Précis of *Observing and influencing preferences in real time: Gaze, morality and dynamic decision-making*

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> Imagine walking down a street with a friend, casually chatting as you make your way towards a movie theatre. Just outside the theatre you are stopped by a homeless person asking for spare change. While stopping and considering you look back and forth between the person and your goal, the movie theatre. Suddenly, your friend tugs your arm and hurries you to move on, less you will miss the beginning of the film. At that moment you are forced to make your decision, to give the homeless person change or not. There might be all sorts of reasons going through your head at that moment for doing one thing or the other. Some of these might have influenced your final decision, or, at least, you could argue so. However, could the precise moment when your friend tugged your arm have affected your choice? And, if so, did the direction you were looking at when you were interrupt have any influence?

This dissertation argues that the answer, to both these questions, is 'Yes'. More generally, in this dissertation several investigations into the interactions between social and sensorimotor processes, on the one hand, and preferences and choices, on the other, are presented. The example above was chosen not only because it illustrates the main findings of the flagship paper of this dissertation (Paper V; see below), but also because it captures the main research themes of the dissertation. These themes can be summed up as dynamic cognition, decisions, and morality.

First, throughout, I assume a perspective of cognition as being continuous and embodied. The key lesson from such an approach is that it emphasis the time course of cognitive processes, how they develop over time and how this can inform our understanding of the mind. Second, all the studies herein concern decisions and preferences. In Papers II and V this takes the form of studying how preferences can be influenced. Paper I investigates how participants choices concerning false feedback about previous decisions evolve. In the remaining papers choices are studied as they unfold in real-time by investigating the time course of eye-movements in various ways. Third, this dissertation addresses questions concerning moral cognition. It does so by treating the moral deliberation of the agent as a decision. The aim has been to investigate parts of our complex moral psychologies by treating moral choices as choices like any others, and see how they might be revealed by eye gaze.

In what follows I present both the theoretical contributions of the dissertation, and through doing so the seven constituent papers, under the three themes previously identified.

I - Dynamics, body and attention

The dissertation is underpinned by the observation that cognition is fundamentally for action in an environment (Wilson & Golonka, 2013; Spivey, 2007; Gibson, 1986). Sensorimotor processes reflect ongoing cognitive activity due to the continuous and distributed nature of cognitive processing. Early evidence for continuous and embodied cognition in tasks beyond motor control was found in linguistics with the development of what is now known as the Visual World Paradigm (VWP; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995; Kamide, Altman & Haywood, 2003;

Andersson, Ferreira & Henderson, 2011). In the VWP, participants are asked to view a scene while listening to a sentence, which usually describes some or all of the objects present on the screen. Participants' eye-movements are measured while they listen to the sentence. Findings indicated that eye-movements were sensitive to immediate processing differences of subtle syntactic features of the target sentences (Tanenhaus et al, 1995). Similarly, investigating the time course of participants' gaze using the VWP has been shown to reveal how interpretations of others' mental states can arise early during understanding, indicating that theory of mind inferences can be performed remarkably fast (Ferguson & Breheny, 2011). Eye-movements have also been used to study recall in memory tasks (Richardson & Spivey, 2000). Recent work has demonstrated that eye-movements might not only reflect ongoing cognition processes but also facilitate them. Johansson and Johansson (2014) showed that recall accuracy and response times were facilitated by congruent gaze manipulations in memory task. Similarly, there is evidence of a facilitating role of eye gaze during insight problem learning tasks. By directing participants' gaze to portions of a visually presented problem where people solving the task tend to look, the success rate of the problem was doubled (Grant & Spivey, 2003).

The papers in this dissertation reflect the embodied and continuous perspective discussed in different ways. In Papers I, III and IV the time course eye gaze is used to investigate aspects of preference formation and decision-making, using task relevant displays in a manner building on the spirit of the VWP. In Paper V the idea that cognitive states are probabilistically reflected in sensorimotor activations used to bias moral choices. Papers VI and VII develop computational models of the time course of eye-movements during choice tasks.

