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**Perception of Facial Emotional Expressions and Touch in
Virtual Face-to-Face Interaction**

Ville J Harjunen

ACADEMIC DISSERTATION

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Supervisors

Niklas Ravaja, PhD
Professor, Department of Psychology and Logopedics
University of Helsinki, Finland

Michiel Spapé, PhD
Post-doctoral researcher, Department of Psychology and Logopedics
University of Helsinki, Finland

Reviewers

Uta Sailer, PhD
Professor, Faculty of Medicine
University of Oslo, Norway

Valeria Gazzola, PhD
Associate Professor, Netherlands Institute for Neuroscience
Netherlands

Opponent

Bettina Forster, PhD
Professor, Department of Psychology
City, University of London, United Kingdom

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Abstract

Emotional expressions as manifested in facial movements, voice, and touch are a crucial part of face-to-face interaction. The majority of existing neuroscientific research on emotional expressions concerns the perception of unimodal emotional cues, such as facial emotional expressions. In natural face-to-face interaction, however, emotions are often expressed as compounds of facial, tactile, prosodic, and postural cues. How the brain processes such multimodal emotional information remains poorly understood. The aim of the current dissertation is to investigate how emotional expressions conveyed consecutively via face and touch are integrated in perceptual processing and decision-making. Four studies were conducted to measure event-related brain potentials (ERPs) and autonomic nervous system responses to simulated touches and facial emotional expression stimuli. The first two studies used virtual reality to investigate how a virtual agent's facial emotional expressions influenced the way the agent's subsequent touch was perceived (Study I) and whether the receiver's individual characteristics influenced this visuo-tactile affective modulation (Study II). Touch perception was measured using self-reports, somatosensory-evoked potentials (SEPs), and cardiac orienting responses (ORs), and the individual characteristics were indexed by behavioural inhibition system sensitivity (BIS) and gender. Study III investigated whether receiving a touch influenced the processing of a subsequent emotional face picture presented on the computer screen. Here, face-evoked ERPs, ORs, and facial electromyography were measured. Finally, the Study IV examined whether a virtual agent's touch and emotional facial expressions influence receivers' decision-making and offer-related ORs in an economic decision-making game. Additionally, the study examined whether the receivers' behavioural inhibition/approach system (BAS/BIS) sensitivities and sensitivity to unfair treatment moderated persuasiveness of nonverbal cues. Study I revealed that happy, angry, and sad facial expressions resulted in amplified SEPs around 20–50 ms after touch onset, whereas in later latencies (250–650 ms), the angry facial expression amplified and the happy expression decreased the SEP amplitudes. In Study II, men with high BIS were found to perceive touch from male agents as especially intense if accompanied by happy, angry, or fearful facial expressions, and they showed pronounced cardiac OR to all the touches. Study III demonstrated that receiving a computer-generated touch did not modulate emotional face processing in any of the measured indices. Finally, in Study IV, people were found to accept unfair offers more often if the agent smiled or touched them before making the offer. The touch had a stronger persuasive influence in people with low sensitivity to unfairness and low approach tendency, whereas the effect of facial expressions was moderated by BIS. Altogether, the findings of the dissertation reveal that a sender's facial emotional expressions modulate subsequent touch perception at a very early stage and that the modulation is based on different emotional information in different temporal stages. In addition, the findings suggest that motivational tendencies and gender influence the manner in which people perceive a sender's

multimodal emotional expressions and make decisions thereafter. These findings are valuable for basic research, but their implications extend also to the development of novel clinical interventions and social virtual reality applications.

