Pain, Touch, and Decision Making

Behavioral and Brain Responses to
Affective Somatosensory Stimulation

Lina Koppel

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Somatosensory Stimulation

Lina Koppel

Department of Biomedical and Clinical Sciences
Linköping University, Sweden
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Cover: Hands receiving pain and touch with thermode and brush used in Papers I & III and Paper II, respectively. Design: Lina & Susanne Koppel.

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Abstract

Stimulation of sensory nerves can give rise to powerful affective experiences. Noxious stimuli can give rise to pain, an unpleasant experience which, in turn, causes suffering and constitutes a major societal burden. Touch, on the other hand, can feel pleasant and plays an important role in social relationships and well-being. Slow, gentle stroking of the skin in particular has been shown to activate C-tactile (CT) afferents, which are thought to signal affective and socially relevant aspects of touch. However, little is known about how pain and affective touch influence everyday decision making.

In Paper I, we investigated the effect of acute physical pain on risk taking and intertemporal choice. Participants ($n = 109$) performed a series of economic decision-making tasks, once while experiencing acute thermal pain and once in a no-pain control condition. Results indicated that pain increased risk taking for monetary gains but not for equivalent losses, and increased impatience.

In Paper II, we investigated the effect of affective touch on betrayal aversion, altruism, and risk taking. Participants ($n = 120$) performed a series of economic decision-making tasks, once while being stroked on the forearm at CT-optimal speed using a soft painter's brush and once in a no-touch control condition. Results indicated no effect of affective touch on any of the outcome measures.

In Paper III, we investigated how the ability to affect an upcoming painful event via voluntary action influences cortical processing of ongoing somatosensory stimulation. fMRI data was collected from 30 participants while they performed a task that involved pressing a response button to reduce the duration of upcoming thermal stimuli. Whole-brain analyses revealed no significant task-related effects in brain regions typically involved in pain, except activation in a cluster in anterior cingulate cortex (ACC) was

greater when upcoming stimulation was painful than when it was nonpainful. However, region-of-interest analyses in anterior insula (AI) and midcingulate cortex (MCC) indicated that the noxious nature of the upcoming stimulation, as well as the ability to affect it, influenced processing of ongoing stimulation in both of these regions. Activation in MCC, but not AI, also correlated with response times.

Taken together, these studies contribute to the broader understanding of everyday decision making, and of how affective experiences such as pain and touch shape everyday decisions and behaviors.

Populärvetenskaplig sammanfattning

Stimulering av nervfibrer i huden kan ge upphov till starka känsloupplevelser. Skadliga eller potentiellt skadliga stimuli kan ge upphov till smärta, en obehaglig upplevelse som i sin tur orsakar lidande och har stora socioekonomiska konsekvenser. Beröring, å andra sidan, kan upplevas som behagligt och är en viktig del av sociala relationer. Förhållandevis lite kunskap finns dock om hur smärta och beröring påverkar vardagligt beslutsfattande. Blir vi otåliga av att uppleva smärta? Tar vi fler risker? Gör beröring oss snällare och mer tillitsfulla? I denna avhandling presenteras tre studier som försöker svara på denna typ av frågor.

I den första studien fick deltagarna smärtsam värmestimulering samtidigt som de fattade beslut om pengar. Besluten involverade t.ex. att välja mellan en säker vinst på 50 kr eller att singla slant om att vinna 100 kr. Resultaten visade att smärta ökade risktagande för vinster, men inte för motsvarande förluster. Deltagare som upplevde smärta var även mer otåliga, dvs. de föredrog i större utsträckning snabba belöningar.

I den andra studien fick deltagarna beröring med en mjuk pensel samtidigt som de fattade beslut. Lätt, smekande beröring aktiverar en särskild typ av nervfibrer, som tros signalera affektiva och socialt relevanta aspekter av beröring. Beröring ökar även utsöndringen av hormonet oxytocin, som sägs öka känslan av tillit till andra människor, även om de vetenskapliga bevisen för detta är motstridiga. Resultaten av studien visade ingen effekt av beröring på beslutsfattande.

I den tredje studien undersöktes hjärnans aktivitet vid smärtsam stimulering. Vi vet sedan tidigare att hjärnan inte bara reagerar på det som händer just nu, utan att den även förbereder inför vad som kan komma att hända i framtiden. Deltagarna fick smärtsam eller icke-smärtsam värmestimulering samtidigt som de utförde en uppgift som innebar att de skulle trycka på en knapp för att förkorta en kommande värmestimulering. Resultaten visade

att hjärnans bearbetning av pågående stimulering påverkades av huruvida nästkommande stimulering var smärtsam eller inte och huruvida den gick att påverka.

Sammantaget bidrar dessa studier till en ökad förståelse av hur människor fattar beslut och hur upplevelser som smärta och beröring påverkar vardagligt beslutfattande och beteende. Smärta har en stark koppling till beteende, eftersom vi snabbt måste kunna agera för att undvika skada. Beröring, däremot, upplevs på olika sätt beroende på den sociala kontexten, vilket troligtvis också påverkar beröringens effekt på beteende.

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None of the research in this thesis would have been possible without the efforts of over 300 participants (and many more, counting the studies that did not make it into the thesis). Thank you for contributing to science!

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In fall 2019, Henrik Danielsson and I started a local chapter of the ReproducibiliTea journal club, in which we discuss topics and papers related to reproducibility and transparency in research. Thank you to all attendees for insightful discussions about the science of doing science.

A big thank you to all the kind and supportive colleagues at CSAN and NEK, who have made me look forward to coming to the office every day. Special thanks to all past and present members of JEDI Lab, GRASP, and EBL, for helpful feedback during countless presentations at lab meetings and for creating such a fun and friendly work environment. Extra special thanks to the following people: Arvid Erlandsson, for an inspiring first conversation back in January 2015, when I was still a master's student in Lund, and for looking out for me every since; Kinga Barrafreem, for great friendship, positive energy, and encouragement in and outside of academia; Mario Kienzler, for being an inspiring academic and a great friend, and for fun and insightful discussions over lunch, fika, and ice cream; Erkin Asutay, for programming help and great company at emotion conferences around the world (Geneva, Chicago, Boston, Los Angeles, Glasgow, and Boston again); and Sarah McIntyre, for many deep conversations about science and life. It is safe to say that the people I have met through work have become some of my closest friends outside of work. Shoutout to my D&D group(s), Boardgame Fridays, and Workoutoholics!

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Linköping, October 2020

Lina Koppel

List of papers

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

- I Koppel, L., Andersson, D., Posadzy, K., Morrison, I., Västfjäll, D., & Tinghög, G. (2017). The effect of acute pain on risky and intertemporal choice. *Experimental Economics*, 20, 878–893.
- II Koppel, L., Andersson, D., Morrison, I., Västfjäll, D., & Tinghög, G. (2017). The (null) effect of affective touch on betrayal aversion, altruism, and risk taking. *Frontiers in Behavioral Neuroscience*, 11, 251.
- III Koppel, L., Novembre, G., Kämpe, R., Savallampi, M., & Morrison, I. (2020). Prediction and action in cortical pain processing. *Manuscript*.

For Papers I and II, L.K. contributed to the study design, collected the data, analyzed the data with D.A., and wrote the paper. For Paper III, L.K. conducted pilot studies, collected fMRI data with M.S. and an MR nurse, analyzed the data with G.N. and R.K., and wrote the first draft of the paper.

Papers not included in the thesis

During my time as a PhD student, I have been involved in a number of different projects investigating a number of different research questions, which have all shaped me as a researcher and contributed to my learning in one way or other. Below is a list of papers, published or under review, to which I have contributed and on which I am included as co-author, but which are not part of the thesis. Five of these papers are multi-lab registered replication reports (Hagger et al., 2016; Bouwmeester et al., 2017; O'Donnell et al., 2018; McCarthy et al., 2018; Verschuere et al., 2018), to which my contribution mainly consisted of data collection but which nonetheless taught me about the research process and opened my eyes to the open science movement. One paper is a multi-lab project that is not a replication study (Van Bavel et al., under review). Several of the papers deal with intuition and reflection in decision making (Koppel et al., 2019; Tinghög et al., 2016; Bouwmeester et al., 2016), as well as affect and decision making (Västfjäll et al., 2016; Baltazar et al., 2019), topics that are highly relevant for this thesis. Choosing which papers to include in the thesis was not trivial. In the end, we selected papers that specifically involve effects of pain or touch, that together include a combination of behavioral and brain data, and on which I am lead author.

- Van Bavel, J. J., Cichocka, A., Capraro, V., Sjästad, H., Nezlek, J. B., Pavlović, T., Alfano, M., Gelfand, M.J., Azevedo, F., Birtel, M. D., Cislak, A., Lockwood, P. L., Ross, R. M., Stoyanova, K. K., Abts, K., Agadullina, E., Amodio, D. A., Apps, M. A. J., Aruta, J. J. B. R., (...) Boggio, P. S. (under review). National identity predicts public health support during a global pandemic. <https://psyarxiv.com/ydt95>
- Koppel, L., Andersson, D., Västfjäll, D., & Tinghög, G. (2019). No effect of ego depletion on risk taking. *Scientific Reports*, 9, 9724.

- <https://doi.org/10.1038/s41598-019-46103-0>
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<https://doi.org/10.1177/2059204319844161>
- Verschuere, B., Meijer, E. H., Jim, A., Hoogesteyn, K., Orthey, R., McCarthy, R. J., Skowronski, J. J., Acar, O. A., Aczel, B., Bakos, B. E., Barbosa, F., Baskin, E., Bègue, L., Ben-Shakhar, G., Birt, A. R., Blatz, L., Charman, S. D., Claesen, A., Clay, S. L., (...) Yıldız, E. (2018). Registered replication report on Mazar, Amir, and Ariely (2008). *Advances in Methods and Practices in Psychological Science*, 1, 299–317.
<https://doi.org/10.1177/2515245918781032>
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<https://doi.org/10.1177/2515245918777487>
- O'Donnell, M., Nelson, L. D., Ackermann, E., Aczel, B., Akhtar, A., Al-drovandi, S., Alshaif, N., Andringa, R., Aveyard, M., Babincak, P., Balatkin, N., Baldwin, S. A., Banik, G., Baskin, E., Bell, R., Bialobrzeska, O., Birt, A. R., Boot, W. R., Braithwaite, S. R., (...) Zrubka, M. (2018). Registered replication report: Dijksterhuis & van Knippenberg (1998). *Perspectives on Psychological Science*, 13, 268–294.
<https://doi.org/10.1177/1745691618755704>
- Bouwmeester, S., Verkoeijen, P. P. J. L., Aczel, B., Barbosa, F., Bègue, L., Brañas-Garza, P., Chmura, T. G. H., Cornelissen, G., Døssing, F. S., Espín, A. M., Evans, A. M., Ferreira-Santos, Fernando, Fiedler, S., Flegr, J., Ghaffari, M., Glöckner, A., Goeschl, T., Guo, L., (...) Wollbrant, C. E. (2017). Registered replication report: Rand, Greene & Nowak (2012). *Perspectives on Psychological Science*, 12, 527–542.
<https://doi.org/10.1177/1745691617693624>
- Tinghög, G., Andersson, D., Johannesson, M., Kirchler, M., Koppel, L., & Västfjäll, D. (2016). Intuition and moral decision-making: The effect of