II – Preference and choice

Choices are thought to be explained by agents' underlying preferences; preferences are theorised mental states, and as such not directly amenable to observation. To solve this, economists have suggested that observable choices can be used to infer the preferences of the agent – this is the idea of revealed preferences (Samuelson, 1938; 1948; Edwards, 1954, Grüne, 2004). Through the framework of revealed preferences we find assumptions of complete and ordered (transitive) preferences readily available to the agent (Edwards, 1954; Glimcher, 2010). Psychological studies have called this view into question by demonstrating procedural and descriptive variance during choice - meaning that the method and formulation when preferences are elicited affects what preferences are revealed. One famous example is the framing effects in the Asian Disease Problem (Tversky & Kahneman, 1981), whereby a loss/gain framing in a choice between risky gambles effects if the risky or certain option is chosen. This is has been taken to imply that general information processing limitations of human cognition also apply to decision-making (Slovic & Lichtenstein, 1983, March, 1978).

One fairly recent challenge in this vein is choice blindness. Choice blindness is the finding that participants, following a choice, are willing to accept their non-chosen alternative as the outcome of their choice when given false feedback about the choice outcome (Johansson et al., 2005; Johansson, Hall, Sikström, Tärning & Lind, 2006; Hall, Johansson, & Strandberg, 2012). However, on key question concerning choice blindness research is to what extent participants are truly accepting the false feedback, and not merely omitting to indicate that they have detected it.

In **Paper I**, we investigated choice blindness from the view-point of continuous cognition. We tracked participants' eye movements and measured their pupil dilation during the presentation of false-feedback in a computerised choice blindness task. Analysis painted a complex story of what goes on for participants during a choice blindness task. First, it showed that during detected trials participants responded faster and that their pupils were significantly more dilated compared to when they failed to detect the false feedback manipulation (see Fig. 1). However, early pupil dilation was similar between detectors and non-detectors, possibly indicating non-conscious error monitoring later overridden by non-detecting participants. When looking at eye-movements, participants also looked less at the face, i.e. the source of the false feedback, more at the response options, and exhibited greater laminarity (recurrent fixations to the same point), when detecting compared to when not. Together this shows how processing differences characterise detections in a choice blindness task, which helps rule out demand effect and cognitive dissonance explanations of the choice blindness paradigm.

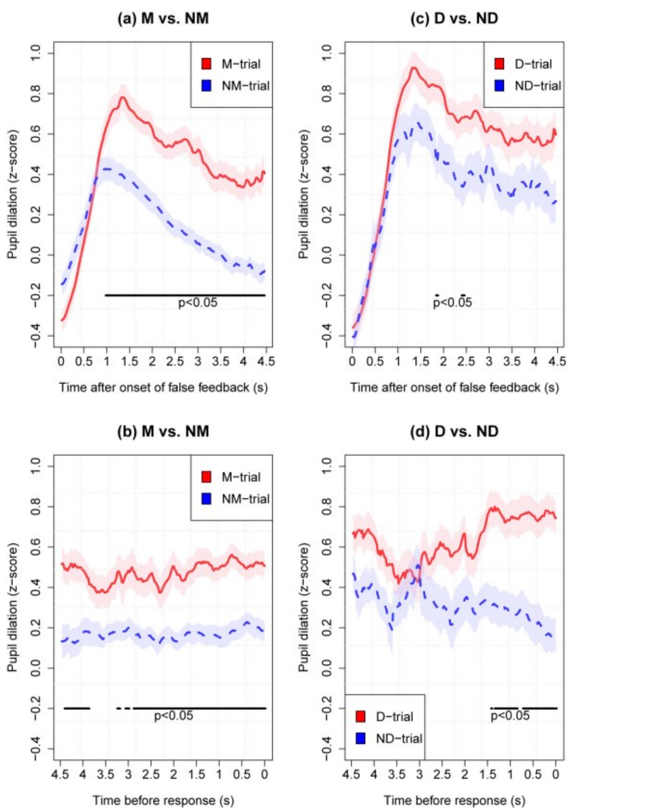

Figure 1 *From Paper I.* Pupil dilation over time during the false feedback portion of a computerised choice blindness task. **(a)** M-trials compared to NM-trials, time-locked to onset of false feedback. **(b)** M-trials compared to NM-trials, time-locked to participant response. **(c)** D-trials compared to ND-trials, time-locked to onset of false feedback. **(d)** D-trials compared to ND-trials, time-locked to participant response. Black lines indicate time points of significant difference by permutation tests.