Tiivistelmä

Kasvonilmeiden, asentojen, äänenpainojen ja kosketuksen kautta välittyvät tunneilmaisut ovat keskeinen osa sosiaalista vuorovaikutusta. Suuri osa olemassa olevasta tunneilmaisujen neurotieteellisestä tutkimuksesta koskee unimodaalisten tunneilmaisuaikavasteiden, kuten kasvonilmeiden prosessointia. Kasvokkaissa vuorovaikutuksissa tunneilmaisut esiintyvät kuitenkin usein kasvonilmeiden, äänenpainojen, asentojen ja kosketuksen sarjamaaisina yhdistelminä. Aivojen tavasta prosessoida tällaisia moniaistisia tunneilmaisuja tiedetään vielä vähän. Tässä väitöskirjatutkimuksessa tutkittiin, miten peräkkäin esitetyt kasvonilmeet ja kosketus integroituvat toisiinsa aistiprosessoinnin tasolla ja vaikuttavat vastaanottajan sosiaaliseen päätöksentekoon. Väitöskirja koostuu neljästä tutkimuksesta, joissa mitattiin aivosähkökäyrän herätevasteita ja autonomisen hermoston reaktioita kosketukseen ja kasvonilmeisiin. Kahdessa ensimmäisessä tutkimuksessa selvitettiin, kuinka virtuaaliodellisuuteen heijastetun ihmishahmon kasvonilmeet (iloinen, suuttunut, pelokas, surullinen ja neutraali) vaikuttavat hahmon lähettämän koneellisesti tuotetun kosketuksen havaitsemiseen (tutkimus I) ja kuinka vastaanottajan välttämistäipumus ja sukupuoli säätelevät kasvonilmeiden vaikutuksia kosketuksen havaitsemiseen (tutkimus II). Kosketuksen havaitsemista mitattiin itseraportoinnin, somatosensoristen herätevasteiden ja sydämen orientaatiorefleksin avulla. Tutkimuksessa III selvitettiin, vaikuttaako koneellisesti tuotettu kosketus sitä seuraavan emotionaalisen kasvokuvan prosessointiin. Kasvonilmeiden prosessointia mitattiin kasvoärsykkeiden aikaansaamien näköherätevasteiden, kasvolihaskäynnäytin ja sydämen orientaatiorefleksin avulla. Tutkimuksessa IV tarkasteltiin virtuaalihahmon kasvonilmeiden ja kosketuksen yhteisvaikutuksia hahmon taloudellisiin tarjouksiin suostumiseen ja tarjousten aiheuttamaan sydämen orientaatiorefleksiin. Samalla tarkasteltiin, mikäli vastaanottajan lähestymis- ja välttämistäipumus sekä herkkyys epäreilulle kohtelulle säätelevät tunneilmaisuiden suostuttelevaa vaikutusta. Tutkimuksen I tulokset osoittivat, että kosketukset, joita edelsi iloinen, suuttunut tai surullinen ilme johtivat voimakkaampiin varhaisiin herätevasteisiin 20 - 50 millisekuntia kosketuksen esittämisestä. Vastaavasti myöhemmät vasteet (250-650 ms) olivat korostuneempia, jos hahmolla oli suuttunut ilme, ja latistuneita jos hahmo hymyili. Tutkimuksessa II havaittiin, että erityisesti miehillä, joilla oli korkea välttämistäipumus, hahmon kosketus sai aikaan voimakkaan sydämen orientaatiorefleksin. He myös kokivat kosketuksen voimakkaana, kun hahmo ilmaisi kasvoillaan suuttumusta, pelkoa tai iloa koskettaessaan. Vastoin oletuksia, tutkimuksessa III koneellisesti tuotettu kosketus ei vaikuttanut kasvonilmeärsyksen prosessointiin millään mitatuista vasteista. Tutkimuksessa IV havaittiin, että virtuaalihahmon kosketus ja iloinen/neutraali kasvonilme lisäsivät suostuvaisuutta hahmon esittämiin epäreiluihin taloudellisiin tarjouksiin. Kosketus johti suurempaan suostuvaisuuteen henkilöillä, joilla oli alhainen herkkyys epäreiludelle ja alhainen lähestymistäipumus. Kasvonilmeiden vaikutusta suostuvaisuuteen sääтели vastaanottajan välttämistäipumus. Yhteenvedona tulokset

osoittavat, että vuorovaikutuksessa ilmaistut kasvonilmeet ja kosketus integroituvat toisiinsa hyvin varhain ja että integraatioprosessi on monivaiheinen. Myös persoonallisuuspiirteillä ja sukupuolella näyttää olevan merkittävä rooli multimodaalisten tunneilmaisuiden havaitsemisessa ja vaikutuksessa päätöksentekoon. Tutkimusten tuloksia voidaan tulevaisuudessa hyödyntää uusien kliinisten interventioiden kehittämisessä sekä virtuaalisten viestintäteknologioiden suunnittelussa.

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List of original publications

The thesis consists of four original research papers, which are referred to in the text using Roman numerals:

- I. Ravaja, N.*, Harjunen, V. J.*, Ahmed, I., Jacucci, G., & Spapé, M. M. (2017). Feeling Touched: Emotional Modulation of Somatosensory Potentials to Interpersonal Touch. *Scientific Reports*, 7, 40504.
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- II. Harjunen, V. J., Spapé, M., Ahmed, I., Jacucci, G., & Ravaja, N. (2017). Individual differences in affective touch: Behavioral inhibition and gender define how an interpersonal touch is perceived. *Personality and Individual Differences*, 107, 88-95.
- III. Spapé, M. M., Harjunen, V. J., & Ravaja, N. (2017). Effects of touch on emotional face processing: A study of event-related potentials, facial EMG and cardiac activity. *Biological Psychology*. 124, 1–10.
- IV. Harjunen, V. J., Spapé, M., Ahmed, I., Jacucci, G., & Ravaja, N. (2018). Persuaded by the machine: The effect of virtual nonverbal cues and individual differences on compliance in economic bargaining. *Computers in Human Behavior*, 87, 384-394.