- time pressure and cognitive load on moral judgment and dictator game giving. *PLoS ONE*, 11. <https://doi.org/10.1371/journal.pone.0164012>
- Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Angonno, C. O., Ba-tailler, C., Birt, A., Brand, R., Brandt, M. J., Brewer, G., Bruyneel, S., Calvillo, D. P., Campbell, D. K., Cannon, P. R., Carlucci, M., Carruth, N., Cheung, T., Crowell, A., De Ridder, D. T. D., Dewitte, S., (...) Zwieneberg, M. (2016). A multi-lab pre-registered report on the ego-depletion effect. *Perspectives on Psychological Science*, 11, 546–573. <https://doi.org/10.1177/1745691616652873>
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Abbreviations

ACC	Anterior cingulate cortex
AI	Anterior insula
BAET	Betrayal Aversion Elicitation Task
BART	Balloon Analog Risk Task
BOLD	Blood-oxygen-level dependent
CT	C-tactile
fMRI	Functional magnetic resonance imaging
IASP	International Association for the Study of Pain
IGT	Iowa Gambling Task
LTMR	Low threshold mechanoreceptor
MAP	Minimum acceptable probability
MCC	Midcingulate cortex
MID	Monetary Incentive Delay
NAcc	Nucleus accumbens
OFC	Orbitofrontal cortex
OT	Oxytocin
PFC	Prefrontal cortex
PI	Posterior insula
ROI	Region of interest
ROTG	Risk-only trust game
rTMS	Repetitive transcranial magnetic stimulation
SI	Primary somatosensory cortex
SII	Secondary somatosensory cortex
TG	Trust game

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1. Introduction

When you burn your hand on a hot stove, you do not just perceive an increase in temperature or the smooth surface of the stove—you experience pain, a highly salient and negative affective experience. When the hand of someone you like brushes against your arm, you do not just perceive the bending of hairs or the temperature of their skin—you experience pleasure, or a positive affective experience. Both these instances are examples of how stimulation of sensory nerves can give rise to powerful affective reactions, which shape our experiences and behaviors. Pain causes suffering and is both a common reason to seek medical treatment and a common consequence of receiving treatment such as surgery. Its unpleasant and disruptive nature makes it easy to see why pain relievers are among the most prescribed pharmaceutical drugs in both Sweden (Socialstyrelsen, 2020) and the United States (Martin et al., 2019) as well as among the most sold over-the-counter drugs (Konkurrensverket, 2017). Touch, on the other hand, can have calming effects and plays an important role in social relationships and well-being. We use our sense of touch every day, not just to handle objects and tools but also as part of our social interactions. A handshake greets a new acquaintance; a hug provides comfort. There is even a specific type of nerve fiber, the C-tactile (CT) afferent, that is thought to signal affective and socially relevant aspects of touch (Löken et al., 2009; Morrison et al., 2010; Olausson et al., 2010).

Yet little is known about how pain and touch influence everyday decision making. Does being in pain increase our proclivity to take risk? Does it make us more impatient? Does affective touch make us kinder and more trusting? Does it increase or reduce risk taking? And how does the ability to avoid upcoming painful events influence the brain's processing of ongoing events?

The papers in this thesis begin to unravel some of these questions, using a mix of approaches from psychology, economics, and neuroscience. In Paper I, we investigate the effect of acute pain on risk taking and intertemporal choice. In Paper II, we investigate the effect of affective touch on betrayal aversion, altruism, and risk taking. In Paper III, we investigate the links between pain, prediction, and action—specifically, how the ability to affect upcoming pain influences the brain’s processing of ongoing stimulation. In exploring these questions, this thesis contributes to the broader understanding of how affective experiences influence decision making and behavior in our everyday lives.

1.1 Touch and pain from the periphery to the brain

The skin is the largest organ in the human body. Through the skin, we experience sensations in four main modalities: touch, temperature, itch, and pain. These sensations come about through the workings of specialized receptors, peripheral nerves, and the central nervous system, which together make up the somatosensory system.

The nerve fibers that transmit information about pain and touch from the receptors in the skin to the central nervous system can be classified as A β , A δ , or C, depending on the axon’s diameter, degree of myelination, and conduction velocity. A β fibers are large, heavily myelinated, and have fast conduction velocity. A δ fibers are medium-sized, lightly myelinated, and have intermediate conduction velocity. C fibers are small, unmyelinated, and have slow conduction velocity. In humans, A β afferents are thought to mainly signal discriminative aspects of touch (although a small fraction of them transmit pain, see Nagi et al., 2019), whereas A δ fibers signal pain and C fibers signal pain and affective aspects of touch.

1.1.1 Peripheral processing of pain

Cutaneous noxious information (i.e., information from the skin about potentially harmful stimuli) is transmitted through A- and C-fiber nociceptors. Unlike other receptors in the skin, which typically respond preferentially only to one type of stimulation (such as warm receptors for warming

sensations or cool receptors for cooling sensations), many (though not all) nociceptors are polymodal, meaning that they respond to multiple types of stimuli that can cause injury, including thermal, mechanical, and chemical stimuli.

C-fiber nociceptors are found in both hairy and glabrous (non-hairy) skin, although they have mainly been studied in hairy skin. Early recordings from single neurons in the monkey hand showed that the firing frequency of C-fiber nociceptors increases monotonically as the temperature of the stimulus increases from 41 to 49°C (LaMotte & Campbell, 1978). This increase in firing frequency correlated with an increase in pain intensity ratings to the same stimuli in humans, suggesting that C-fibers signal pain in response to heat stimuli. Microneurography studies in humans have also indicated their involvement in various kinds of pain (for a review, see Ackerley & Watkins, 2018). In contrast, patients with a hereditary condition that involves a severe reduction of C-fibers (and moderate reduction of A δ fibers) have reduced pain sensation (Einarsdottir et al., 2004; Minde et al., 2004).

A-fiber nociceptors can be categorized into two types: type I and type II (Treede et al., 1995, 1998). Type I A-fibers are found in both hairy and glabrous skin and their conduction velocity typically falls between the A β and A δ range. They respond only at very high temperatures (typically above 53°C) when short-duration heat stimuli are applied, but their firing frequency increases as the duration of the stimulus increases, suggesting that they are involved in pain sensations during sustained high-intensity heat stimuli (Meyer & Campbell, 1981). Type II A-fiber nociceptors are thought to only occur in hairy skin and their conduction velocity is slower than type I A-fibers. They respond to heat in a way that is similar to C-fiber nociceptors (i.e., rapid firing at first, but then slowly decreasing), but are either unresponsive or have high thresholds to mechanical stimuli.

Because of their different response properties, A- and C-fiber nociceptors are thought to contribute to different aspects of the painful sensation. Type II A-fibers are thought to signal a “first pain” sensation—a brief, pricking pain—in response to thermal stimuli, because of their fast conduction velocity and rapid firing at the start of a heat stimulus (Campbell &

LaMotte, 1983). Type I A-fibers are thought to contribute to the first pain sensation in response to mechanical stimuli, because they only respond to heat stimuli of longer duration and at higher temperature. C-fibers are thought to signal a “second pain” sensation—a burning sensation that is longer-lasting but less well localized—in response to both thermal and mechanical stimuli, because of their slow conduction velocity.

In sum, evidence indicates that A- and C-fiber nociceptors signal pain in response to noxious stimuli. However, this does not mean that activity in these nociceptors always signals pain or that a painful experience is solely determined by peripheral activity. For example, nociceptors must reach a certain firing frequency for pain to be perceived (see e.g., Tillman et al., 1995; Yarnitsky et al., 1992). Furthermore, contextual factors such as expectations can influence the perception of a stimulus as painful (for reviews, see Atlas & Wager, 2012; Fields, 2018). Pain can also occur even in the absence of nociceptive input, as is the case for pain resulting from social rejection (Eisenberger et al., 2003), observing others in pain (Singer et al., 2004), or simply imagining being in pain (Derbyshire et al., 2004; Raij et al., 2016) (although these studies have been criticized for inferring painful experience based on activation in brain regions typically involved in physical pain, known as the problem of reverse inference, see Poldrack, 2006). The difference between nociception and pain is also emphasized in the current definition of pain by the International Association for the Study of Pain (IASP) as an “unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage” (Raja et al., 2020). Thus, to fully understand pain, one needs to look beyond peripheral processing.

1.1.2 Cortical processing of pain

The brain regions most consistently activated during painful stimulation, regardless of stimulus type, are the primary and secondary somatosensory cortices (SI and SII), thalamus, insula, anterior cingulate cortex (ACC), and prefrontal cortex (PFC; Apkarian et al., 2005). Together, these brain areas are known as the “pain neuromatrix”, or simply “pain matrix”, following Melzack's (1999) terminology. SI and SII are thought to code the sensory-discriminative component of pain (such as location), while the insula

(particularly the anterior part) and ACC are thought to code the affective-motivational component, and PFC codes second-order appraisals of the painful experience (Apkarian et al., 2005; Price, 2000).

Evidence for the distinction between sensory-discriminative and affective-motivational components comes from studies showing, for example, that hypnotic suggestion to increase or reduce pain unpleasantness during the application of a painful stimulus is associated with changes in activation in ACC but not in somatosensory cortices (Rainville et al., 1997). ACC activation also correlates with pain unpleasantness ratings (Tölle et al., 1999). Conversely, hypnotic suggestions to alter pain *intensity* has been shown to modulate activation in SI (Bushnell et al., 1999). Furthermore, a patient who had suffered a stroke involving SI and SII was unable to determine the location and nature of a noxious stimulus but reported an unpleasant feeling that he wanted to avoid (Ploner et al., 1999).

Pain is an unpleasant experience, but it serves an adaptive function in that it motivates action to avoid or reduce physical injury. This motivation to act is arguably part of the painful experience itself (Morrison et al., 2013). Indeed, some of the brain activation that is observed during painful stimulation represents an action component that is unspecific to pain (Perini et al., 2013, 2020). Specifically, the midcingulate cortex (MCC) is activated during action execution (a button press) regardless of whether ongoing stimulation is painful or nonpainful (Perini et al., 2013, 2020), suggesting that the MCC plays an important role in producing voluntary action to avoid harm. The MCC also works closely with the anterior insula (AI) in producing action during pain: functional connectivity between AI and MCC increases with self-reported urge to move during pain (Perini et al., 2020).