Given a bounded rational approach to cognition and the findings of preference anomalies in relation to standard decision theory, an alternative view of preferences as being constructed suggests itself (March, 1978; Slovic, 1995; Payne, Bettman & Schkade, 1999, Ariely & Norton, 2008). One particularly powerful piece of evidence for this view is preference change through choice (Brehm, 1956). In a standard experiment, participants rate items, and then make a series of choices between them. They then rate them a second time. Ratings are now more spread so that chosen items are valued higher and rejected items valued lower. This particular method of demonstrating preference change through choice has been criticised on methodological ground (Chen & Risen, 2010), leading to the development of alternative paradigms such as blind choice (Egan, Santos & Bloom, 2010; Sharot, Velasquez & Dolan, 2010), as well as introducing a second round of choice in a choice blindness task (Johansson, Hall, Tärning, Sikström & Chater, 2014; Taya, Gupta, Farber, & Mullette-Gilman, 2014).

In **Paper II**, we developed a choice blindness task for dyads, testing if a) dyads will be blind to false feedback about past mutual choices, and, b) if they will, like individuals, change their preference in a second round of choices. In the study pairs of participants formed dyads and were instructed to make mutual choices between faces presented in pairs. On some trials, dyads were given false feedback regarding their choice. In a later stage of the experiment, dyads were asked to make a second round of choices between some of the same face pairs as previously. The presence of two observers and a mutual explicit verbal agreement prior to choice did not immunize the dyads to the effects of choice blindness. Dyads were as consistent as individuals for non-manipulated trials, but often changed their preferences for manipulated trials, with the effect being largest during non-detected trials (see Fig 2). Importantly, in the case of dyads there is little reason to believe that there was something like a mutual preference waiting to be discovered or revealed. Instead, the crucial mediating factor appears to be participants' beliefs about their previous choices and actions. This suggests that a self-perception account might be able to better countenance the evidence from the preference change through choice literature.

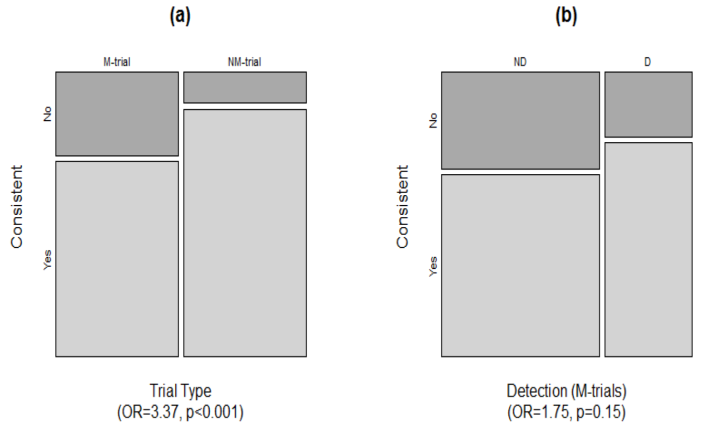

Figure 2 *From Paper II* (a) Mosaic plot showing the percentage of trials with consistent and inconsistent choices in the second phase of Experiment 2 depending on manipulation. Width of bars is proportional to number of trials. (b) Mosaic plot showing percentage of trials with consistent and inconsistent choices for the M-trials in Experiment 2 divided by detection.

If preferences are not revealed or discovered as a result of choice, then they are constructed during the choice process. Adopting a constructed view, hence, invites us to view preference and choice in a dynamic framework and study their evolution in real time. One important tool to do so with is eye-tracking and to use it study the dynamic deployment of visual attention. The remainder of the papers in the dissertation in different way study how choices are made in the moment.