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Abbreviations

BIS/BAS	Behavioural inhibition/approach system
CS	Corrugator supercilii
EASI	Emotions as social information -model
ECG	Electrocardiography
EEG	Electroencephalography
ERP	Event-related potential
fEMG	Facial electromyography
GEE	Generalized estimating equation
HMD	Head-mounted display
IAPS	International affective picture system
IBI	Interbeat interval
JS	Justice sensitivity
LN	Levator labii superioris alaeque nasi
MLM	Multilevel linear model
OO	Orbicularis oculi
OR	Orienting response
SEP	Somatosensory-evoked potential
SI	Primary somatosensory cortex
VR	Virtual reality
ZM	Zygomaticus major

1 Introduction

Emotions regulate the way we interact and collaborate with each other by structuring ongoing interactions, conveying information about our intentions to others, and solving problems in social relationships (Keltner and Haidt, 1999). These social functions of emotions are largely based on nonverbal emotional expressions, which refer both to direct facial, gestural, postural, vocal, or tactile manifestations of the individual's internal emotional state and to everyday actions (e.g., walking and shutting a door) executed in an emotional manner (Atkinson, 2013). A substantial amount of research has been conducted to understand how people perceive and identify emotions from nonverbal expressions. Initially, investigation of this cognitive process, also referred to as emotion perception (Mitchell & Phillips, 2015), was based on behavioural measures, observational techniques, and self-reports (Darwin, 1872/1998; Ekman, 1992; Frijda, 1986). Research investigated how people interpret and label different facial, vocal, and gestural emotional cues. Later, research extended to the physiological responses and brain activity associated with the perception of different expressive behaviours, with the focus being on facial emotional expressions (see George, 2013, for a review). As a result of the research efforts, it became evident that seeing another person expressing emotion on their face activates broad networks in the perceiver's brain, including areas related to configural visual processing of the face and those involved in producing the corresponding emotion in the perceiver (Calvo & Nummenmaa, 2016).

While studies on facial expression processing continue to dominate research on emotion perception, interest has increased in the perception of other nonverbal emotional expressions as well (Schirmer & Adolphs, 2017). One of these is touch, which is a particularly important channel of emotional communication in intimate relations (Gallace & Spence, 2010). The majority of neuroscientific research on emotional touch concerns the processing of gentle caressing that selectively stimulates the so-called CT afferents that innervate hairy skin (Löken, Wessberg, Morrison, McGlone, & Olausson, 2009). Receiving this CT touch vigorously activates the posterior insula, an area involved in detecting emotional relevance (Olausson et al., 2002). More recent studies have demonstrated that social contextual cues, such as information about the toucher's gender, modulate the somatosensory processing of the CT touch already at the level of early decoding of tactile sensory features in the primary somatosensory cortex (e.g., Gazzola et al., 2012).

Despite the growing understanding of emotion perception from face and touch, the cognitive processes by which different unimodal sensory signals integrate into a holistic percept remain poorly understood. Understanding the integration process is crucial, since in natural face-to-face interaction, emotions are often expressed as multimodal compounds of emotional cues. For example, let us think about a situation in which a mother caresses her baby or where a couple hugs after a long separation. The baby sees their mother's smile and feels her fingertips on their cheek. Similarly, a man sees his spouse sparkling with joy and then feels their arms around him. In both

situations, separate sensory inputs from vision and tactile sense become a part of the same affective message and it is extremely difficult, or sometimes impossible, for the perceiver to disentangle the inputs. How the binding of facial and tactile emotional inputs occurs and at which stage of cognitive processing it begins is poorly understood. Therefore, this dissertation research aims to increase scientific understanding in this regard.

However, investigating the perception of multimodal emotional expressions in ecologically valid settings poses new methodological challenges for experimental brain research. For example, it is not possible to ask a human confederate to show certain facial expressions and to touch the participant with accuracy at the millisecond level and to then ask them to repeat the actions hundreds of times to obtain reliable brain responses to the stimuli. Therefore, novel methodological approaches are needed to attain high ecological validity without compromising experimental control. Virtual reality (VR) accompanied by electrophysiological measures offers a solution to the problem (see Blascovich et al., 2002), as, with VR, the facial and tactile emotional expressions can be presented as originating from a single embodied source, a photorealistic co-present virtual human, in a vivid but highly controlled manner.

This dissertation consists of four research articles that together address two general aims: 1) to understand how serially conveyed facial emotional expressions and touch modulate each other at the level of sensory-perceptual processing and 2) to understand how these nonverbal emotional expressions ultimately influence social decision-making between the interactants.

The introduction proceeds as follows. In Sections 1.1 and 1.2, I briefly examine the concept of emotion and competing emotion models. Thereafter, in Section 1.3, I review earlier neuroscientific research regarding the perception of facial emotional expressions and interpersonal touch and take a brief look at the influence of facial emotional expressions and touch on social decision-making. Section 1.4 describes the methodological potential of VR and haptic technology. Finally, in Section 1.5, I reiterate my research aims and present five research questions addressed over the course of this dissertation.

1.1 Defining emotion

Most people, including emotion researchers, find no difficulty in understanding emotions on an introspective level, but they struggle when asked to define the phenomenon in exact scientific terms. This is unsurprising, given that emotion has no unitary essence but rather is a distributed process consisting of multiple *components* including cognitive appraisals, neurophysiological activity, action tendencies, feelings, and expressive behaviours (Panksepp, 2005; Russell, 2009; Scherer, 1984). A person who undergoes an emotional episode performs a rapid automatic evaluation of the situation's relevance to him- or herself (appraisal), has an urge to act in a certain way (i.e., action tendency), exhibits coordinated changes in autonomic and central nervous system activity, and expresses these changes in words and body language. In addition, the person feels a holistic emotional experience in their consciousness. All these coordinated changes are part of the concept of emotion (Sander, 2013).