The brain is not simply a “reaction machine” that remains passive until activated by external or internal events. Rather, the brain is often described as a “prediction machine”, which makes predictions about future events and compares and adjusts those predictions against incoming information (Barrett & Simmons, 2015; Clark, 2013). In line with this, pain-related regions have been shown to be active *before* a stimulation occurs and to predict whether or not it is perceived as painful. For example, pre-stimulus activity in AI is greater for stimuli that are subsequently rated as painful than for stimuli rated as nonpainful (Ploner et al., 2010; Wiech et al., 2010). How

does the ability to affect pain via voluntary action influence such predictions? In Paper III, we investigate how the noxious nature of an upcoming event, as well as the ability to affect it via a button press, influences ongoing somatosensory processing.

1.1.3 Peripheral processing of touch

Like pain, touch can be thought of in terms of a sensory-discriminative component and an affective component. Discriminative aspects of touch are signaled by A β low-threshold mechanoreceptors (LTMRs), which are located in both hairy and glabrous skin. A β LTMRs transmit information about pressure, vibration, slip, and texture, all of which are important for the ability to explore and manipulate objects (for reviews, see Abraira & Ginty, 2013; McGlone et al., 2007, 2014).

Affective aspects of touch, on the other hand, are believed to be signaled by C-fibers known as C-tactile (CT) afferents. These fibers are located only in hairy skin (or at least have not yet been found in glabrous skin) and respond maximally to gentle stroking at velocities around 1–10 cm/s (rather than simple pressure or slower or faster stroking speeds; Löken et al., 2009). The non-human mammalian equivalent of CT afferents (C-LTMRs) was discovered in cats many years ago (Zotterman, 1939), but their functional role remained unclear and it was even believed that CTs did not exist in the human skin. The reason for this lies in the difficulty in studying CTs: the type of gentle stroking that is optimal for activating CTs activates a range of receptor types, not just CTs. The development of the microneurography technique partly solved this issue, and the existence of CTs in the human face was discovered in the late 1980s (Johansson et al., 1988; Nordin, 1990). Soon thereafter, CTs were discovered in the hairy skin of the forearm, where they are encountered about as often as A β s (Vallbo et al., 1993, 1999).

CT afferents are believed to signal affective aspects of touch for several reasons. First, the stroking speed at which they fire most frequently is also the speed that is rated as most pleasant (Löken et al., 2009). More specifically, both firing frequency and pleasantness ratings follow an inverted-U-shaped pattern as stroking velocities increase from 0.1 to 30 cm/s, with

peaks around 1–10 cm/s. Second, just like the conduction velocity of C-fiber nociceptors is too slow for first pain sensations, the conduction velocity of CTs is too slow to be useful for discriminative aspects of touch. Third, a patient with a peripheral neuropathy syndrome that involves loss of myelinated afferents was able to detect soft brush stroking on the forearm and hand dorsum (sites where CTs are abundant) with better-than-chance accuracy and reported it as pleasant, but was not able to detect the direction of stroking, to detect the stroking when applied to the palm of the hand, or to detect vibratory stimuli on the forearm (Olausson et al., 2002; see also Olausson et al., 2008). Conversely, patients with reduced density of unmyelinated nerve fibers (including CTs) perceive brush stroking at CT-optimal velocities as less pleasant than healthy controls, but are equally good at perceiving the direction of stroking (Morrison et al., 2011).

Because of these properties, it has been suggested that CT afferents play an important role in touch in close social interactions (Löken et al., 2009; Morrison et al., 2010; Olausson et al., 2010). Indeed, humans spontaneously stroke other humans, but not inanimate objects, at CT-optimal speeds (Croy et al., 2016). In addition, CTs show a preference for touch at skin temperature (Ackerley et al., 2014), lending further support to the role of CTs in touch between individuals. This is not to say that social and affective aspects of touch are *only* mediated by CT afferents. Touch on glabrous skin can still be pleasant (Francis et al., 1999; Krämer et al., 2007), and deep pressure touch, which occurs for example during massage therapy and hugging, is both pleasant and calming (Case et al., 2020), suggesting that there is more to social and affective touch than activation of CTs. Nevertheless, the CT system is the most well studied.

1.1.4 Cortical processing of touch

Discriminative and affective aspects of touch are believed to be processed in different parts of the brain. Discriminative touch consistently activates SI and SII, whereas affective touch activates SII and posterior insula (PI; Morrison, 2016a). A key study was conducted by Olausson et al. (2002), who compared CT-optimal brushing of the forearm to no brushing in a patient lacking myelinated afferents, as well as in healthy controls. Results showed that CT-optimal brushing activated SI and PI in healthy individuals,

but only activated PI in the patient. Taken together with behavioral findings that the patient was able to perceive pleasant aspects of touch without being able to distinguish discriminative aspects, these results suggest that the PI is involved in processing affective aspects of touch.

Other studies have compared pleasant touch of the forearm (where CTs are abundant) to the same type of touch of the palm (where CTs are absent), or compared CT-optimal touch to non-CT touch. For example, CT-optimal brushing of the forearm activates PI and orbitofrontal cortex (OFC), but the same type of brushing on the palm activates somatosensory cortices SI and SII and mid/anterior insula (McGlone et al., 2012). Furthermore, brush stroking at preferred (vs. nonpreferred) speeds is associated with greater activation in contralateral PI when the brushing is administered on the arm, but is associated with greater activation in both contralateral PI and in contralateral SI and bilateral SII when it is administered on the palm, suggesting that PI activation might be sufficient for processing pleasant touch in hairy skin (Perini et al., 2015). An activation likelihood estimation (ALE) meta-analysis of 17 fMRI studies of pleasant touch (regardless of stimulus type or stimulation site) found that PI was more likely to be activated during pleasant touch, whereas SI was more likely to be activated during discriminative touch, and SII had a high likelihood of being activated by both types of touch (Morrison, 2016a). Additional areas that have been implicated in pleasant touch include superior temporal regions (Davidovic et al., 2016; Gordon et al., 2013a; Voos et al., 2013), OFC (Francis et al., 1999; McGlone et al., 2012; Perini et al., 2015; Rolls et al., 2003; Voos et al., 2013), and ACC (Case et al., 2016; Gordon et al., 2013b; Rolls et al., 2003). Interestingly, inhibition of SI using repetitive transcranial magnetic stimulation (rTMS) does not seem to affect touch pleasantness ratings, even though it affects sensory discrimination (Case et al., 2016).

1.2 Pain and decision making

1.2.1 Effects of pain on reward processing

Pain has been shown to increase the motivation to obtain a monetary reward. Gandhi et al. (2013) investigated the effect of acute pain on response

times and hedonic ratings of rewards in the Monetary Incentive Delay (MID) task (Knutson et al., 2000). In this task, participants are presented with monetary incentives and are asked to press a response button upon the presentation of a target cue. The incentive is awarded if the response time is below a certain threshold (e.g., 750 ms). Gandhi et al. (2013) found that participants ($n = 37$) who performed the task while experiencing painful thermal stimulation had reduced response times compared to when they performed the task in a no-pain control condition (although this was only true for the highest [\$4] incentives; there was no overall main effect of pain on response times and no effect for medium [\$1] or low [\$0.04] incentives). Furthermore, there was no significant difference between the pain and control condition in participants' ratings of how much they liked or disliked the reward after the outcome was revealed. Taken together, Gandhi et al. interpret these results as an increased motivation to obtain reward without accompanying increased pleasantness of the reward.

On the other hand, a study comparing patients with the chronic pain condition fibromyalgia ($n = 17$) to a group of healthy controls ($n = 15$) found no difference in response times in the MID task (Martucci et al., 2018). Nevertheless, patients and controls differed in terms of brain activation during reward anticipation and outcome, measured using fMRI. During anticipation of gains (compared to no gain), activation in the nucleus accumbens (NAcc) increased in both patients and controls, but activation in the medial prefrontal cortex (mPFC) increased only in controls. NAcc activation has previously been linked to anticipation of monetary rewards in the MID task (Knutson et al., 2001; Knutson et al., 2005; Miller et al., 2014; for a review, see Knutson & Greer, 2008) and mPFC activation has been linked to reward probability (Knutson et al., 2005) and reward outcome (Knutson et al., 2003). Thus, one of several possible interpretations of the results from Martucci et al. (2018) is that the reduced anticipatory mPFC activity in chronic pain patients during gain anticipation reflects reduced reward probability estimates, although further research would be needed to confirm or dismiss this possibility. Furthermore, in response to a gain (vs. no gain) outcome, mPFC activity increased in both patients and controls, in line with previous findings (Knutson et al., 2003). However, in patients but not in controls, mPFC activation also increased in response to

no-loss (vs. loss), as if the absence of a negative outcome was experienced as a reward.

In sum, the studies by Gandhi et al. (2013) and Martucci et al. (2018) both suggest altered reward processing during pain.

1.2.2 Effects of reward on pain processing

Monetary gains and losses can also influence the perception of nociceptive stimuli. This has been most clearly demonstrated in experiments in which participants rate the intensity and unpleasantness/pleasantness of thermal stimuli after winning money, losing money, or neither, in a wheel-of-fortune game (Becker et al., 2013, 2017). Specifically, Becker et al. (2013) found that participants (Experiment 1, $n = 25$; Experiment 2, $n = 24$ [tested twice on separate days]) rated the stimuli as less unpleasant and intense after winning compared to losing money. This was the case for all stimulus intensities included (1.5°C below, 1.5°C above, and 2.5°C above participants' pain threshold), although wins mainly influenced stimuli that were subjectively rated (in a neutral condition) as painful and losses mainly influenced stimuli that were subjectively rated as non-painful. Another study (Becker et al., 2017; $n = 24$) using the same task found that monetary wins and losses influenced the perceived intensity only of the medium intensity stimuli (1.5°C above the pain threshold) and not of the higher intensity stimuli (2.5°C above the pain threshold; this study did not include stimuli 1.5°C below pain thresholds and participants did not rate pleasantness/unpleasantness). Furthermore, the difference in pain intensity ratings following wins compared to losses correlated with activity in medial orbitofrontal cortex (mOFC) during win (but not loss) trials. MOFC, in turn, showed increased negative connectivity with rostral AI, anterior-dorsal ACC, and SI when pain and reward co-occurred. These findings suggest that pain inhibition by reward does not reflect reduced nociceptive processing but is better explained by higher-order processes.

It is possible that the pain-relieving aspects of monetary wins in the above studies could at least in part be attributed to the winning component of the game rather than the monetary rewards per se. To investigate whether winning in itself can influence pain perception, Becker et al. (2015) conducted a study using the same wheel-of-fortune game as above, except

outcomes involved changes in temperature of the painful stimuli rather than monetary gains and losses. Participants ($n = 35$) received continuous painful thermal stimuli throughout the game. On test trials, participants selected one of two colors by pressing a button, which started the spinning of the wheel. If the wheel landed on their chosen color, the temperature of the stimulation decreased. If it landed on the color they had not chosen, the temperature of the stimulation increased. If it landed on a third color, which they could not select, the temperature neither increased nor decreased. On control trials, participants did not make any choice; they just spun the wheel and the result was either temperature decrease, increase, or neither. Results of the study indicated that perceived pain (assessed both using subjective ratings of intensity and using a behavioral measure) was lower on trials when participants “won” pain relief compared to corresponding control trials in which the temperature decreased.