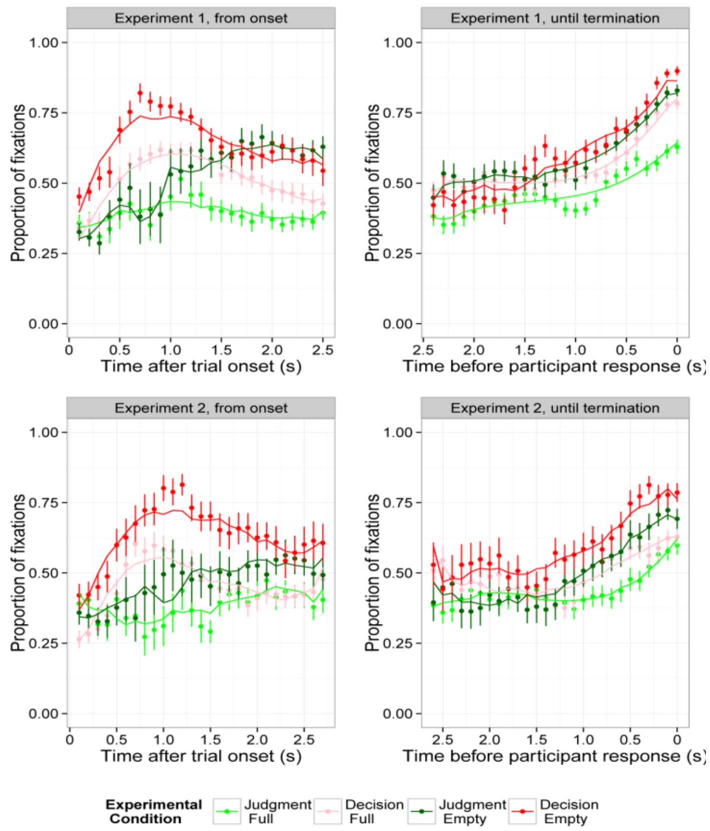

Figure 3 *From Paper III*. Time course of fixations to chosen option by condition plotted from onset of trial (left panels) and until participant response (right panels). Both Experiments are shown. Points represent empirical data in 100ms time bins. Error bars represent standard errors. Lines represent fitted model values from growth curve analysis.

In **Paper III** we investigated how patterns in the deployment of visual attention vary between decision and judgment tasks under varying amounts of environmental information. These cognitive processes are usually studied in separate literatures, but can be assumed to co-occur during visits in familiar, but changing, environments like the supermarket. When no task-relevant information was present participants appeared to search for, and quickly orient to, their preferred option (see Fig. 3). When the task environment allowed, participants engaged with it using slow integrative processes to improve the quality of both their decisions and judgments. While the links between visual attention and decision making appeared to be both pervasive and robust, the exact role of visual attention depended on the set-up of the task environment and was clarified only through comparison with another cognitive process – an important methodological lesson for understanding cognition outside of the lab.

Understanding the role of visual attention during decision-making is not only important for understanding how choices unfold, but because many models of choice have linked visual attention as a causal factor in determining choice. One important computational model attempting to explain the role visual attention plays during choice is the attentional drift-diffusion model (aDDM; Krajbich, Armel & Rangel, 2010; Krajbich & Rangel, 2011); a development of the diffusion model. The diffusion model assumes that decisions are made as a result of the brain first assigning values to options, and then comparing these values. The comparison is assumed to be a diffusion process driven by accumulation of stochastic (relative) evidence integrated to some decision bound (Ratcliff, 1978; Ratcliff & McKoon, 2008; Bogacz, 2007). Originally developed to predict response times in memory retrieval tasks, the diffusion model has been used extensively to study perceptual decision-making (Hanes & Schall, 1996; cf. Shadlen & Kiani, 2013; Van Zandt, Colonius & Proctor, 2000).

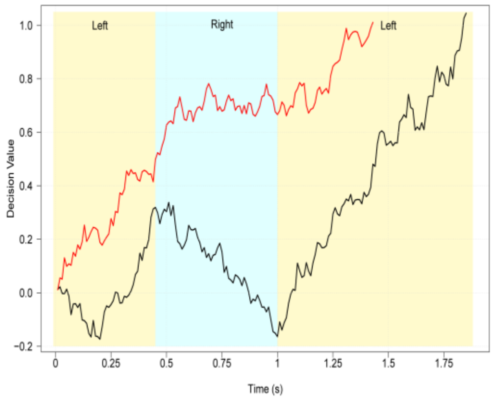

Figure 4. Example of two simulation runs of the aDDM model with varying gaze bias (*θ*) parameters. Model parameters were set to be *d* = 0.003, *σ* = 0.03 and the sample rate to be once every 10ms. The red line represents a model with *θ* = 0.8, and the black line represents a model with *θ* = 0.3. The options in both cases had values, left = 6 and right = 5. Gaze direction represented by yellow (left) and blue (right) background.

