave me the opportunity and the necessary motivation to achieve my desired goals, in particular to my parents, my relatives and my close friends.

I also want to make a special dedication to my beloved Niki, who suddenly passed away while I was completing my doctoral degree in Australia, thus breaking my heart for not being able to give her a last goodbye in Italy. Niki, you have been a good companion and an emotional lifesaver during most of my adulthood.

Acknowledgments

I started my PhD research with the ambitious objective of modelling mind-reading capabilities in machines. Obviously, the limited time available to complete my research required me to focus on a particular aspect of social cognition and to narrow down the research to investigate a limited set of research gaps identified in literature. Thus, in this dissertation, I focused the attention on face-to-face social interactions and I explored how face processing capabilities can be explained by embodied mechanisms lying at the core of a mind-reading process. This led to findings advancing both face processing and embodied cognition research.

At the end of this PhD program I still find myself passionate and highly interested in solving one of the most challenges mysteries of human mind, namely how we understand others. However, now I have a better understanding of what is my research community and what is the methodology suitable for my research. I will never neglect my original computer science background, but this PhD program helped me to acquire more confidence as a cognitive science researcher. Computer science remains my preferred methodology to assess the advanced hypotheses the reader will find in this dissertation. Furthermore, having being part of a social robotics lab offered nice opportunities to test models of cognition on robots and it provided a duplex benefit: on the one hand it is possible to enrich cognitive research community with new insights on how human social cognition might work, on the other hand it is possible to contribute the society with a novel disruptive technology like social robots. My hope is that the reader will enjoy this dissertation as I enjoyed my journey through this research program. I wish that findings and discussions pro-

vided by this dissertation can help the reader to draw inspiration for innovative theories on human cognition, thus contributing to explain what makes us humans.

This work was not possible without the people who believed in me and gave me the opportunity to join this doctoral research degree. I came in Australia after my Master degree for a one year experience to challenge myself by learning how to live independently in a foreign country. Like most of the young people coming to Australia, I found a job in the kitchen of a busy restaurant few weeks after I landed. As a sign of fate, one morning I found the advertisement of a research scholarship for a PhD program fitting my profile. I applied knowing it would have been a competitive process and the chances to get accepted would have been low. However, after few weeks, I received the good news from Prof. Mary-Anne Williams and Dr Benjamin Johnston: I was going to stay in Australia for at least other four years. Prof. Mary-Anne Williams likes to say she ‘rescued’ me from that kitchen, and, although I do not regret that experience, I am glad she ‘rescued’ me! Therefore, special thanks go to these two great supervisors, but also to the rest of the lab who supported my ideas and contributed to my research outcomes.

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Author's Research Contributions

Herse, S., Vitale, J., Ebrahimian, D., Tonkin, M., Ojha, S., Sidra, S., Johnston, B., Phillips, S., Gudi, C., Clark, J., Judge, W., and Williams, M.-A. (2018). Bon appetit! robot persuasion for food recommendation. In *Proceedings of 2018 ACM/IEEE International Conference on Human-Robot Interaction, Chicago, IL, USA, March 5-8, 2018 (HRI '18)*. ACM.

Novianto, R. and Vitale, J. (2014). (Eds) Proceedings of the 1st workshop on attention for social intelligence. 6th International Conference of Social Robotics (ICSR '14).

Ojha, S., Vitale, J., and Williams, M.-A. (2017). A domain-independent approach of cognitive appraisal augmented by higher cognitive layer of ethical reasoning. In *39th Annual Meeting of the Cognitive Science Society*, pages 2833–2838.

Tonkin, M., Vitale, J., Herse, S., Williams, M.-A., Judge, W., and Wang, X. (2018). Design methodology for the ux of hri: A field study of a commercial social robot at an airport. In *Proceedings of 2018 ACM/IEEE International Conference on Human-Robot Interaction, Chicago, IL, USA, March 5-8, 2018 (HRI '18)*. ACM.

Tonkin, M., Vitale, J., Ojha, S., Clark, J., Pfeiffer, S., Judge, W., Wang, X., and Williams, M.-A. (2017a). Embodiment, privacy and social robots: May i remember you? In *Proceedings of the 9th International Conference on Social Robotics (ICSR '17), Tsukuba, Japan, November 22-24, 2017*, pages 506–515, Cham. Springer International Publishing.

