Learning from the brain

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Learning from the brain

Best practices for the use of neuroimaging data in psychology research

Academisch Proefschrift

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door

Lukas Snoek

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Awesome thesis title

Some funky subtitle of my fancy thesis

Lukas Snoek

Contents

Chapter 1

Introduction

The first chapter of the thesis, which introduces your PhD project. The filler-text below was created with the postmodernism generator[1].

Something about the coming about of this thesis. More of a "lessons learned" rather than a coherent research topic.

1.1 The brain is not a dictionary

Something about looking at populations of neurons/voxels/areas rather than simple one-to-one relationships. Shared states.

1.2 The brain (probably) does not care about your hypothesis

Facial expression models.

[1]http://www.elsewhere.org/journal/pomo

1.3 Interpretability and prediction are a trade-off (for now)

A plea for prediction but a cautionary tale for interpreting predictive models (confounds)

1.4 Exploration should be embraced more

Something about the "context of discovery" (cf. TCM), preregistration, and confirmation vs. exploration (Morbid curiosity.)

1.5 Proper generalization is hard

Within and between subject variance is not noise, but unexplained variance (AU limitations).

1.6 Psychology is complex, so it needs complex models

Which need to be fit on complex, large datasets. (AOMIC)

Chapter 2

Shared states: using MVPA to test neural overlap between self-focused emotion imagery and other-focused emotion understanding

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* Shared first authorship

Abstract

The present study tested whether the neural patterns that support imagining "performing an action", "feeling a bodily sensation" or "being in a situation" are directly involved in understanding *other people's* actions, bodily sensations and situations. Subjects imagined the content of short sentences describing emotional actions, interoceptive sensations and situations (self-focused task), and processed scenes and focused on *how* the target person was expressing an emotion, *what* this person was feeling, and *why* this person was feeling an emotion (other-focused task). Using a linear support vector machine classifier on brain-wide multi-voxel patterns, we accurately decoded each individual class in the self-focused task. When generalizing the classifier from the self-focused task to the other-focused task, we also accurately decoded whether subjects focused on the emotional actions, interoceptive sensations and situations of *others*. These results show that the neural patterns that underlie self-imagined experience are involved in understanding the experience of other people. This supports the theoretical assumption that the basic components of emotion experience and understanding share resources in the brain.

2.1 Introduction

To navigate the social world successfully it is crucial to understand other people. But how do people generate meaningful representations of other people's actions, sensations, thoughts and emotions? The dominant view assumes that representations of other people's experiences are supported by the same neural systems as those that are involved in generating experience in the self (e.g., Gallese et al., 2004; see for an overview Singer, 2012). We tested this principle of self-other neural overlap directly, using multi-voxel pattern analysis (MVPA), across three different aspects of experience that are central to emotions: actions, sensations from the body and situational knowledge.

In recent years, evidence has accumulated that suggests a similarity between the neural patterns representing the self and others. For example, a great variety of studies have shown that observing actions and sensations in other people engages similar neural circuits as acting and feeling in the self (see for an overview Bastiaansen et al., 2009). Moreover, an extensive research program on pain has demonstrated an overlap between the experience of physical pain and the observation of pain in other people, utilizing both neuroimaging techniques (e.g., Lamm et al., 2011) and analgesic interventions (e.g., Rütgen et al., 2015; Mischkowski et al., 2016). This process of "vicarious experience" or "simulation" is viewed as an important component of empathy (Carr et al., 2003; Decety, 2011; Keysers & Gazzola, 2014). In addition, it is argued that mentalizing (e.g. understanding the mental states of other people) involves the same brain networks as those involved in self-generated thoughts (Uddin et al., 2007; Waytz & Mitchell, 2011). Specifying this idea further, a constructionist view on emotion proposes that both emotion experience and interpersonal emotion understanding are produced by the same large-scale distributed brain networks that support the processing of sensorimotor, interoceptive and situationally relevant information (Barrett & Satpute, 2013; Oosterwijk & Barrett, 2014). An implication of these views is that the representation of self- and other-focused emotional actions, interoceptive sensations and situations overlap in the brain.

Although there is experimental and theoretical support for the idea of self-other neural overlap, the present study is the first to directly test this process using MVPA across three different aspects of experience (i.e. actions, interoceptive sensations and situational knowledge). Our experimental design consisted of two different tasks aimed at generating self- and other-focused representations with a relatively large weight given to either action information, interoceptive information or situational information.