In the aDDM formulation of the diffusion model, the key feature is that the slope of integration – capturing how much evidence is accumulated – varies depending on the direction of the agent's attention:

$$V_t = V_{t-1} + d\left(r_{fix} - \theta r_{nonfix}\right) + N(0, \sigma)$$

Where Vt is the decision value, d is the parameter controlling the overall drift rate, r is the value of each option, fixated and non-fixated, θ is a gaze bias parameter and N is white Gaussian noise. The theta parameter indicates the magnitude of gaze bias in the decision process, and represents the novel contribution of the aDDM (see Fig 4). One important aspect of the aDDM model is that it specifies the mechanism by which there can be a causal relationship between gaze and choice. Agents bias their decision process through gazing towards different options, and for equally or similarly valued options this can, in fact, determine the decision. These ideas are further developed in Papers IV-VII, which all concern moral cognition and are presented below.

III – Moral cognition

Standard models of human moral cognition build debates about the role of emotion and reasoning in moral judgments. This has been a fruitful juxtaposition, and one that is pervasive across cognitive science. In particular, two models have been dominant. The first is the the Dual-Process Model (Greene, 2007; Greene, Morelli, Lowenberg, Nystrom & Cohen, 2008; Paxton & Green, 2010). On this account moral judgments are proposed to arise from the competition between fast, affective responses and slow, deliberate reasoning. This dual-system view mirrors similar distinctions in psychology from reasoning to decision-making (Evans, 2003; Kahneman, 2003). The second, the Social-Intuitionist Model, argues that fast intuitions, which sometimes have an affective base, underlie most moral judgments and choices (Haidt, 2001; Haidt & Björklund, 2008). These intuitions are thought to be partly founded in biologically grounded similarities between all humans (Petrinovich & O'Neill, 1996; Haidt, Rozin, McCauley & Imada, 1997), and partly shaped by interacting social and cultural constraints contributing to each individual's morality (Haidt et al. 1993; Graham & Haidt, 2010).

While these models have great merit, they are lacking in the dimensions that are at the centre of this dissertation. While claiming to capture the process of generating moral judgments and choices, they do not actually contain many clear process predictions. This is likely due to how these models are presented and studied; moral cognition is treated as being comprised of a number of cognitive modules, each dedicated towards processing specific forms of information. However, the computational properties of the system are typically not spelled out, and neither is how strictly the modular metaphor is to be interpreted. For the cognitive science of morality to move forward, I argue that specifying process claims is a crucial step that needs to be taken. The following papers in the dissertation stalk out one way of doing so.

In **Paper IV**, we investigated participants' gaze patterns when responding to novel visual representations of classical trolley dilemmas (see Fig 5) . The key question was if visual attention would be deployed differently when participants responded with the deontological option or the utilitarian option, as these types of moral choices have been hypothesised to arise from different underlying psychological processes. The two main findings are, first, that gaze-cascades are present during moral decision-making, indicating an active role of gaze during moral preference formation (Shimojo, Simion, Shimojo & Scheier, 2003). Second, that by examining differences in the distribution of attention and in the dynamics of eye gaze, processing differences between utilitarian and deontological responses was found. The latter finding indicates how eye gaze can be used to study moral cognition in real-time. This suggests that the general framework of embodiment and continuous processing, outlined earlier, also applies to the moral case.