Tonkin, M., Vitale, J., Ojha, S., Williams, M.-A., Fuller, P., and Judge, W. (2017b). Would you like to sample? Robot engagement in a shopping centre. In *The 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN '17)*.

Vitale, J. (2014). Attention for the development of empathic bonds: From facial expressions to interoception. In *1st Workshop on Attention for Social Intelligence*. Oral presentation.

- Vitale, J. (2016). Towards embodied face processing theories: a computational view. In *International School of Human-Centred Computing Bremen*. Doctoral colloquium presentation.
- Vitale, J., Tonkin, M., Herse, S., Ojha, S., Clark, J., Williams, M.-A., Wang, X., and Judge, W. (2018). Be more transparent and users will like you: A robot privacy and user experience design experiment. In *Proceedings of 2018 ACM/IEEE International Conference on Human-Robot Interaction, Chicago, IL, USA, March 5-8, 2018 (HRI '18)*. ACM.
- Vitale, J., Tonkin, M., Wang, X., Ohja, S., Williams, M.-A., and Judge, W. (2017a). Privacy by design in machine learning data collection: A user experience experimentation. In *Symposium on Designing the User Experience of Machine Learning Systems*. AAAI Spring Symposia 2017.
- Vitale, J., Williams, M.-A., and Johnston, B. (2014a). Socially impaired robots: Human social disorders and robots' socio-emotional intelligence. In *6th International Conference on Social Robotics (ICSR '14)*, pages 350–359.
- Vitale, J., Williams, M.-A., Johnston, B., and Boccignone, G. (2014b). Affective facial expression processing via simulation: A probabilistic model. *Biologically Inspired Cognitive Architectures*, 10:30–41.
- Vitale, J., Williams, M.-A., and Johnston, B. (2016). The face-space duality hypothesis: A computational model. In *38th Annual Meeting of the Cognitive Science Society*, pages 514–519.
- Vitale, J., Williams, M.-A., and Johnston, B. (2017b). Facial motor information is sufficient for identity recognition. In *39th Annual Meeting of the Cognitive Science Society*, pages 3447–3452.
- Wang, X., Williams, M.-A., Gardenfors, P., Vitale, J., Abidi, S., Johnston, B., Kuipers, B., and Huang, A. (2014). Directing human attention with pointing. In *The 23rd IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN '14)*, pages 174–179.

Williams, M.-A., Johnston, B., Vitale, J., Tonkin, M., Judge, W., and Pandey, A. K. (2017). (Eds) Proceedings of the 1st workshop on human-robot engagement. 26th International Joint Conference on Artificial Intelligence.

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Abstract

Face perception and cognition skills are critically needed by humans to be proficient in social cognition. Social cognition is defined as the ability to make sense of others' actions and react appropriately to them. For example, determining the identity of an interaction partner is an essential precondition to engaging socially with people. In addition, recognising facial expressions contributes to regulating human social exchanges. In fact, it assists in determining the mental state of the interaction partner and selecting the best subsequent behavioural response.

Humans show a preference for faces at a very early stage. This preference is maintained throughout their lives and it contributes to the acquisition of face recognition skills, which develop with time and experience. However, newborns have the ability to process face stimuli and imitate observed facial expressions from birth. This early imitation behaviour is a plausible way to collect sensory-motor information about the configuration of observed facial muscles. If recognising people is acquired by encountering new faces, how do humans acquire such a skill? Are there any interactions between face recognition and facial motor information processing? If so, how do these mechanisms possibly interact?

I provide answers to these research questions by looking at theories of embodied cognition. Embodied cognition research suggests that cognition extends beyond the brain to include body parts. I argue that mechanisms interacting with physical or mental aspects of the body provide sensory-motor information of the observed facial stimuli. This motor information, in turn, is sufficient for the acquisition of face identity recognition capabilities. I validate this thesis by providing mathematical models

and computational simulations describing face perception and cognition. Furthermore, I show that altering the motor representations of facial configurations leads to significant deficits in face processing capabilities. The computationally simulated dysfunctions resemble the impairments observed in clinical populations affected by social disorders, namely autism, schizophrenia and psychopathy. Hence, I argue that the bodily processes modelled in this dissertation not only have causal relationships to social cognition, but they profoundly shape it. This work is a contribution to a better computational understanding of face perception and cognition and it provides initial evidence supporting embodied social cognition theories.