Different emotion theorists have focussed on different components and perceive the components' causal order differently. While some focus on the conscious conceptualisation of one's body state and see that as the starting point of an emotional episode (Barrett, 2006), others see emotions as arising from cognitive appraisals about the situation's implications to one's wellbeing and goals (Lazarus, 1991). Despite the differences, the majority of emotion models (e.g., appraisal theories, basic emotion theories, and dimensional approaches) posit that some level of cognitive appraisal of the situation's functional value is required to elicit an emotional response (Sander, Grandjean, & Scherer, 2018). The eliciting appraisals are likely to be automatic and unconscious and occur on the spot via a constructive combination of information from the external environment, body, and memories (e.g., Moors, 2014). In a few, limited, situations, such as hearing a loud bang or tasting something disgusting, emotional responses can, however, be elicited by a reflex-like mechanism lacking any interpretation of the relation between the event and perceiver (see Zajonc, 1980; Lang & Bradley, 2010).

Throughout the history of emotion research, emotions have been seen as products of natural selection that have promoted our ancestors' survival in harsh and dangerous circumstances (Darwin, 1872/1998; Ekman, 1992; Ledoux, 1989). Therefore, emotions are readily evoked by biologically relevant events and objects that threaten or nurture an individual's goals to stay alive and thrive (Bradley, 2009; Ekman, 1992; Frijda, 1986; Lazarus, 1991, Scherer, 1984). For example, a refugee who escapes an intense fire is driven by fear that vanishes and turns into relief only after reaching safety. However, not all emotion-inducing events are directly related to survival; they can also be related to other concerns, such as loss of self-esteem (Frijda, 1986). In other words, our emotional landscape is not fully determined by natural selection but is constantly modified by personal life history and culture, which together shape our goals, desires, and values and adapt our behaviour to changing environmental demands (Frijda & Sundararajan, 2007; Mesquita & Boiger, 2014).

Environmental demands are in constant change. Therefore, it is only logical that emotions are characterized by a brief onset and short duration. The transitory nature

of emotion makes them distinct from other affective phenomena such as moods, attitudes, dispositions, and motives (see Ekman, 1992; Sander, 2013). Emotions activate a multitude of organs, which makes them particularly costly in terms of metabolic resources (Levenson, 2011). As a metabolically costly and swift mechanism, emotions can be seen as an extension to the automated homeostatic regulation system that safeguards biological life (Damasio, 2003).

To conclude, emotions can be defined as combinations of cognitive appraisals, neurophysiological activity, action tendencies, feelings, and expressive behaviours. They are elicited by events with a particular relevance to the person and are relatively brief in duration compared to other affective phenomena (Sander et al., 2018). This minimal definition of emotion unites emotion researchers across epistemological boundaries (Sander, 2013). Aside from this common ground, there are disagreements that culminate in competing emotion models on how to conceptualize variation in emotional states. I describe some of these models next, as they help to understand different conceptual and methodological approaches with which to study emotion perception.

1.2 Models of emotion

Among the various models of emotion, basic emotion theories, dimensional theories, action tendency models, and appraisal theories are arguably the most prominent. Basic emotion theories have their roots in Darwin's (1872/1998) seminal work on emotional expressions, which was continued by Paul Ekman, and Nico Frijda in their cross-cultural research on emotion recognition (Ekman, 1992, Frijda, 1986). A basic tenet of the theories is that there is a small set of fundamental emotions, which have their roots in evolutionary history and differ from each other in terms of adaptive functions, expressive behaviours, and neurophysiological signature (Ekman, 1992, 1999). The typical set of basic emotions includes anger, disgust, fear, joy, sadness, and surprise (Ortony & Turner, 1990). Originally, this set was identified based on observed regularities in facial expressions (Matsumoto & Ekman, 2009) and autonomic nervous system activity (see Kreibig, 2010). Later, emotion-specific activity patterns were demonstrated in distinct networks of distributed neural substrates (Saarimäki et al., 2016). Despite its long roots and the evidence supporting it, the model has been challenged by an accumulation of findings which suggest, for instance, that there is no one-to-one mapping between specific brain regions and distinct emotion categories and that the way to label facial emotional expressions varies more than suggested by basic emotion theorists (e.g., Barrett, 2013).

In contrast to the distinct categories favoured by basic emotion theories, dimensional theories describe emotions as occurring on a spectrum (Russell, 1980; Russell & Barrett, 2009). Many dimensional theories build on Russell's (1980; 2003) circumplex model of affect and the core affect theory, according to which all conscious emotional states arise from two fundamental neurophysiological systems: one related to valence (positive vs. negative) and another related to arousal (tense vs. relaxed).

These systems form a core affect that is consciously accessible as feeling good or bad, tense or relaxed (Russell, 2005; Posner, Russell, & Peterson, 2005). The main criticism of dimensional models is that they lack the resolution of basic emotion theories in distinguishing clearly different emotional instances (e.g., disgust and fear) and focus mainly on conscious feelings (e.g., Sander, 2013).