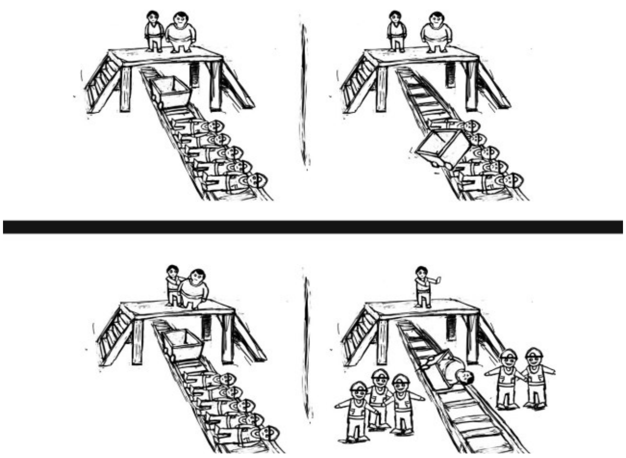

Figure 5. Example of choice screen used in the experiment, in this case showing the 'Footbridge problem' (Thomson, 1985). .**Top panels**. The choice option associated with a deontological action. The agent does not interfere and refrains from pushing the fat man; the five workers are killed. **Bottom panels.** The choice option associated with a utilitarian action. The agents pushes the fat man off the footbridge; the fat man derails the Trolley and dies but the five workers survive.

In **Paper V,** the embodied processing perspective is applied one step further. There, the hypothesis that where participants are looking is causally connected to what they will end up choosing was tested. In three experiments, we introduced a novel gaze-contingent interruption paradigm. Participants freely viewed response alternatives to abstract moral statements such as "Is murder justifiable?" Concurrently, their eye-movements were monitored using a remote eye-tracker and participants' total dwell time to each alternative aggregated. Once a pre-defined amount of dwell time to each alternative had been reached, participants' deliberation was interrupted and their decision prompted (see Fig. 6). We found that participants would choose the target alternative in 59.6% of trials in Experiment 1, indicating that eye gaze tracked the developing moral decision process. In Experiments 2 & 3, participants chose the randomly assigned target alternative in 58.2% and 55.4% of trials, demonstrating that participants' moral choice could be biased by manipulating the timing of their

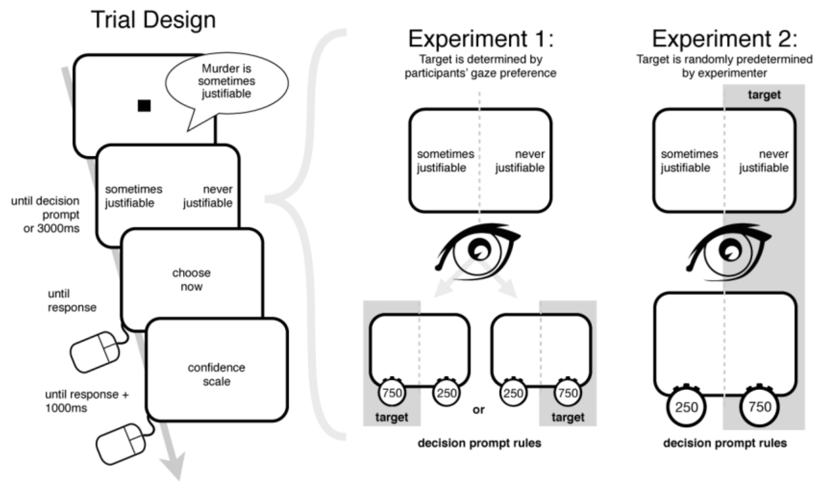

Figure 6. Illustration of the gaze-contingent interruption paradigm introduced in *Paper V*. Participants view alternatives and their decisions are prompted when they have distributed their gaze according to predefined rules. In **Experiment 1**, participants had to have viewed any one alternative at least 750ms and the other alternative at least 250ms for their decision to be prompted. In **Experiment 2**, one alternative was randomly predetermined as target, and participants' decisions were prompted once they had viewed the target alternative for at least 750ms and the non-target for at least 250ms.

decision based on monitoring eye gaze. Further analysis showed that the current direction of participants' eye gaze was more important for determining their choice compared to relative exposure, which might indicate the presence of a leaky integrator underlying evidence accumulation in this task. It, thus, appears that moral deliberation can be understood as an embodied process, whereby eye gaze continuously tracks a decision maker's trajectory through a moral state space. As such, the timing of our interactions with a task environment, such as options presented on a screen, or our general surroundings, can have a definite impact on what choices we make and what preferences we construct. If so, one key implication might be that our moral identities are far less stable than common sense suggests.