In the *self-focused* emotion imagery task (SF-task) subjects imagined performing or experiencing actions (e.g., *pushing someone away*), interoceptive sensations (e.g., *increased heart rate*) and situations (e.g., *alone in a park at night*) associated with emotion. Previous research has demonstrated that processing linguistic descriptions of (emotional) actions and feeling states can result in neural patterns of activation associated with, respectively, the representation and generation of actions and internal states (Oosterwijk et al., 2015; Pulvermüller & Fadiga, 2010). Furthermore, imagery-based inductions of emotion have been successfully used in the MRI scanner before (Oosterwijk et al., 2012; Wilson-Mendenhall et al., 2011), and are seen as robust inducers of emotional experience (Lench et al., 2011). In the *other-focused* emotion understanding task (OF-task), subjects viewed images of people in emotional situations and focused on actions (i.e., *How* does this person express his/her emotions?), interoceptive sensations (i.e., *What* does this person feel in his/her body) or the situation (i.e., *Why* does this person feel an emotion?). This task is based on previous research studying the neural basis of emotion oriented mentalizing (Spunt & Lieberman, 2012).

With MVPA, we examined to what extent the SF- and OF-task evoked similar neural patterns. MVPA allows researchers to assess whether the neural pattern associated with one set of experimental conditions can be used to distinguish between another set of experimental conditions. This relatively novel technique has been successfully applied to the field of social neuroscience in general (e.g., Gilbert et al., 2012; Brosch et al., 2013; Parkinson et al., 2014), and the field of self-other neural overlap in particular. For example, several MVPA studies recently assessed whether experiencing pain and observing pain in others involved similar neural patterns (Corradi-Dell'Acqua et al., 2016; Krishnan et al., 2016). Although there is an ongoing discussion about the specifics of shared representation in pain based on these MVPA results (see for an overview Zaki et al., 2016), many authors emphasize the importance of this technique in the scientific study of self-other neural overlap (e.g., Corradi-Dell'Acqua et al., 2016; Krishnan et al., 2016).

MVPA is an analysis technique that decodes latent categories from fMRI data in terms of multi-voxel patterns of activity (Norman et al., 2006). This technique is particularly suited for our research question for several reasons. First of all, although univariate techniques can demonstrate that tasks activate the same brain regions, only MVPA can statistically test for shared representation (Lamm & Majdandžić, 2015). We will evaluate whether multivariate brain patterns that distinguish between mental events in the SF-task can be used to distinguish, above chance level, between mental events in the OF-task. Second, MVPA analyses are particularly useful in research that is aimed at examining distributed representations (Singer, 2012). Based on our constructionist framework, we indeed hypothesize that the neural patterns that will represent self- and other focused mental events are distributed across large-scale brain networks. To capture these distributed patterns, we used MVPA in combination with data-driven univariate feature selection on whole-brain voxel patterns, instead of limiting our analysis to specific regions-of-interest (Haynes, 2015). And third, in contrast to univariate analyses that aggregate data across subjects, MVPA can be performed within-subjects and is thus able to incorporate individual variation in the representational content of multivariate brain patterns. In that aspect within-subject MVPA is sensitive to individual differences in how people imagine actions, sensations and situations, and how they understand others. In short, for our purpose to explicitly test the assumption that self and other focused processes share neural resources, MVPA is the designated method.

We tested the following two hypotheses. First, we tested whether we could classify *self-imagined* actions, interoceptive sensations and situations above chance level. Second, we tested whether the multivariate pattern underlying this classification could also be used to classify the how, what and why condition in the *other-focused* task.

2.2 Methods

Subjects

In total, we tested 22 Dutch undergraduate students from the University of Amsterdam (14 females; M_{age} = 21.48, $s.d._{age}$ = 1.75). Of those 22 subjects, 13 subjects were tested twice in 2 sessions about 1 week apart. Half of those sessions were used for the model optimization procedure. The other half of the sessions, combined with an additional nine subjects (who were tested only once), constituted the model validation set (see Model optimization procedure section). In total, two subjects were excluded from the model validation dataset: one subject was excluded because there was not enough time to complete the experimental protocol and another subject was excluded due to excessive movement (>3 mm within data acquisition runs).

All subjects signed informed consent prior to the experiment. The experiment was approved by the University of Amsterdam's ethical review board. Subjects received 22.50 euro per session. Standard exclusion criteria regarding MRI safety were applied and people who were on psychopharmacological medication were excluded a priori.