1.2.3 Pain as a dual-systems manipulation

The research reviewed thus far suggests that pain and reward exert mutual influence over each other. These findings are perhaps not surprising given that pain and reward rely on overlapping anatomical circuitry and neurotransmitter systems (opioids and dopamine; for a review, see Leknes & Tracey, 2008). On a larger scale, financial insecurities such as unemployment are associated with increased consumption of over-the-counter painkillers (Chou et al., 2016), and activity in reward-related brain regions during adolescence predicts pain complaints two years later (Nees et al., 2017).

But how does pain influence decision making? Decision making involves not only reward processing, or valuing the magnitude of a potential gain or loss. In our everyday lives, we constantly have to make decisions that involve some level of risk, or choose between outcomes that occur at different points in time (intertemporal choice), or take into account how our decisions affect other people and how their decisions will affect us. How does pain influence these types of choices?

According to dual-process theories, decisions result from an interaction between intuitive (System 1) and reflective (System 2) processes (Epstein, 1994; Evans, 2003; Kahneman, 2003, 2011; Kahneman & Frederick, 2002; Stanovich & West, 2000). System 1 is typically characterized as fast,

automatic, effortless, and affective. System 2 is typically characterized as slow, controlled, effortful, and analytical. System 2 monitors the decisions made by System 1 and can either endorse, correct, or override them. However, decisions are frequently made under suboptimal conditions, such as when we are under time pressure (see, e.g., Kirchler et al., 2017; Tinghög et al., 2016), when we experience cognitive load (Tinghög et al., 2016), or when our self-control resources are depleted (Koppel et al., 2019). In such situations, System 2 may be less able to operate, either because it is too slow or because our attention and effort is needed elsewhere.

Pain is both salient and attention-demanding, so it seems likely that pain disrupts System 2 processes in decision making. For example, pain has been shown to reduce performance on attention-demanding tasks, both in chronic pain patients (Eccleston, 1994; Gunnarsson et al., 2016) and in healthy participants experiencing acute pain (Crombez et al., 1996, 1997; for a review, see Eccleston & Crombez, 1999). Perseverance in a physically painful task has also been used as a measure of self-control in the self-control literature (Rosenbaum, 1980; Schmeichel & Vohs, 2009; Schmeichel & Zell, 2007; Silvestrini & Rainville, 2013), suggesting that pain is mentally burdensome.

System 1 works very well in many situations but can also lead to biases in decision making. For example, people tend to be risk averse in the gain domain and risk seeking in the loss domain, known as the reflection effect of prospect theory (Kahneman & Tversky, 1979). Increasing reliance on System 1 should enhance this effect. Indeed, previous studies have found that manipulations such as time pressure (Kirchler et al., 2017) and stress (Porcelli & Delgado, 2009) reduce risk taking for gains and increase risk taking for losses. Increasing reliance on System 1 should also increase preferences for immediate over delayed rewards, because choosing a delayed reward arguably requires self-control, a System 2 feature. In Paper I, we test these predictions using pain as a way to disrupt System 2 and increase reliance on System 1.

1.2.4 Decision making in chronic pain patients

Current knowledge of the effect of pain on decision making mainly comes from experiments investigating the performance of chronic pain patients in

the Iowa Gambling Task (IGT; Bechara et al., 1994). In this task, players choose among four decks of cards with varying gain/loss ratios. Two of the decks contain cards with small gains and small losses. These are “good” decks because they result in positive earnings in the long run. The other two decks contain cards with larger gains but also larger losses. These are “bad” decks because they result in negative earnings in the long run. Players do not know which decks are good and which are bad when they begin the task; they are simply instructed that their goal is to earn as much money as possible.

The IGT was originally developed as a test of the somatic marker hypothesis, which posits that cognitive processes such as decision making are guided by affective processes, known as “somatic markers” (Damasio, 1994). Healthy participants normally begin by sampling cards from each deck and gradually learn to stick to the good decks. This choice behavior is accompanied by increased anticipatory physiological arousal (as indicated by increased skin conductance response) when participants are about to make draws from the bad decks, suggesting that choices are guided by affective processes (Bechara et al., 1996).

Patients with chronic pain have been found to have impaired performance in the IGT—that is, they keep choosing cards from both kinds of decks (Apkarian et al., 2004; Biagianti et al., 2012; Tamburin et al., 2014; Verdejo-García et al., 2009; Walteros et al., 2011; but see Mongini et al., 2005). The reduced performance has been suggested to be due to a lack of somatic markers, because patients’ physiological arousal does not increase when they choose cards from the bad decks (Elvemo et al., 2014). However, it is unclear from these studies how pain influences risk preferences per se, because the IGT involves choosing between options with initially unknown values and probabilities (and thus involves a learning component rather than simple choices between outcomes with known values and probabilities) and also involves weighting immediate over longer-term outcomes.

To the best of my knowledge, only one previous study of chronic pain and economic decision making has used a task other than the IGT. Berger et al. (2014) compared chronic back patients ($n = 13$) with controls ($n = 21$) on a loss aversion task, in which participants chose to accept or reject gambles that involved a 50/50 percent chance of monetary gain or loss. Results

indicated increased gain sensitivity among patients compared to controls. That is, as the value of the potential gain increased, the probability of acceptance increased more for patients than for controls. There was no significant effect on loss sensitivity, although the average loss sensitivity was greater for patients than for controls—that is, as losses became greater, the probability of acceptance decreased more for patients than for controls, but this difference was not statistically significant.

1.2.5 Effects of acute pain on decision making

Little is known about how acute pain influences decision making. However, a related literature has investigated decision making following the cold pressor task, which involves immersing one hand in ice-cold water. A well-cited study (Porcelli & Delgado, 2009) found that the cold pressor task resulted in reduced risk taking in the gain domain and increased risk taking in the loss domain—in other words, an enhanced reflection effect of prospect theory. These researchers employed a within-subjects design in which participants ($n = 27$) made a series of choices between a high-probability (but non-certain) outcome and a low-probability outcome, first after immersing their hand in room-temperature water (control task) and then again after immersing their hand in ice-cold water.

Another study (Lighthall et al., 2009) found no overall effect of the cold pressor task on risk taking. These researchers employed a between-subjects design ($n = 45$) and assessed risk taking using the Balloon Analog Risk Task (BART; Lejuez et al., 2002), which does not separate between potential gains and losses. However, there was a significant interaction between condition and gender, indicating that the cold pressor task increased risk taking in men and reduced risk taking in women.

Yet another study (Barnhart et al., 2019) investigated performance on the IGT and the BART as a function of self-reported pain in the cold pressor task. Here, all participants ($n = 146$) completed the cold pressor task before performing the decision tasks. Results indicated that self-reported pain during the cold pressor task predicted reduced risk taking in the BART but had no significant effect in the IGT. Furthermore, participants who had been told that they might be asked to complete a second cold pressor task (*pain threat* condition; $n = 36$) were less risk taking in the BART than

participants in a control condition ($n = 36$), who had received no threat of additional pain (the study involved two additional conditions, not reported here). Note that this study did not compare decisions following the cold pressor task to decisions following a control task.

In sum, research investigating the effects of the cold pressor task on risk taking has yielded mixed results. However, these studies differ also in terms of experimental design and in how risk taking was assessed. Furthermore, the two studies that compared the cold pressor task to a control task both involved small samples. Most importantly, these studies investigated decision making *following* a painful procedure rather than investigating decision making *during* pain. In Paper I, we investigate the effect of concurrent acute pain on decision making, specifically risk taking and intertemporal choice.

1.3 Touch and decision making

1.3.1 The Midas effect

Touch has a range of positive effects on both individual and interpersonal levels, including improved mood, attachment, stress reduction, and pain reduction (for reviews, see Morrison, 2016b; Shamloo et al., 2020). Touch has also been shown to increase positive evaluations and compliance with requests (for a review, see Schirmer et al., 2016). This effect has been called the “Midas effect”, after the Greek myth about King Midas who was gifted with the ability to turn everything he touched into gold. For example, students at a library who received half-a-second hand-to-hand contact from the librarian checking out their books rated the librarian more favorably than students who had received no physical contact (Fisher et al., 1976). Customers at a bookstore who were touched briefly on the arm by the salesperson gave more favorable ratings of the store (Hornik, 1992a). Restaurant guests who were touched briefly on the arm by the server gave more favorable ratings of both the server and the restaurant (Hornik, 1992b). In an experiment, participants (students) who had been touched by the experimenter (a college instructor) during a demonstration of how to measure their pulse from their wrist had more positive attitudes both toward the

experimenter and toward a subsequent lecture given by the experimenter, compared to participants who had received the same demonstration but without physical contact (Legg & Wilson, 2013).

The studies above suggest that touch can influence people's judgments and evaluations. But touch has also been found to affect behavior. A classic example is a study by Kleinke (1977), in which female experimenters approached individuals in a shopping mall and asked if they could lend them a dime. Experimenters either approached the participants at approximately 0.5-meter distance and touched them lightly on the arm or stayed at one-meter distance without physical contact (the study also involved an additional factor, eye gaze, not relevant here). Results showed that individuals who had been touched gave on average more dimes than individuals who had not been touched. In a similar study (Brockner et al., 1982), a dime was placed in a phone booth and individuals leaving the booth who had taken the dime were approached by a male or female experimenter, who asked the participant if they had found a dime that the experimenter had left in there. As they made their request, the experimenter either lightly touched the participant on the arm at 0.5-meter distance or stayed at one-meter distance without making physical contact (as in the previous study, this study also included an additional factor, eye gaze). Results indicated that the proportion of participants who returned the dime was greater in the touch than the no-touch condition (although this difference was only significant at $p < .06$, one-tailed test).

Another classic study showed that restaurant guests who had been briefly touched on the shoulder or on the hand by the waitress as she returned the change gave larger tips than guests who had not been touched (Crusco & Wetzel, 1984). This finding has been replicated subsequent studies (Hornik, 1992b; Stephen & Zweigenhaft, 1986). Furthermore, individuals who had been touched briefly on the arm or shoulder by a confederate were more likely to agree to take part in a 10-minute survey, compared to individuals who had not been touched (Hornik & Ellis, 1988) and customers in a supermarket were more likely to agree to try a new product if they had been touched on the arm by the person demonstrating the product (Hornik, 1992b). A meta-analysis of 13 published studies with a total of

2,322 participants found that touch had a small but consistent effect on compliance requests (Segrin, 1993).