Variation in emotional states can also be examined based on action tendencies (see Carver, 2004; Harmon-Jones & Gable, 2008). For example, some emotional states, such as joy and anger, are associated with an urge to go towards or approach an object, whereas others, such as fear and disgust, are associated with urge to go away or withdraw from an object (Harmon-Jones & Gable, 2008). A particularly important contribution of the action tendency models is the realization that negative emotion can be both approach- or withdrawal-oriented (Harmon-Jones, Gable, Peterson, 2010).

Finally, there are the so-called appraisal theories, according to which people evaluate situations, events, and objects with respect to factors of novelty versus familiarity, pleasantness versus unpleasantness, goal-relevance, whether they are causal elicitors, and coping abilities with respect to them (Scherer, 1984; see Moors, Ellsworth, Scherer & Frijda, 2013 for a review). The models assume that there are regularities among certain types of situations, appraisal values, and emotional responses elicited by the appraisals (Moors, 2014). For example, a person might encounter a stranger who insults his or her friend, and the person might appraise the situation as unexpected, highly relevant, and incongruous with his or her goals, the stranger as accountable for the situation, and oneself as capable of coping with the circumstances. This appraisal gives rise to core experience (or a core relational theme) of other-blame followed by the conscious feeling of anger (e.g., see Smith & Lazarus, 1993).

As can be seen, different emotion models emphasize different components of emotion and different phases of emotional episodes. Moreover, the models differ in their level of abstraction (Sander et al., 2018). For instance, the dimensions of arousal and valence describe a conceptual space in which the basic emotion categories can be mapped. The basic emotion categories, in turn, can be seen as higher-order concepts for the endless variations in the multiple appraisal factors (novelty, pleasantness, goal-relevance, etc.). According to Sander et al. (2018), there may still be a lower conceptual level present in some emotion models that mainly concerns rapid, minimally reflective evaluations of emotionally salient events (e.g., loud noises). These evaluations differ from reflective appraisals, as they require very scarce processing of the evoking event and are reflected in reflex-like changes in the organism's sensory intake, attentional orienting, and motor preparation (see Figure 1). A suitable example of emotional responses on this level are the startle reflex and the cardiac orienting response (Bradley, 2009).

Examining the competing emotion models as parts of a large conceptual framework that combines all the mentioned levels becomes especially useful when trying to make sense of a complex affective phenomenon, such as communicating emotions in face-to-face interaction. To lend structure to this complex phenomenon,

we can use basic emotion categories to label the facial expressions and dimensional approach to measure people’s conscious reactions to the expressions. Then, examining different emotional expressions through the lens of action tendencies can help determine whether their neural and behavioural influences on the perceiver are related to the expressed motivational orientation. For example, facial expressions of anger, disgust, and fear all convey negatively valenced emotions, but fear and disgust both signal motivations to withdraw, whereas anger is related to approach motivation. It is possible that perceivers respond differently to approach- and avoidance-related negative expressions in face-to-face contexts. Finally, inspecting the influences of emotional expressions through appraisals of novelty, goal-relevance, causality, and coping, can reveal yet another layer of emotion perception. For instance, it is possible that certain emotional expressions are appraised as more salient or unexpected in certain social contexts and thus evoke stronger attention-related neural responses.

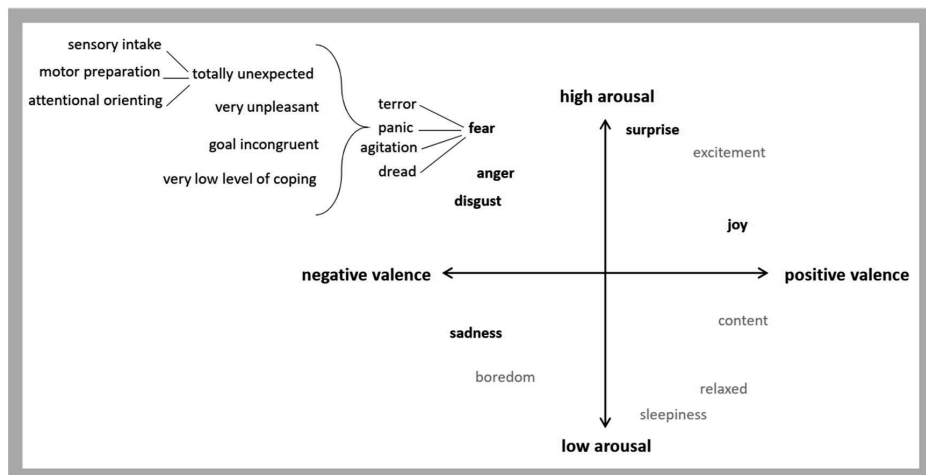


Figure 1. Conceptual hierarchy of emotion-related concepts as presented in dimensional (vertical and horizontal axes), basic emotion approach (emotion words in bold), and appraisal theories (within curly brackets) illustrated based on the written description of Sander et al. (2018). The upper left corner presents how the concept of fear can be break down to smaller and smaller conceptual units. The hierarchical order presented here is conceptual and does not describe the temporal order of the units.

In sum, a complementary set of emotion models help guide research on emotion perception in complex naturalistic settings, such as face-to-face interaction. Before going deeper to such complex settings, I examine the elementary features of facial emotional expressions and interpersonal touch and how they are perceived and processed in the brain.