Experimental design

Self-focused emotion imagery task

The self-focused emotion imagery task (SF-task) was created to preferentially elicit *self-focused* processing of action, interoceptive or situational information associated with emotion. Subjects processed short linguistic cues that described actions (e.g., *pushing someone away*; *making a fist*), interoceptive sensations (e.g., *being out of breath*; *an increased heart rate*), or situations (e.g., *alone in a park at night*; *being falsely accused*) and were instructed to imagine performing or experiencing the content. The complete instruction is presented in the Supplementary Materials; all stimuli used in the SF-task are presented in Supplementary Table S1. Linguistic cues were selected from a pilot study performed on an independent sample of subjects (n = 24). Details about this pilot study are available on request. The descriptions generated in this pilot study were used as qualitative input to create short sentences that described actions, sensations or situations that were associated with negative emotions, without including discrete emotion terms. The cues did not differ in number of words, nor in number of characters ($F < 1$).

Chapter 3

How to control for confounds in decoding analyses of neuroimaging data

Chapter 4

The Amsterdam Open MRI Collection, a set of multimodal MRI datasets for individual difference analyses

CHAPTER 5

Choosing to view morbid information involves reward circuitry

Chapter 6

Using predictive modeling to quantify the importance and limitations of action units in emotion perception

Chapter 7

Comparing models of dynamic facial expression perception

Chapter 8

Summary and general discussion

My view on going forward.

8.1 Explore!

Theories are like toothbrushes, no one likes to use someone else's.

8.2 Think *big*

Big, complex datasets to train big, complex models.

8.3 Rethink psychology education

Embrace and teach interdisciplinary.

Appendices

Appendix A

Supplement to Chapter 2

A.1 Stimuli used for SF-task

Table A.1 Stimuli used for SF-task

Class	Dutch	English translation
	Hard wegrennen	Running away fast
	Iemand wegduwen	Pushing someone away
	Iemand stevig vastpakken	Holding someone tightly
	Je hoofd schudden	Shaking your head
	Heftige armgebaren maken	Making big arm gestures
	Ergens voor terugdeinzen	Recoiling from something
	Je ogen dichtknijpen	Closing your eyes tightly
	Je ogen wijd open sperren	Opening your eyes widely
	Je wenkbrauwen fronsen	Frowning with your eyebrows
	Je schouders ophalen	Raising your shoulders
	Op de vloer stampen	Stamping on the floor

Table A.1 Stimuli used for SF-task *(continued)*

Class	Dutch	English translation
Action	In elkaar duiken	Cowering
	Je schouders laten hangen	Slumping your shoulders
	Je vuisten ballen	Tighten your fists
	Je borst vooruit duwen	Push your chest forward
	Je tanden op elkaar zetten	Clench your teeth
	Je hand voor je mond slaan	Put your hand in front of your mouth
	Onrustig bewegen	Moving restlessly
	Heen en weer lopen	Walking back and forth
	Je hoofd afkeren	Turning your head away
	Een brok in je keel	A lump in your throat
	Buiten adem zijn	Being out of breath
	Een versnelde hartslag	A fast beating heart
	Je hart klopt in de keel	You heart is beating in your throat
	Een benauwd gevoel	An oppressed feeling
	Een misselijk gevoel	Being nauseous
	Druk op je borst	A pressure on your chest
	Strak aangespannen spieren	Tense muscles
	Een droge keel	A dry throat

TABLE A.1 Stimuli used for SF-task *(continued)*

Class	Dutch	English translation
Interoception	Koude rillingen hebben	Cold shivers
	Bloed stroomt naar je hoofd	Blood is going to your head
	Een verdoofd gevoel	A numb feeling
	Je hebt tintelende ledenmaten	Tingling limbs
	Een verlaagde hartslag	A slow heartbeat
	Je hebt zware ledematen	Heavy limbs
	Een versnelde ademhaling	Fast breathing
	Je hebt hoofdpijn	Headache
	Je hebt buikpijn	Stomachache
	Zweet staat in je handen	Sweaty palms
	Je maag keert zich om	Your stomach churns
	Vals beschuldigd worden	Being falsely accused
	Dierbare overlijdt	A loved one dies
	Vlees is bedorven	Meat that has gone off
	Je wordt bijna aangereden	You are almost hit by a car
	Iemand naast je braakt	Someone next to you vomits
	Huis staat in brand	House is on fire
	Zonder reden ontslagen worden	Being fired for no reason