In sum, the studies reviewed above suggest that brief touch increases positive evaluations and compliance with requests. However, these studies have in common that they exclusively investigated “simple” forms of touch, which are too brief to activate CT afferents. In addition, the majority of studies were conducted in field settings with low experimental control (for an exception, see Legg & Wilson, 2013). Thus, it is difficult to discern whether any effect of touch is due to the touch itself or some other non-verbal behavior that comes with the touch (e.g., physical proximity). In Paper II, we investigate the effect of CT-optimal, affective touch on decision making in a laboratory setting.

To the best of my knowledge, only one previous study has investigated effects of more prolonged, dynamic touch on decision making. Specifically, Morhenn, et al. (2008) compared participants’ decisions in a standard trust game, following either 15 minutes of Swedish massage ($n = 42$) or 15 minutes of rest ($n = 30$). In the trust game, participants are randomly paired with another person. Both participants receive a starting endowment. The first player (the investor) decides how much, if any, of their endowment to send to a second player (the trustee). The amount they choose to send is tripled in the trustee’s account. The trustee then decides how much to send back to the investor. Results from the study by Morhenn et al. (2008) indicated that massage had no effect on the amount sent by investors, but it increased the amount returned by trustees, suggesting that touch increases reciprocity. However, although massage is commonly perceived as pleasant, this study did not involve touch specifically targeted at CT afferents. Thus, it remains unknown how CT-optimal, affective touch, which is said to have a special role in social relationships, influences decision making.

1.3.2 The role of oxytocin in touch and decision making

A wide range of experiments have shown that cutaneous stimulation increases the release of the neuropeptide oxytocin (OT; for reviews, see Uvnäs-Moberg et al., 2015; Walker et al., 2017). CT afferents specifically have been suggested to play a role in mediating this effect, based on the observation that effects of CT-targeted (affective) touch on positive affect,

stress, and pain perception mirror those of endogenously released and exogenously administered OT (Walker et al., 2017).

Support for the role of CTs in OT release also comes from studies investigating links between plasma OT and pleasant touch in human and non-human animals. For example, unconscious male rats that were stroked on the back for 1 minute showed increased levels of plasma OT, both during and 10 minutes after the touch, compared to before (Stock & Uvnäs-Moberg, 1988). Affective touch has also been shown to activate OT neurons in the paraventricular nucleus of the rodent hypothalamus (Okabe et al., 2015). A study of 10 male dogs and their female owners found that OT levels increased in both dogs and owners following a 3-minute interaction during which the owner talked to and pet the dog (Handlin et al., 2011). In humans, OT levels have been found to increase after a 15 minute massage (Morhenn et al., 2012), although another study found that OT levels only increased when the massage was followed by a trust game (Morhenn et al., 2008). Baseline OT levels have also been found to correlate positively with level of partner support (Grewen et al., 2005) and frequency of partner hugs (Light et al., 2005). More recently, plasma OT levels were found to increase in response to touch in humans, but only when the touch was performed by a partner and not when it was performed by a stranger (Handlin et al., under review).

Taken together, the studies reviewed above suggest that touch, particularly affective touch, increases OT release. OT, in turn, has been suggested to increase trust and prosocial behavior. In a highly influential study, Kosfeld et al. (2005) investigated the effect of intranasally administered oxytocin on behavior in a standard trust game. Participants received a dose of 24 intranasal units of OT or placebo and were then randomly assigned to the role of investor or trustee. Results showed that investors who had been given OT ($n = 29$) transferred on average more money than investors who had been given placebo ($n = 29$; one-sided t-test). The proportion of participants who transferred the maximum amount also differed between groups: 45% of participants in the OT group transferred the maximum amount, compared to 21% in the placebo group (although no statistical test of this difference was reported). There was no statistically significant effect of OT administration on trustees' back transfers, or on investors' decisions

in a risk game that was identical to the trust game except payoffs were determined by chance rather the trustee's decision.

To date, the Kosfeld et al. study has been cited over 4,260 times in Google Scholar. However, the findings have been difficult to replicate in subsequent studies (for a review, see Nave et al., 2015). A meta-analysis of seven published studies found no consistent effect of intranasal OT administration on trust (Nave et al., 2015). A recent high-powered ($n = 677$) replication of the Kosfeld et al. study found no significant effect but indicated that the evidence was stronger for the null hypothesis (Declerck et al., 2020).

Several criticisms have been raised regarding the literature on OT and trust, including low statistical power (Walum et al., 2016), publication bias (Lane et al., 2016), and mixed support for the underlying assumption that intranasal OT passes the blood-brain barrier and reaches target areas (Leng & Ludwig, 2016). Furthermore, studies correlating endogenous OT release with behavior in the trust game have also found inconsistent results (for a review, see Nave et al., 2015). Although these studies escape the criticism regarding intranasal OT passing the blood-brain barrier, they instead have been questioned because some methods of measuring plasma OT have been shown to be unreliable (Christensen et al., 2014; McCullough et al., 2013). Our study circumvents all of these criticisms, as we do not directly investigate the effect of OT on decision making, but rather assess the effect of affective touch, which presumably increases endogenous OT release, on decision making.

2. Aims

The general aim of the thesis is to increase the understanding of how pain and affective touch influence everyday decision making. The specific aims are as follows:

- Paper I:** How does acute pain influence risk taking and intertemporal choice?
- Paper II:** How does affective (CT-optimal) touch influence betrayal aversion, altruism, and risk taking?
- Paper III:** How does the ability to avoid upcoming painful stimulation by voluntary action influence the brain's processing of ongoing stimulation?

3. Methods

3.1 Ethics

All studies were conducted in accordance with current ethical standards for research involving human participants. Appropriate inclusion criteria were used, such as medication use for studies involving pain (Papers I and III) and no magnetic metal for research involving MRI (Paper III). All participants provided written informed consent in accordance with the Declaration of Helsinki, which included information that they could withdraw from the experiment at any time without any negative consequences and without specifying a reason. Decision tasks were incentivized and thus involved no deception, in line with current standards in the field of economics. Anatomical scans from the fMRI study (Paper III) were inspected by a radiologist, and in case of abnormalities the participant was contacted by a physician for follow-up.

3.2 Participants

Participants for all studies were recruited from a subject pool at Linköping University using the Online Recruitment System for Experiments in Economics (ORSEE; Greiner, 2015). In order to be eligible to participate in studies involving pain (Papers I and III), participants could not be taking anxiolytic, antidepressant, pain relieving, or other medication that could influence the perception of pain. In addition, participants in Paper III had to be 18–40 years old and meet conventional inclusion criteria for MRI research (i.e., right-handed, no magnetic metals in body, no preexisting neurological history such as injury or stroke, not be taking medication related to neurological or psychiatric disorder such as epilepsy, and not be claustrophobic).

3.3 Pain stimuli

Pain was delivered using a 3×3 cm thermal stimulator probe (Q-sense, Medoc Ltd., Ramat Yishai, Israel) on the dorsal part of the left forearm. An MRI-compatible version (Pathway model ATS) was used for fMRI sessions. Prior to the experiment, participants' thresholds for warmth, cold, and heat pain (and/or heat pain limit) were determined using a procedure in which the thermode had a baseline temperature of 32°C and increased or decreased at a speed of 1°C/s until participants pressed a response button positioned in their right hand. For warmth and cold thresholds, participants were instructed to press the button when they felt a difference in temperature. For pain thresholds (Paper III only), they were instructed to press when they started to feel pain. For pain limits, they were instructed to press when the temperature reached their maximum tolerable temperature. After they had pressed the button, the temperature returned to baseline. If the thermode reached 50°C before participants pressed, the temperature automatically returned to baseline. Each stimulus type was measured four times.

In Paper I, painful stimulation during the experiment was based on participants' pain limits (although we refer to these as "pain thresholds" in the paper; $M = 48.07^\circ\text{C}$, $SD = 1.38$). Due to safety settings on the Q-sense, the thermode could not have a temperature above 47°C for the full duration of each decision task. Therefore, the thermode was programmed to reach the participant's pain limit at the start of each trial, where it remained for five seconds and then varied between the pain limit and 2°C below it until the start of the next trial. Before the experiment started, participants experienced the pain stimulation for one minute, during which they were allowed to adjust to a higher or lower temperature, in order to make sure that the stimulation was at an appropriate level.

In Paper III, stimuli referred to as *painful* corresponded to participants' pain thresholds ($M = 44.86^\circ\text{C}$, $SD = 1.77$) and stimuli referred to as *very painful* corresponded to their pain limits ($M = 47.86^\circ\text{C}$, $SD = 1.41$), with a maximum temperature of 49°C and at least 2°C difference between painful and very painful stimuli. Nonpainful stimuli corresponded to baseline temperature, 32°C. The thermode was programmed to be at target temperature for the duration of each stimulus (1–4 s).

3.4 Touch stimuli

Touch stimuli consisted of gentle stroking with a 75 mm painter's brush at 3 cm/s, as is typical in research on affective touch. This procedure and stroking velocity is optimal for activating CT afferents and is typically rated as pleasant (e.g., Löken et al., 2009). Brushing area was approx. 9 cm of hairy skin on the left dorsal forearm. Brushing began 60 seconds before participants started the first decision task, in order to familiarize participants with the stimulation, and continued until participants had finished all three decision tasks.

3.5 Economic games

Paper II involved three standard economic games: the Betrayal Aversion Elicitation Task (BAET; Aimone, Ball, & King-Casas, 2015), a dictator game, and the Balloon Analog Risk Task (BART; Lejuez et al., 2002). Each is described in detail below.

3.5.1 The Betrayal Aversion Elicitation Task

The BAET (Aimone et al., 2015) was developed to assess betrayal aversion, defined as people's reluctance to take risk when the outcome depends on a human counterpart rather than chance alone (Bohnet & Zeckhauser, 2004). The task consists of a trust game (TG) and a risk-only trust game (ROTG), illustrated in Figure 1. Both games involve two players, an investor and a trustee. In the trust game, the investor chooses between *in* (trust) and *out* (do not trust). If they choose *out*, both players receive 50 SEK. If they choose *in*, the amount they receive depends on the trustee's choice. The trustee chooses between *left* (reciprocate) and *right* (betray). If they choose *left*, both players receive 75 SEK. If they choose *right*, the investor receives 40 SEK and the trustee receives 110 SEK.

All participants played in the role of investor. They were informed that prior to the study, a group of 20 participants had played the game in the role of trustee. Their task as investors was to choose *in* or *out* for each possible value of the number of trustees that had chosen *left*. They made their decisions by filling out a choice list table consisting of 21 rows reporting all

Figure 1. The Betrayal Aversion Elicitation Task.

possible proportions of trustees choosing *left*, starting with “20 out of 20” in the first row and ending with “0 out of 20” in the last row.

The risk-only trust game is identical to the trust game, except payoffs depend on a random lottery rather than on the trustee’s decision. The lottery was described as an urn containing 20 colored balls that each can be either yellow or green. If a yellow ball is drawn, both players receive 75 SEK. If a green ball is drawn, the investor receives 40 SEK and the trustee receives 110 SEK. The actual number of yellow and green balls was predetermined based on the number of the 20 previous participants who had chosen *left* and *right*, respectively, in the trust game. Thus, the probability of drawing a yellow ball is the same as the probability of being paired with a trustee who chose *left*.