1.3 Nonverbal communication of emotions

The foundations of research on nonverbal emotional expressions were laid in Darwin's (1872/1998) seminal work *The Expression of the Emotions in Man and Animals*. Darwin saw nonverbal emotional expressions as "serviceable motor habits" crucial to the individual's survival. For example, when feeling afraid, people keep their eyes wide open to efficiently scan the environment for potential dangers, whereas when feel disgusted, people wrinkle their noses and look away to minimize sensory exposure to the repulsive objects or events (e.g., George, 2013; Susskind et al., 2008).

What has long intrigued emotion researchers is that the functionality of nonverbal emotional expressions is not limited to intrapersonal adaptive reactions but extends to interpersonal interactions as well (Keltner & Haidt, 1999). Perceiving others' nonverbal emotional expressions helps understand their affective states, intentions, and relational orientations (i.e., submissive vs. dominant) and to coordinate the interaction accordingly (Ekman, 1992; Fridlund, 1992). The emotional expressions of others may also inform us about relevant events or objects in the environment (e.g., snake on the ground) that we did not notice or to which we did not know how to react (Mineka & Cook, 1993). These functions are clearly present, for instance, in the context of childcare when the child looks to their caregiver to decide whether a situation is dangerous. In dyads and groups, emotions can also be expressed to evoke complementary or reciprocal emotional responses in the recipients (Keltner & Haidt, 1999). For instance, a person who has just been caught violating a norm can express shame with a submissive body posture to evoke empathy in the witnesses (Keltner, 1995) or anger with frowning and a dominant body posture to invoke fear in them (e.g., Evans et al., 2008).

Nevertheless, the social influence of an emotional expression depends largely on how the recipient perceives and interprets it. Indeed, the majority of emotion research concerns perception rather than the production of emotional expressions. I next move to emotion perception, focussing on facial expressions and touch and describing how these two types of nonverbal expressions are perceived, interpreted, and processed in the brain.

1.3.1 Facial emotional expressions

The facial muscles involved in different emotional expressions control large and spatially separate parts of the face, which allows people to distinguish between different emotional expressions based on very scarce visual information such as blurred images (Smith & Schyns, 2009). Indeed, people have long been thought to be innately predisposed to recognize emotions from facial cues, irrespective of their cultural background or life history (Darwin, 1872/1998; Ekman, 1992; Frijda, 1986). This assumption of universality is also supported by a large amount of cross-cultural studies that have demonstrated how people from isolated, illiterate communities label the facial expressions of basic emotions using similar emotion words as people from major cultural groups (Ekman, 1999).

Despite this dramatic cross-cultural evidence, criticism of the assumption of the universality of basic emotions comes from several sides (Crivelli & Fridlund, 2018; Gendron, Crivelli, & Barrett, 2018). For example, while people are able to recognize certain emotional expressions, they are better at identifying the emotional expressions of those who belong to the same ethnic, national, and geographical group as they (Jack, Blais, Scheepers, Schyns, Caldara, 2009). Moreover, recognition performance is higher in western and literate people than in people living in isolated, illiterate communities (e.g., Aviezer, Hassin, Bentin, & Trope, 2008) and varies substantially depending on surrounding social cues (Crivelli, Russell, Jarillo, & Fernández-Dols, 2017). Therefore, on the level of emotion recognition, the perception of facial emotional expressions is relatively consistent but heavily influenced by exposure, cultural background, and social framing.

1.3.1.1 Emotional face processing: The involved neural networks

In addition to behavioural studies, a substantial amount of research has been conducted to examine the neural systems involved in processing the facial expressions associated with emotion (George, 2013). According to current understanding, emotional face processing involves a broad network of neural substrates (Calvo & Nummenmaa, 2016). The network includes areas from the visual cortex such as the inferior occipital and fusiform gyri, which are involved in processing invariant aspects in the face (e.g., facial identity), and the superior temporal sulcus, which is sensitive to perceiving biological movement (Gobbini & Haxby, 2007). In addition to these visual perceptual regions, the perception of facial emotional expressions activates areas that are also involved when the perceiver goes through a similar emotional episode (e.g., Adolphs, 2002; Calvo & Nummenmaa, 2016). These areas include the amygdala, the insula, the pulvinar, the ventromedial prefrontal cortex, the orbitofrontal cortex, the anterior cingulate cortex, the supplementary motor area, the somatosensory cortex, the inferior and middle temporal gyri, and the temporal pole (Breiter et al., 1996; Calvo & Nummenmaa, 2016; Roy, & Wager, 2012; Tamietto & de Gelder, 2010; Wicker, Perrett, Baron-Cohen, & Decety, 2003). Some of these regions seem to be activated in an emotion-specific manner. For instance, the amygdala has been found to activate more strongly in response to fearful than to neutral or happy expressions (Morris et al., 1996), whereas the insula and basal ganglia have been shown to selectively activate in response to disgusted faces (Wicker et al, 2003). By contrast, areas such as the amygdala and insula are also part of the so-called salience network, which is responsive to all kinds of emotionally salient stimuli (see George, 2013, for a review).