Table A.1 Stimuli used for SF-task *(continued)*

Class	Dutch	English translation
Situation	Een ongemakkelijke stilte	An uncomfortable silence
	Alleen in donker park	Alone in a dark park
	Inbraak in je huis	A house burglary
	Een gewond dier zien	Seeing a wounded animal
	Tentamen verknallen	Messing up your exam
	Je partner bedriegt je	You partner cheats on you
	Dierbare is vermist	A loved one is missing
	Belangrijke sollicitatie vergeten	Forgot a job interview
	Onvoorbereid presentatie geven	Giving a presentation unprepared
	Je baas beledigt je	Your boss offends you
	Goede vriend negeert je	A good friend neglects you
	Slecht nieuws bij arts	Bad news at the doctor
	Bommelding in metro	A bomb alarm in the metro

Note: The stimulus materials presented in Table S1 were selected from a pilot study. In this pilot study we asked an independent sample of twenty-four subjects to describe how they would express an emotion in their behavior, body posture or facial expression (action information), what specific sensations they would feel inside their body when they would experience an emotion (interoceptive information), and for what reason or in what situation they would experience an emotion (situational information). These three questions were asked in random order for twenty-eight different negative emotional states, including anger, fear, disgust, sadness, contempt, worry, disappointment, regret and shame. The descriptions generated by these subjects were used as qualitative input in order to create our stimulus set of twenty short sentences that described emotional actions, sensations or situations. With this procedure, we ensured that our stimulus set held sentences that were validated and ecologically appropriate for our sample.

Appendix B

Supplement to Chapter 3

Appendix C

Supplement to Chapter 5

Appendix D

Supplement to Chapter 6

Appendix E

Supplement to Chapter 7

Appendix F

Data, code and materials

Bibliography

Contributions to the chapters

List of other publications

Alilović, J., Timmermans, B., **Reteig, L. C.**, van Gaal, S., & Slagter, H. A. (2019). No evidence that predictions and attention modulate the first feedforward sweep of cortical information processing. *Cerebral Cortex, 29* 2261–2278. https://doi.org/10.1093/cercor/bhz038

van Schouwenburg, M. R., Sörensen, L. K. A., de Klerk, R., **Reteig, L. C.**, & Slagter, H. A. (2018). No differential effects of two different alpha-band electrical stimulation protocols over fronto-parietal regions on spatial attention. *Frontiers in Neuroscience* 12:433. https://doi.org/10.3389/fnins.2018.00433

Slagter, H. A., Mazaheri, A., **Reteig, L. C.**, Smolders, R., Figee, M., Mantione, M., … Denys, D. (2017). Contributions of the Ventral Striatum to Conscious Perception: An Intracranial EEG Study of the Attentional Blink. *Journal of Neuroscience, 37*, 1081–1089. https://doi.org/10.1523/jneurosci.2282-16.2016

Slagter, H. A., Prinssen, S., **Reteig, L. C.**, & Mazaheri, A. (2016). Facilitation and inhibition in attention: Functional dissociation of prestimulus alpha activity, P1, and N1 components. *NeuroImage, 125*, 25–35. https://doi.org/10.1016/j.neuroimage.2015.09.058

Nederlandse samenvatting (Summary in Dutch)

Replace this with the Dutch title of your thesis

The summary goes here.

Acknowledgments

This section is optional, but theses typically include acknowledgments (*dankwoord* in Dutch) at the end. You may want to mix languages to thank people in their native tongue (though most Dutch speakers write it entirely in Dutch). But the standard language of the thesis template is English. You can switch temporarily by wrapping the text in language tags like so: `[Your Dutch text here]{lang=nl}`. This is important for things like hyphenation to work properly.

Bibliography

Barrett, L. F., & Satpute, A. B. (2013). Large-scale brain networks in affective and social neuroscience: Towards an integrative functional architecture of the brain. *Current opinion in neurobiology*, *23*(3), 361–372.

Bastiaansen, J. A., Thioux, M., & Keysers, C. (2009). Evidence for mirror systems in emotions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1528), 2391–2404.

Brosch, T., Bar-David, E., & Phelps, E. A. (2013). Implicit race bias decreases the similarity of neural representations of black and white faces. *Psychological science*, *24*(2), 160–166.

Carr, L., Iacoboni, M., Dubeau, M.-C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the national Academy of Sciences*, *100*(9), 5497–5502.

Corradi-Dell'Acqua, C., Tusche, A., Vuilleumier, P., & Singer, T. (2016). Cross-modal representations of first-hand and vicarious pain, disgust and fairness in insular and cingulate cortex. *Nature communications*, *7*(1), 1–12.

Decety, J. (2011). Dissecting the neural mechanisms mediating empathy. *Emotion review*, *3*(1), 92–108.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in cognitive sciences*, *8*(9), 396–403.