The variable of interest is the minimum acceptable probability (MAP) of being paired with a trustee who chose *left* (or drawing a yellow ball) for which a participant is willing to choose *in*. Each participant’s MAP can be inferred by calculating the mean between the last proportion for which they chose *in* and the first proportion for which they chose *out*, going from the top to the bottom of the choice list table. Betrayal aversion is then calculated as $BA = MAP_{TG} - MAP_{ROTG}$. If $MAP_{TG} > MAP_{ROTG}$, participants are said to be betrayal averse. If $MAP_{TG} = MAP_{ROTG}$, participants are said to be

betrayal neutral. If $MAP_{TG} < MAP_{ROTG}$, participants are said to be betrayal seeking. Previous studies have shown that individuals tend to be betrayal averse, with average betrayal aversion rates of 0.04 (Aimone et al., 2015) and 0.07 (Quercia, 2016) in studies using the BAET specifically.

3.5.2 Dictator game

The dictator game is a standard measure of altruism (see, e.g., Engel, 2011). In the dictator game, the first player (the dictator) decides how to distribute a sum of money between themselves and a second player. The second player does nothing; they simply receive the amount that the first player has decided. In our study, participants played in the role of dictator and chose how to distribute 100 SEK between themselves and UNICEF.

3.6.3 The Balloon Analog Risk Task

The BART (Lejuez et al., 2002) is a computer game designed to assess risk taking. On each trial, a picture of a balloon is presented on the screen. The participant is instructed that they can earn money in the task by pressing a button to pump up the balloon. Each pump inflates the balloon and increases potential earnings by a small amount (0.10 SEK in our study). The participant can choose to stop pumping up the balloon at any time they like and collect their earnings for that trial. However, the game is designed so that each balloon will explode after a certain number of pumps (randomly determined for each balloon). If the balloon explodes, the trial automatically ends and the participant earns 0 for that balloon. The task involves 30 trials (30 balloons). Risk taking is operationalized as the average number of pumps per trial, excluding trials on which the balloon exploded. This variable is known as *adjusted average pumps*.

3.6 fMRI

Functional magnetic resonance imaging (fMRI) is a widely used, non-invasive method to study the function of the brain. fMRI takes advantage of the fact that blood flow increases to regions of the brain where neurons become active. The increase in blood flow leads to a temporary local surplus in oxygenated blood, because the amount of blood sent to the active area is

greater than what is needed to replenish the used-up oxygen. In an fMRI experiment, the participant is brought into a strong magnetic field and the blood-oxygen-level dependent (BOLD) signal is measured as they perform various tasks. The BOLD signal builds on the fact that deoxygenated and oxygenated blood have different magnetic properties. By comparing the BOLD signal during some task to a control task or baseline, it is possible to infer which brain regions are involved in performing that task or processing those stimuli.

fMRI has good spatial resolution, with voxel sizes typically around $3 \times 3 \times 3 \text{ mm}^3$. The temporal resolution is limited by the hemodynamic response time, which peaks around 4–6 seconds following stimulus onset. There are no known risks to participants as long as standard safety guidelines are followed.

3.7 Reproducibility and transparency

In recent years, there has been increasing awareness within the scientific community about issues surrounding the reproducibility and transparency of research. This “credibility revolution” was fueled, in part, by low replicability of published findings (e.g., Camerer et al., 2016, 2018; Open Science Collaboration, 2015) as well as increased awareness of issues such as *p*-hacking (Simmons et al., 2011). Several suggestions have been put forward to increase reproducibility and transparency, including preregistering hypotheses and analysis plans, sharing data, materials, and code in open repositories, and publishing open access—among many others (see, e.g., Munafò et al., 2017). Over the course of my doctoral studies, I have increasingly started to implement these practices, and this is reflected also in the papers included in this thesis. Papers I and II were published open access and materials are publicly available in online supplements. Paper III was preregistered on the Open Science Framework. The preregistration includes a description of the methods, analysis plan, and hypotheses for the main contrasts of interest.

4. Summary of papers

4.1 Paper I

4.1.1 Background and aim

Pain is a salient and attention-demanding experience that motivates people to act. Thus, it has the potential to influence many everyday decisions. In Paper I, we investigated the effect of acute pain on risk taking and intertemporal choice. We theorized that pain would disrupt the reflective System 2 and increase reliance on the intuitive System 1, which might result in increased reliance on automatic biases such as the reflection effect of prospect theory (i.e., reduced risk taking for gains and increased risk taking for losses) as well as increase impatience.

4.1.2 Methods

109 participants (35% female; age 23.4 ± 3.5 years [$M \pm SD$]) completed a series of decision-making tasks, once while experiencing acute thermal pain (pain condition) and once without pain (control condition), in counterbalanced order. In the risky gains task, participants chose between receiving a sum of money with certainty and receiving a (larger) sum of money with 50% probability. In the risky losses task, they chose between losing a sum of money with certainty and losing a (larger) sum of money with 50% probability. In the intertemporal choice task, they chose between a smaller, sooner monetary reward and a larger, later monetary reward. One decision was randomly selected for actual compensation.

4.1.3 Results

The proportion of risky choices in the gain domain was greater in the pain condition than in the control condition. This effect was statistically

significant both in the within-subjects analyses and in the between-subjects analyses of the first round of the tasks, and remained after controlling for factors such as age and gender. However, the difference between pain and control in estimated parameters of risk aversion was only significant in the between-subjects analysis, not in the within-subjects analysis.

There was no statistically significant difference in the proportion of risky choices in the loss domain between the pain condition and the control condition, neither within-subjects nor between-subjects. There were also no effects on estimated parameters of risk aversion, neither within nor between subjects.

The proportion of impatient choices was greater in the pain condition than in the control condition, but this effect was only significant within subjects and not between subjects. Likewise, the estimated discount factor was lower in the pain condition than in the control condition (indicating greater impatience), but this difference was only significant within subjects and not between subjects.

4.1.4 Discussion

Paper I revealed two main findings. First, acute pain increased risk taking in the gain domain but not in the loss domain. Second, acute pain increased impatience; that is, participants in pain showed greater preference for immediate, smaller over delayed, larger monetary rewards. These findings are not entirely in line with predictions based on dual-process theories. However, they are in line with research showing that chronic pain patients exhibit impaired performance on the IGT, which manifests as increased risk taking (Apkarian et al., 2004; Biagianti et al., 2012; Tamburin et al., 2014; Verdejo-García et al., 2009; Walteros et al., 2011). A speculative interpretation is that individuals in pain engage in a form of mood repair by which they opt for larger (but riskier) monetary gains in order to offset the negative affective state that pain causes. Indeed, previous research has found that pain increases the motivation to obtain monetary rewards, while not affecting the pleasure associated with the reward (Gandhi et al., 2013), and that monetary rewards can reduce the perceived intensity and unpleasantness of nociceptive stimuli (Becker et al., 2013, 2017).

4.2 Paper II

4.2.1 Background and aim

Touch has been shown to increase the release of oxytocin, which in turn has been suggested to play a role in trust and prosocial behavior, although empirical findings have been inconsistent. Touch is also said to have a “Midas effect” on judgments and decisions, meaning that it increases positive evaluations and increases compliance with requests. However, this proposition is almost exclusively based on field experiments investigating effects of brief forms of touch, such as a tap on the shoulder. In Paper II, we investigated the effect of affective (CT-optimal) touch on betrayal aversion, altruism, and risk taking.

4.2.2 Methods

120 participants (43% female; age 24.8 ± 6.0 years [$M \pm SD$]) completed a series of decision-making tasks assessing betrayal aversion (the BAET), altruism (a dictator game in which participants distributed 100 SEK between themselves and UNICEF), and risk taking (the BART), once while being stroked on the forearm at 3 cm/s using a soft painter’s brush (touch condition) and once without being stroked (control condition), in counterbalanced order. At the end of the experiment, participants answered questions assessing touch pleasantness, game understanding (of the BAET), and attachment style. One decision was randomly selected for actual compensation.

4.2.3 Results

Results indicated no statistically significant differences between the touch condition and the control condition in (a) the proportions of betrayal averse, betrayal neutral, and betrayal seeking participants, (b) mean level of betrayal aversion, (c) mean amount donated to UNICEF, or (d) adjusted average pumps in the BART, neither in within-subjects analyses nor in between-subjects analyses of the first round of the tasks. There also was no statistically significant moderation of any of the effects by gender, perceived pleasantness of touch, or attachment style.

4.2.4 Discussion

In sum, Paper II found no effect of affective touch on any of the outcome measures—betrayal aversion, altruism, or risk taking—suggesting that affective touch *per se* does not influence decision making. It is possible that the effects of touch observed in field experiments are mediated by processes that we were unable to activate using continuous, CT-optimal touch in a laboratory setting, either because such processes are specific to brief touch or because of contextual variables, or a combination of both. We did not set out to directly test the effect of OT on decision making and therefore did not measure OT levels. Therefore, it is impossible to tell whether the absence of an effect of touch on decision making can be attributed to a failure to increase OT levels or whether OT levels increased without an accompanying effect on behavior. However, given the methodological issues and low replicability of the literature on OT and trust (Declercq et al., 2020; Nave et al., 2015), it is possible that even if OT levels did increase in our study we still would not have observed an effect on behavior.

4.3 Paper III

4.3.1 Background and aim

Pain motivates action to avoid harm. Previous research has shown that the MCC plays an important role in this action component during pain (Perini et al., 2013, 2020), whereas AI responds to pain regardless of action and also predicts whether an upcoming stimulation is perceived as painful (Ploner et al., 2010; Wiech et al., 2010). In Paper III, we investigated how the ability to affect an upcoming painful event with a voluntary action (a button press) influences the brain's processing of ongoing stimulation. We predicted that AI would be involved in predicting upcoming painful stimulation, whereas MCC would be involved only when action matters (i.e., when pain can be avoided by pressing a button).

4.3.2 Methods

fMRI data were collected from 30 participants (43% female; age 24.3 ± 3.3 years [$M \pm SD$]) while they performed a task that involved pressing a

response button to reduce the duration of upcoming thermal stimuli. Each trial involved the administration of a painful or nonpainful stimulus (S1), followed by a very painful or nonpainful stimulus (S2). Participants were instructed to press a response button as fast as they could upon presentation of a response cue during S1. On *controllable* trials (50% of all trials), pressing the response button within a 450 ms time window reduced the duration of S2 from 4 s to 1 s. On *uncontrollable* trials, pressing the response button had no effect on the duration of S2. Participants were instructed to press the response button on all trials, even if pain was uncontrollable. At the start of each trial, participants were presented with a brief (3 s) instruction screen, informing them about the predictive relationship between S1 and S2 (painful or nonpainful) and controllability of the upcoming stimulus (response button: enabled or disabled) on that trial.