The majority of the results reviewed above are based on functional magnetic resonance imaging (fMRI), which is useful in detecting which areas and networks are involved in emotional face processing. However, the fMRI methodology lacks the temporal resolution required to determine when and in which order the processing occurs. Disentangling the various processing stages is important, since emotional face processing involves so many low- and high-level cognitive functions. Electroencephalography (EEG) offers a sufficiently high temporal resolution to

determine the time course of those functions, using multiple surface electrodes to measure voltage changes on the scalp that are the result of summing neurons' postsynaptic potentials (Luck, 2005). The most common means of investigating emotional face processing with EEG is to measure the so-called event-related potentials (ERPs; George, 2013), which are assumed to result from bursts of postsynaptic potentials related to a specific sensory, motor, or cognitive event (Rugg & Coles, 2008). By time-locking the ERP responses to the onset of the emotional face stimulus, one is able to examine the time-course of emotional face processing with a temporal resolution of few ms (Luck, 2005). I next review some of the key ERP findings related to emotional face processing.

1.3.1.2 Temporal dynamics of emotional face processing

ERP studies on emotional face processing reveal that the processing that distinguishes between emotional and neutral faces starts at a very early stage, with coarse information extraction taking place around 100 ms post-stimulus (Schirmer & Adolphs, 2017). There are two ERP components (positively or negatively directed waves or peaks) linked to this early stage: a positive parieto-occipital P1 component (for a review, see Vuilleumier & Pourtois, 2007) and a negative fronto-central N1 component (e.g., Luo, Feng, He, Wang, Luo, 2010). The P1 is thought to have an extrastriate visual origin, whereas the N1 is assumed to be related to the coarse information processing that occurs in the networks between the orbitofrontal cortex and the amygdala (Luo et al., 2010; Schirmer & Adolphs, 2017). It is also possible that the both components are part of the same attentional modulation process that originates from the colliculo-pulvinar pathway that afferents the amygdala (Adolphs, 2002). The amygdalar involvement in these two early components is supported by the observation that both N1 and P1 are selectively amplified by fearful compared to happy and neutral facial expressions in conditions of limited attentional resources (Luo et al., 2010).

A modifying influence on emotional expressions also occurs in the N170 component, which is an electrophysiological index of configural face processing (e.g., Batty & Taylor, 2003). The N170 can be detected at lateral occipitotemporal electrodes around 130–200 ms and is commonly accompanied by vertex positive potential (VPP), which peaks at the same temporal range. The N170 and VPP are thought to originate from the same neural dipole, located around the fusiform gyrus and superior temporal sulcus (e.g., Itier & Taylor, 2002). A recent meta-analysis of 57 studies revealed that the N170 is stronger in response to emotional than neutral expressions and particularly amplified in response to angry, fearful, and happy facial stimuli (Hinojosa, Mercado, & Carretie, 2015), therefore suggesting that even the configural stage of visual processing is affected by the expression's emotional features.

After configural face processing, a distributed cortical network becomes involved. This stage is suggested to relate to extracting meaning and selecting a response to the expression (Adolphs, 2002). Starting at between 250–400 ms, this stage is

characterized by two late positive components: P300 and LPP (Schupp et al, 2004). The P300 is known to be responsive to all kinds of unexpected, meaningful, or task-relevant stimuli and is thought to reflect processes related to attention allocation and memory activation (Polich & Kok, 1995). In facial emotion recognition tasks, the P300 as well as LPP are more enhanced in response to emotional than neutral faces (Eimer & Holmes, 2007). While many studies have suggested that the late processing stage is not sensitive to any particular emotion (Eimer & Holmes, 2007), others have shown the P300 to be sensitive to different emotional expressions depending on the availability of attentional resources. For instance, Luo and colleagues (2010) showed that when attentional resources are scarce due to attentional blink, the fearful expression elicits stronger P300 than a happy or neutral expression, but when the attentional resources are adequate, the P300 is equally sensitive to fearful and happy expression but less so to neutral faces. Finally, computational clustering of face-evoked ERP components based on basic emotion categories has been used to show that amplitudes in P300 and LPP time ranges differ, at least between fearful, happy, and neutral facial expressions (Zhang, Luo, & Luo, 2013).

To conclude, there seems to be at least three temporal stages of emotional face processing: 1) attentional amplification of visual perception, indexed by the P1/N1 components; 2) emotionally amplified face-specific processing, indexed by the N170/VPP components; and 3) attention and memory-related semantic or response selection stage, characterized by sustained and more broadly localized P300 and LPP components. In addition to these electrocortical changes, there are emotional face-related reactions in the autonomic nervous system, which I review next.