Gilbert, S. J., Swencionis, J. K., & Amodio, D. M. (2012). Evaluative vs. trait representation in intergroup social judgments: Distinct roles of anterior temporal lobe and prefrontal cortex. *Neuropsychologia*, *50*(14), 3600–3611.

Haynes, J.-D. (2015). A primer on pattern-based approaches to fmri: Principles, pitfalls, and perspectives. *Neuron*, *87*(2), 257–270.

Keysers, C., & Gazzola, V. (2014). Dissociating the ability and propensity for empathy. *Trends in cognitive sciences*, *18*(4), 163–166.

Krishnan, A., Woo, C.-W., Chang, L. J., Ruzic, L., Gu, X., López-Solà, M., Jackson, P. L., Pujol, J., Fan, J., & Wager, T. D. (2016). Somatic and vicarious pain are represented by dissociable multivariate brain patterns. *Elife*, *5*, e15166.

Lamm, C., Decety, J., & Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage*, *54*(3), 2492–2502.

Lamm, C., & Majdandžić, J. (2015). The role of shared neural activations, mirror neurons, and morality in empathy–a critical comment. *Neuroscience Research*, *90*, 15–24.

Lench, H. C., Flores, S. A., & Bench, S. W. (2011). Discrete emotions predict changes in cognition, judgment, experience, behavior, and physiology: A meta-analysis of experimental emotion elicitations. *Psychological bulletin*, *137*(5), 834.

Mischkowski, D., Crocker, J., & Way, B. M. (2016). From painkiller to empathy killer: Acetaminophen (paracetamol) reduces empathy for pain. *Social cognitive and affective neuroscience*, *11*(9), 1345–1353.

Norman, K. A., Polyn, S. M., Detre, G. J., & Haxby, J. V. (2006). Beyond mind-reading: Multi-voxel pattern analysis of fmri data. *Trends in cognitive sciences*, *10*(9), 424–430.

Oosterwijk, S., & Barrett, L. F. (2014). Embodiment in the construction of emotion experience and emotion understanding. *Routledge handbook of embodied cognition. New York: Routledge*, 250–260.

Oosterwijk, S., Lindquist, K. A., Anderson, E., Dautoff, R., Moriguchi, Y., & Barrett, L. F. (2012). States of mind: Emotions, body feelings, and thoughts share distributed neural networks. *NeuroImage*, *62*(3), 2110–2128.

Oosterwijk, S., Mackey, S., Wilson-Mendenhall, C., Winkielman, P., & Paulus, M. P. (2015). Concepts in context: Processing mental state concepts with internal or external focus involves different neural systems. *Social neuroscience*, *10*(3), 294–307.

Parkinson, C., Liu, S., & Wheatley, T. (2014). A common cortical metric for spatial, temporal, and social distance. *Journal of Neuroscience*, *34*(5), 1979–1987.

Pulvermüller, F., & Fadiga, L. (2010). Active perception: Sensorimotor circuits as a cortical basis for language. *Nature reviews neuroscience*, *11*(5), 351–360.

Rütgen, M., Seidel, E.-M., Silani, G., Riečansky, I., Hummer, A., Windischberger, C., Petrovic, P., & Lamm, C. (2015). Placebo analgesia and its opioidergic regulation suggest that empathy for pain is grounded in self pain. *Proceedings of the National Academy of Sciences*, *112*(41), E5638–E5646.

Singer, T. (2012). The past, present and future of social neuroscience: A european perspective. *Neuroimage*, *61*(2), 437–449.

Spunt, R. P., & Lieberman, M. D. (2012). An integrative model of the neural systems supporting the comprehension of observed emotional behavior. *Neuroimage*, *59*(3), 3050–3059.

Uddin, L. Q., Iacoboni, M., Lange, C., & Keenan, J. P. (2007). The self and social cognition: The role of cortical midline structures and mirror neurons. *Trends in cognitive sciences*, *11*(4), 153–157.

Waytz, A., & Mitchell, J. P. (2011). Two mechanisms for simulating other minds: Dissociations between mirroring and self-projection. *Current Directions in Psychological Science*, *20*(3), 197–200.

Wilson-Mendenhall, C. D., Barrett, L. F., Simmons, W. K., & Barsalou, L. W. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia*, *49*(5), 1105–1127.

Zaki, J., Wager, T. D., Singer, T., Keysers, C., & Gazzola, V. (2016). The anatomy of suffering: Understanding the relationship between nociceptive and empathic pain. *Trends in cognitive sciences*, *20*(4), 249–259.