4.3.3 Results

An analysis of response times found a main effect of controllability, indicating that participants responded faster when the upcoming stimulation was controllable compared to uncontrollable. There were no main effects of ongoing stimulation (painful vs. nonpainful) or upcoming stimulation (painful vs. nonpainful) and no significant interactions between any of the factors.

A whole-brain analysis of activation during S1 found no significant main effects or interactions between ongoing stimulation, upcoming stimulation, and controllability in any of the predicted brain regions. However, a cluster in ACC showed greater activation when upcoming stimulation was painful than when it was nonpainful (regardless of whether it was controllable by action and regardless of whether ongoing stimulation was painful or nonpainful), and a nearby cluster in ACC showed greater activation for upcoming pain than nonpain when ongoing stimulation was also painful.

Region-of-interest (ROI) analyses found a significant two-way interaction between upcoming stimulation and controllability in right AI (contralateral to stimulation) and significant three-way interactions between ongoing stimulation, upcoming stimulation, and controllability in both left AI (contralateral to the response hand) and MCC. In all cases, activity was greater when upcoming stimulation was painful and controllable. Finally,

MCC activation correlated negatively with response times on trials on which upcoming stimulation was painful and controllable by action. There was no corresponding correlation between response times and AI activation.

4.3.4 Discussion

The findings from Paper III suggest that both AI and MCC are involved in predicting and producing behavioral responses to avoid upcoming painful events. Although whole-brain analyses did not reveal any significant effects or interactions in any of the predicted brain regions, ROI analyses found interactions between upcoming pain and controllability in both AI and MCC. This interaction was expected in MCC, which is involved in producing motor responses during both pain and nonpain (e.g., Perini et al., 2013, 2020). BOLD responses in MCC also correlated with response times, suggesting that the MCC has a particular role in producing motor responses to pain, even when the pain has not yet occurred. Somewhat more surprisingly, we also found an interaction between upcoming pain and controllability in AI. Nevertheless, this finding is in line with research showing that AI is sensitive to the behavioral relevance of pain and that functional connectivity between AI and MCC correlates with a self-reported urge to move during pain (Perini et al., 2020). In sum, our findings suggest that cortical processing of pain is influenced by the noxious nature of upcoming events as well as the ability to affect those events.

5. General discussion

5.1 Main findings

The main findings of the thesis can be summarized as follows. First, pain increased risk taking for monetary gains, but not for equivalent losses, and increased impatience (Paper I). Second, affective touch had no effect on betrayal aversion, altruism, or risk taking (Paper II). Third, both AI and MCC were involved in predicting and acting to avoid upcoming painful stimulation (Paper III).

5.2 Why did we find effects of pain but not of touch?

Pain and affective touch can be viewed as opposite ends of an affective somatosensory continuum: both involve peripheral and central processing, but one is negative and the other is positive. One might think that they would influence behavior in opposite directions. Yet we here found an effect of one but not the other. Why?

A fair comparison between the effects of pain and touch cannot be made, because (a) we do not directly compare their effects and (b) we investigate their effects on different types of decisions—risk taking and intertemporal choice for pain and betrayal aversion, altruism, and risk taking (but using a different task) for touch. The comparison is also complicated by the tendency to use the term *pain* to refer to a subjective experience that is typically separated from the sense of nociception (Gilam et al., 2020; Raja et al., 2020), whereas the term *touch* does not necessarily refer to an emotional experience. Nevertheless, the fact that we found an effect of pain but no effect of touch on decision making raises some questions. Are effects of touch more dependent on the social context (e.g., identity of the toucher) than effects of pain? Are effects of positive affect generally weaker or more ambiguous than effects of negative affect? Is pain a stronger manipulation

of System 1–System 2 processing than touch? I will briefly consider each of these questions.

It is of course possible that the results from Paper II reflect a false negative effect, i.e., that there is an effect of touch on decision making but that our study failed to find it. However, a study that was published shortly after ours also found no effect of CT-optimal touch on decision making in the lab (Rosenberger et al., 2018). Specifically, Rosenberger et al. (2018) compared CT-optimal touch to control touch (e.g., brushing at 0.3 cm/s) on subsequent back-transfers in a repeated trust game in which participants played either with the experimenter (Experiment 1; $n = 50$) or with an unknown person (Experiment 2; $n = 79$) and on a measure of social value orientation in which participants distributed a sum of money between themselves and an unknown other participant (Experiment 3; $n = 45$). Results were similar to ours in that they indicated no effect of affective touch on any of the outcome measures.

5.2.1 Contextual modulation of pain and touch

Affective touch typically occurs between individuals. Although CT-targeted touch is perceived as pleasant regardless of whether it is performed by a human experimenter or a robot (Tricoli et al., 2013), in everyday interactions the identity of the toucher can have a great impact on how touch is perceived. Imagine receiving a soft caress from a romantic partner, and then imagine the same type of touch from a stranger—you probably think the former is pleasant and the latter is unpleasant. In line with this, research has shown that the perception of touch is associated with the strength of the emotional bond between the toucher and the receiver: the closer the bond, the greater the acceptability of touch (i.e., the more body areas can be touched) and the more pleasant the touch is perceived (Suvilehto et al., 2015, 2019). The identity of the toucher also modulates brain responses to touch, particularly in SI and insula (Gazzola et al., 2012; Suvilehto et al., 2020). For example, the specific pattern of activity in these regions can distinguish whether the touch is performed by a partner or a stranger, even when the kinematic properties of the touch are the same (Suvilehto et al., 2020).

The identity of the toucher can also modulate endogenous OT release. Handlin et al. (under review) measured plasma OT levels in female participants who were touched on the arm by their male partners and a male stranger, in counterbalanced order. Results indicated that in participants who were first touched by their partner, OT levels increased from baseline during partner touch as well as during subsequent stranger touch. However, in participants who were first touched by the stranger, OT levels did not increase during stranger touch and, compared to those who were first touched by their partner, showed a lower OT increase during subsequent partner touch.

What these findings might be telling is that it is not touch *per se* that causes prosocial behavior. Rather, touch carries different meanings depending on the social context, and this, in turn, determines the behavioral response. A tap on the shoulder by a waitress might communicate some form of need or affection, which influences the perception of the waitress, which in turn influences tipping behavior. In contrast, prolonged brushing by an experimenter might appear out of context, and even if it is perceived as pleasant and has physiological effects, such effects might not spill over onto behavior in an unrelated task.

In contrast to touch, pain is not typically thought of as a social experience. Although pain can arise as a consequence of the actions of other individuals, the *meaning* of pain—i.e., potential or actual tissue damage—is arguably the same regardless of what the cause is. This is not to say that the painful experience perfectly corresponds to nociceptive input; on the contrary, pain, like any emotional experience, is constructed by the brain, which takes into account not only nociceptive input but also factors such as expectations (Atlas & Wager, 2012) and the presence of monetary gains or losses (Becker et al., 2013, 2017). In line with this, the current IASP definition of pain emphasizes that pain is a personal experience, influenced by biological, psychological, and social factors, and that pain “cannot be inferred solely from activity in sensory neurons” (Raja et al., 2020, p. 2). Nevertheless, once evoked, pain is typically a signal of potential or actual harm.

5.2.2 Is pain more painful than touch is pleasant?

Negative events tend to have greater impact than positive ones. This tendency is known as negativity bias and has been observed in a wide variety of domains, including decision making (for reviews, see Baumeister et al., 2001; Rozin & Royzman, 2001; Taylor, 1991). For example, in risky choice, potential losses tend to be weighted more heavily than potential gains, a finding known as loss aversion (Kahneman & Tversky, 1984; Tversky & Kahneman, 1991). As Kahneman and Tversky (1979) put it, “losses loom larger than gains” (p. 279). Furthermore, people’s *feelings* about potential losses are weighted more heavily than their feelings about potential gains (Charpentier et al., 2016).

In a similar vein, pain might have a stronger effect than touch because it involves negative, rather than positive, affect. In a discussion of the role of emotions in economic decision making, Loewenstein (2000) writes (in a footnote): “I restrict attention to negative emotions because their effects resemble those of drive states such as hunger and feeling states such as pain. The effects of positive emotions are more subtle and complex.” (p. 426). Indeed, “drive states” such as hunger and “feeling states” such as pain typically signal some form of problem or threat—e.g., threat of tissue damage—and there is adaptive value in having a mechanism that makes such states unpleasant and motivates us to do something about it. As discussed in Paper III, part of the painful experience is an “urge” to move, and MCC activation during pain represents an action component that is unspecific to pain (Morrison et al., 2013; Perini et al., 2013, 2020). In contrast, stimuli that activate LTMRs do not typically cause harm, so there is no immediate danger in not acting. On the contrary, touch is sometimes conceptualized as a safety signal; touch requires physical proximity to other individuals, and physical proximity carries additional benefits such as thermoregulation and protection from predators (Morrison, 2016b).

But are effects of positive affect states generally more subtle and complex than those of negative affect states? A quick survey of the literature on affect and risk taking suggests that neither positive nor negative affect influence behavior in a straightforward manner. People in positive (compared to neutral or negative) affect states may have more optimistic risk perceptions (Nygren et al., 1996; Wright & Bower, 1992), but are not necessarily

more risk seeking (Isen & Geva, 1987; Isen & Patrick, 1983; Nygren et al., 1996). People in negative affect states have less optimistic risk perceptions (Johnson & Tversky, 1983; Wright & Bower, 1992), but can be less risk seeking (Raghunathan & Pham, 1999), more risk seeking (Leith & Baumeister, 1996; Mittal & Ross, 1998; Raghunathan & Pham, 1999), or neither (Engelmann et al., 2015; Ferrer et al., 2017). In an attempt to address these seemingly contradictory findings, we investigated how the affective consequences of risky behavior might modulate the effect of incidental affect on risk taking (Koppel, Mederyd, et al., in prep.). Findings from an initial (but low-powered) study suggested that the effect of pain and touch on risk taking depended on whether participants had been told that risk taking has positive, negative, or no effects on mood. However, we were unable to replicate these findings in a more well-powered online study using affective pictures as affect manipulation rather than pain and touch.

The question of whether behavioral effects of negative affect states are stronger than those of positive affect states is confounded with the question of whether negative affect states are *experienced* as more negative than positive affect are experienced as positive. In experimental settings, behavioral effects of positive and negative affect are necessarily dependent on the manipulations used to induce them. In Paper I and III, we calibrated the pain stimulation to a level that participants subjectively perceived as painful. We did not perform a corresponding calibration for touch pleasantness in Paper II, but instead used the kind of stimulation that previously has been shown to be pleasant and to optimally activate CTs. It is possible that the pain was more unpleasant than the touch was pleasant, and that this difference in subjective experience can help explain why we found an effect of pain but not of touch. Another possibility is that affective touch and pain operate on different time courses. Effects of pain might be more immediate, whereas effects of affective touch might occur on a longer time scale and/or after repeated exposure.