In **Paper VI** and **Paper VII**, we demonstrate that the aDDM model can be fit to data from moral choices. In Paper VI participants made binary choices between moral propositions, the same as used in Paper V, while in Paper VII participants made binary choices between charitable organisations, one of which would later receive a donation. In both cases, a fixation dependent model was found to provide the best fit to the response time data. Additionally it could account for response times, choice distributions, and many (though not all) aspects of the participants' fixation behaviour (see Fig 7).

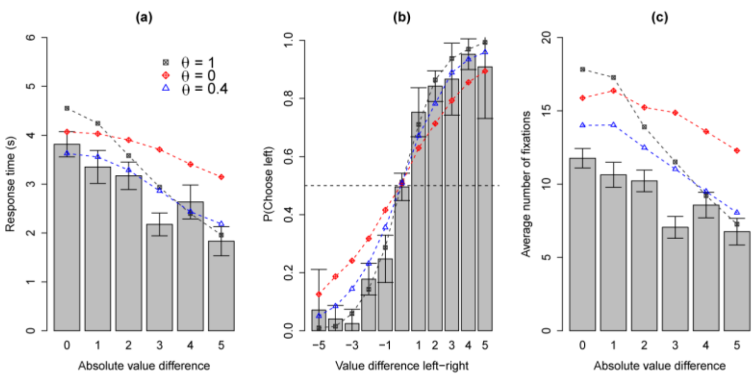

Figure 7: *From Paper VII.* Basic psychometrics. **(a)** Average response times as a function of the value difference between options. **(b)** Probability of choosing the option presented on the left-hand side of the screen as a function of the value difference between the left and right option. **(c)** Average number of fixations in a trial as a function of the value difference between options. Blue lines represent the best fitting aDDM model. Grey bars represent even trials of the empirical data. Error bars denote 95% confidence intervals.

This indicates that a similar diffusion process might be operating even for choices between right and wrong alternatives. However, the fixation process might be different for choices using the materials in Papers VI and VII. Apart from the moral content, one apparent difference is the use of text-based options in Papers VI & VII compared to images of products in previous works.

It is worth emphasising that this represents only a first step towards understanding some of the computational properties of moral decision-making, and that the current formulation of the aDDM model is likely an oversimplification of the underlying dynamics. Nevertheless, it is particularly interesting to take a modelling approach in the case of moral decisions. For one, it allows for precise predictions of the quantitative state of an agent's moral decision process, in a way that has not been anticipated by any hitherto proposed account of moral cognition. Even if it turns out that moral and non-moral decisions might require alternative parametrisations of the same model, this work highlights the possibility for a domain general account of both moral and non-moral aspects of human decision-making. At the same time, it is instructive to compare general moral models with the simple diffusion framework. How should the concerns about emotions, intuitions and the social context be understood? The full answers to these questions are for future work to discover, but by taking the first steps, Papers VI-VII show that these are very much empirical, and, importantly, from now on, modelling questions.

IV – Conclusions and interdisciplinary contributions

The findings of the dissertation inform our understanding of human cognition in three different ways. First, they demonstrate the viability of approaching cognition from a dynamic perspective generally, and explore new areas to do this in. Second, the findings here support a constructed preference view of decision-making, and provide novel reasons for adopting that view. Third, they demonstrate that eye gaze can be used to productively study moral cognition and show that moral choices are in part constituted by gaze dependent decision mechanisms. Of these, the most important contribution is the introduction of a clear time course perspective in the study of how moral choices are formed: to begin to understand how moral decisions unfold over time (cf. .Gantman & Van Bavel, 2015; Fiedler & Glöckner, 2015)

In this précis I have reviewed literature from fields ranging from economics to neuroscience and presented findings with relevance to philosophy of mind and self-knowledge (Paper I), preference formation and decision making (all Papers), economic behaviour (Paper III), moral and social psychology (Paper II, IV-VII), cognitive neuroscience (Paper I; Papers V-VII). Given the emphasis on the embodied nature of (moral) preferences, the dissertation also has implications for building embodied moral agents in cognitive robotics (Balkenius et al., 2016).

(4000 words, including figure texts)

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