5.2.3 Pain and touch as dual-systems manipulations

According to dual-process theories, decisions result from an interaction between intuitive (System 1) and reflective (System 2) processes (Epstein, 1994; Evans, 2003; Kahneman, 2003, 2011; Kahneman & Frederick, 2002;

Stanovich & West, 2000). System 2 is typically conceptualized as a monitoring system that oversees the decisions made by System 1 and overrides them when necessary. However, overriding System 1 requires effort. In situations where we need to make fast decisions or our attention or effort is used elsewhere, System 2 might be less able to fulfil its monitoring role. As a result, decisions are more intuitive and automatic biases are enhanced.

In Paper I, we theorized that pain would disrupt System 2 processes, because of its high salience and demands on attention and cognition (Crombez et al., 1996, 1997; Ecclestone, 1994; Ecclestone & Crombez, 1999; Gunnarsson et al., 2016). One could argue that touch should also disrupt System 2 processes, perhaps by diverting attention away from the decision tasks. Alternatively, one could argue that any affective state is more resource-demanding than a relatively affectively neutral state, and that touch might disrupt System 2 because its affective content is taking up mental resources. However, the opposite seems equally—or perhaps *more*—likely: the calming effects of touch might create optimal conditions for System 2 to operate. Thus, in terms of disrupting System 2, pain might be a stronger manipulation than touch. Being in pain is hard; feeling good is easy.

On the other hand, people in happy moods are more likely to rely on simple heuristics (e.g., Bless et al., 1996; Ruder & Bless, 2003), suggesting that positive affect from touch might increase reliance on System 1. For example, participants in a happy mood who had listened to a story about going out for dinner were more likely to “recall” typical information related to the content of the story even though that information had not been presented, compared to participants in a sad mood (Bless et al., 1996). Participants in a happy, compared to sad, mood were also more likely to make judgments based on how easily information came to mind that was in favor of a given position, known as the ease of retrieval heuristic (Ruder & Bless, 2003). However, it is unclear from these studies whether the effect is driven by the happy or sad mood. Furthermore, the effect of affect has also been shown to depend on which processing style (global, heuristic or local, systematic) is most accessible at the moment (for a review, see Huntsinger et al., 2014).

In terms of the type of content that goes into a judgment or decision, System 1 is typically described as emotional, whereas System 2 is

unemotional. For example, there is a stronger negative correlation between judgments of benefits and judgments of risk when people have five seconds to respond compared to when they have more time (Finucane et al., 2000), and skin conductance responses predict risky choice under time pressure but not time delay (Persson et al., 2018). In other words, under circumstances when System 2 is less able to monitor System 1, people to a greater extent rely on affect when they make judgments and decisions. The tendency to rely on affect in making judgments and decisions has been described in a number of influential theories, including feelings-as-information theory (Schwarz, 1990), the risk-as-feelings hypothesis (Loewenstein et al., 2001), and the affect heuristic (Slovic et al., 2007). These theories posit that people make judgments by consulting an affect pool, as if asking themselves “How do I feel about it?”. Thus, if affect from pain or touch influences a decision, that is arguably a System 1 process. However, even if positive affect from touch indeed appeals to System 1, it does not necessarily mean that touch disrupts System 2.

5.3 Implications and open questions

The papers in this thesis deal with questions that have interested researchers from a variety of disciplines for a long time. Why and how do we make the choices that we make? The research in this thesis should be seen as basic research aiming to get a better understanding of these types of questions, rather than as applied research that aims to solve a practical issue. We do not usually have our hand on a hot stove while deciding whether to lose 50 SEK with certainty or lose 100 SEK with 50% probability. We also do not usually get brushed on the arm with a painter’s brush while deciding how to distribute 100 SEK between ourselves and UNICEF. However, we do regularly make decisions that involve risk, time, and other people, and we live with the consequences of these decisions every day.

The research in this thesis brings us a little bit closer to understanding how people make the choices that they make, and how various circumstances can push our behavior in a certain direction. Both pain and touch are commonly occurring sensations that shape our experiences and behaviors. By using standard outcome measures (decision tasks) from behavioral

economics in a controlled laboratory setting, we can study how factors like pain and affective touch influence decision making and thereby contribute to the broader understanding of how everyday decisions are made. In economics, the focus is often on the outcome of the decision; however, the process by which we arrive at a given decision is equally interesting. The use of fMRI further helps us disentangle the underlying processes. fMRI allows us to infer which regions of the brain are active at a given time, which helps us understand how various experiences and behaviors come about.

Still, this thesis leaves open a number of questions. For example, can the findings tell us anything about decision making in chronic pain patients? And how do people make decisions *about* pain and touch?

5.3.1 Decision making in chronic pain patients

Pain is a common reason to seek medical treatment. 70% of Europeans report having one or more painful experiences per month (Vowles et al., 2014), and 19% report having chronic pain (Breivik et al., 2006). The high prevalence, together with its unpleasant and disruptive nature, makes pain a large societal problem with a high cost.

Can the findings from this thesis tell us anything about decision making in chronic pain patients? Chronic pain patients have been shown to have impaired performance in the Iowa Gambling Task (IGT), which involves choosing between decks of cards with varying gain/loss ratios (Apkarian et al., 2004; Biagianti et al., 2012; Tamburin et al., 2014; Verdejo-García et al., 2009; Walteros et al., 2011). However, less is known about how chronic pain influences everyday decisions such as those that involve choosing between outcomes with different levels of (known) risk or choosing between rewards that are delivered at different points in time (intertemporal choice).

To investigate whether the findings from Paper I generalize to chronic pain, we administered the decision-making tasks to a sample of patients with fibromyalgia ($n = 32$; all women) as well as a group of healthy controls that were matched on age and gender ($n = 22$; Koppel, Nagi, Wentzel Olausson, Gerdle, and Olausson, unpublished data). Fibromyalgia is a condition characterized by chronic widespread pain as well as allodynia, i.e., increased pain response to stimuli that are not typically perceived as painful. Tasks in the fibromyalgia study were identical to the tasks in Paper I, except

the intertemporal choice task was not incentivized. Results indicated no statistically significant overall difference in risk taking—neither in the gain domain nor in the loss domain—or intertemporal choice, between patients and controls.

The sample size in the fibromyalgia study is substantially smaller than the sample size in Paper I, so it is possible that our failure to find an effect is due to low statistical power. However, chronic pain also differs from acute pain in many ways. For example, chronic pain states typically are associated with a number of additional symptoms besides pain, such as anxiety and depression. The mechanisms by which acute pain becomes chronic are not yet fully understood. Therefore, it is uncertain to what extent behavioral effects of acute and chronic pain should be expected to be comparable.

5.3.2 Decision making *about* pain and touch

The papers in this thesis investigated effects of pain and touch on decision making, where decisions involved monetary outcomes and somatosensory stimulation was unrelated to the decision tasks. But what about decision making *about* pain and touch? People often make decisions that involve non-monetary outcomes or make decisions that involve trade-offs between monetary and non-monetary outcomes. For example, we spend money on pain relief and take out sick days at work. These decisions can have enormous societal consequences: in 2008, the estimated cost of pain-related healthcare and reduced worker productivity due to pain ranged from 560–635 billion dollars in the United States, which is greater than the costs of heart disease, cancer, and diabetes (Gaskin & Richard, 2012; for corresponding numbers in Sweden, see Gustavsson et al., 2012). In addition, pain relief is the most commonly reported reason for opioid misuse (Han et al., 2017). Touch, on the other hand, contributes to well-being and plays an important role in social relationships throughout life (Gallace & Spence, 2010; Jakubiak & Feeney, 2017). However, during the current COVID-19 pandemic, physical distancing recommendations make salient that touch itself involves a level of risk—the risk of infection. So how do people make these types of decisions?

In a series of experiments (Koppel et al., in prep.), we compared risky decisions involving painful outcomes to equivalent decisions involving monetary outcomes. Previous research has shown that when outcomes are affect-rich (e.g., painful), people are relatively insensitive to probabilities (e.g., Rottenstreich & Hsee, 2001; Sunstein, 2001), and this probability insensitivity can result in greater risk aversion for affect-rich than affect-poor outcomes (Pachur et al., 2014; Suter et al., 2015). Our findings indicated no support for the hypothesis that people to a greater extent neglect probabilities and are more risk averse when outcomes are affect-rich (painful) than when outcomes are affect-poor (monetary), at least not when decisions were made from description, i.e., when the magnitude and probability of each choice option was explicitly stated. First, participants were not more or less risk averse when they chose between painful outcomes than when they chose between equivalent monetary outcomes, although there seemed to be a (nonsignificant) trend toward increased risk aversion for painful outcomes when decisions were made from experience (i.e., when decisions were made after sampling from each probability distribution). Second, decisions involving painful outcomes were more in line with an expected-value heuristic than decisions involving monetary outcomes, indicating that participants paid more attention to probability information in affect-rich than affect-poor decisions. Third, willingness to pay to avoid pain or monetary loss did not increase more for monetary than for painful outcomes as probabilities increased, although there seemed to be a trend in that direction for higher-stake gambles. Fourth, there was no statistically significant difference in preferences for pain vs. equivalent monetary losses as a function of probability.

The findings from Koppel et al. (in prep.) should perhaps be interpreted with some caution as they are based on studies with relatively small samples (total $n = 174$). A potential explanation for the null findings is that all experiments involved within-subjects designs in which participants made repeated decisions about both monetary and painful outcomes. This may have made changes in probabilities more salient and facilitated the combination of outcomes with their associated probabilities.

5.4 Limitations and future directions

Future studies need to examine both the robustness and the underlying processes of the findings from Paper I. For example, does pain influence the value function or the probability weighting function of prospect theory? Does pain influence the relative value of immediate versus delayed rewards or the choice? To the best of my knowledge, only one other published study has investigated the effect of acute pain on intertemporal choice. Specifically, Rassu et al. (2018) investigated intertemporal choices before and after participants ($n = 85$) had been randomly assigned to either a pain condition (in which pain was induced using the application of a heating pad together with a capsaicin solution) or a control condition. Intertemporal choice was assessed using a questionnaire consisting of 60 hypothetical choices between an immediate and delayed monetary reward. Results indicated no significant effect of condition on intertemporal choice, but increased self-reported pain in the pain condition was associated with lower impatience in the pain condition (although the effect was small). Methodological differences might help explain why their results were different from ours.

Future studies also need to corroborate the findings from Paper III, especially given that our whole-brain analyses revealed no significant effects in any of the predicted brain regions and cluster sizes in regions where a significant effect was found (e.g., ACC) were very small (4–5 voxels). Finally, although Paper II revealed no significant effects of CT-optimal touch on decision making in a laboratory setting, this does not mean that touch does not play an important role in social relationships and well-being. Future research should continue to explore how touch, both of the kind that is optimal for activating CT afferents and other kinds of touch, contributes to decision making and the development and maintenance of social bonds over time.

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Linköping University
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