1.3.1.3 Emotional face processing and autonomic nervous system activity

Electrocardiography is an electrophysiological measure used to record electrical changes on the skin caused by the heart's ventricular contractions. The ECG signal consists of sequences of Q, R, and S wave components. In psychophysiological experiments, researchers typically measure the latencies between successive R waves (also called as interbeat intervals or IBIs; Berntson, Quigley, & Lozano, 2007). The IBIs describe the temporal variations between cardiac cycles and are used to calculate indices such as heart rate (R-waves, i.e., beats per minute) and heart-rate variability. In addition to these, the IBI can also be used as an immediate event-related measure of cardiac activity (Bradley, Lang, & Cuthbert, 1993). In studies where pictures of facial emotional expressions have been shown to the participants, presentation of angry and fearful facial expressions has been shown to evoke a brief deceleration in cardiac cycles (i.e., an increase in IBIs) around 1000–3000 ms post-stimulus that is larger than the deceleration evoked by happy face stimuli (Jönsson & Sonny-Borgström, 2003; Peltola, Leppänen & Hietanen, 2011). Such deceleration, also referred to as a cardiac orienting response (OR, Bradley, 2009; Sokolov, 1990), also occurs in response to unexpected and aversive stimuli when, for instance, blasting noise into the participant's ear or showing the participant an aversive picture of snake and a wounded body (Bradley, Lang, & Cuthbert, 1993). Consequently, cardiac OR

has been seen as an index of increased sensory intake and attentional orienting to potentially threatening events (Bradley, 2009). In the context of emotional face processing, cardiac OR reveals a glimpse of the somatic manifestation of increased sensory intake in response to emotionally salient facial behaviours.

With facial electromyography (fEMG), in turn, we can measure changes in electrical activity produced by contractions in facial muscle fibres. Recordings of fEMG in response to emotional facial expression stimuli have revealed activity in corresponding muscle groups of the perceiver from between 500 and 1000 ms post-face stimulus (Dimberg & Thunberg, 1998). For example, seeing a happy face has been shown to activate the zygomaticus major (ZM; draws the angle of the mouth) and orbicularis oculi (OO; draws the eye lid) muscles, and seeing an angry face has been shown to activate the corrugator supercilii (CS; pulls the eyebrow downward) muscle. These muscles are the exact same muscles involved in producing a smile or frown in the sender (Dimberg, 1990). Thus, the sender's emotional expressions are mirrored by the perceiver's facial musculature. The reason for this unconscious mimicry is unclear, but it has been suggested to represent a primitive form of emotional contagion that fosters the ability to understand others' emotional states through motor simulation (Hatfield, Bensman, Thornton, & Rapson, 2014).

Compared to ERPs, both autonomic responses are much later, although the mechanisms that evoke them are argued to be very early and unconscious (Critchley et al., 2005). Accompanying the ERPs by autonomic nervous system measures is important as it allows us to follow up the pipeline of emotional face processing beyond the initial information extraction stage to the stages of somatic changes and motor preparation. Next, I move to the other nonverbal channel of emotional communication: interpersonal touch.

1.3.2 Interpersonal touch

1.3.2.1 The physiology of touch

The skin of adult human covers an area of approximately 17 m², forming the largest sensory organ of our species (Montagu, 1972). With the various receptors innervating the skin and organs, we perceive the shapes of our external environment, use our limbs and tools to manipulate its objects, and interact with others around us.

Two functionally distinct subsystems, the kinesthetic and cutaneous systems, constitute the human tactile sense. The kinesthetic system provides information on one's limb movements and body orientation and operates based on receptors innervating the muscles and internal organs (Clark & Horch, 1986). The cutaneous system is responsible for detecting changes in pressure, texture, shape, and temperature on the skin (Lederman & Klatzky, 2009). Many different receptors are specialized to discriminate these different tactile features, and together, these receptors form the so-called discriminative touch system (McGlone, Wessberg, Olausson, 2014). Mechanoreceptors are the largest group of these receptors and are selectively activated by skin deformations such as stretching, vibration, or pressure (e.g., Johnson,

2001). In addition to the discriminative touch system, other receptors, known as CT-afferents, are selectively responsive to gentle stroking and innervate the non-glabrous (i.e., hairy) skin and activate the most in response to a caress moving at a speed of 3–5 cm/s (e.g., Löken et al., 2009). People have been shown to perceive this CT-optimal stroking as particularly pleasant (Olausson et al., 2007).

The processing of touch begins with the receptors but does not end there. For example, the mechanoreceptors innervating hand skin convert the tactile event into electrical signals that ascend the spinal cord via long axons (Mountcastle, 1957, Abraira & Ginty, 2013) to the brainstem, whence it moves further to the contralateral thalamus (Abraira & Ginty, 2013). Thence, the signal is sent to the contralateral primary somatosensory cortex (SI) where a serial processing of the signal's tactile features extracts information of the location, orientation, velocity, and intensity of the touch (e.g., Iwamura, 1998). Electroencephalography studies have revealed that medial nerve stimulation of the wrist results in series of short-latency somatosensory-evoked potentials (SEPs) peaking around 20–50 ms post-stimulus in the contralateral central electrodes (e.g., Rossini, Gigli, Marciari, Zarola, Caramia, 1987). These early SEPs were first thought to have a thalamic origin but have since been shown to originate from the contralateral primary somatosensory cortex. (see Urbano et al., 1997)

From the SI, the signal moves on to the secondary somatosensory cortex (SII), where features are bound together to form a unitary representation of the tactile event (Servos, Lederman, Wilson, Gati, 2001). After passing the SII, the flow of processing divides into two different streams: one terminating in the insula and another in the posterior parietal cortex. The insula, especially in its posterior part, is suggested to have a central role in detecting the emotional relevance of the touch (Davidovic, Starck, Olausson, 2019), whereas processing in the posterior parietal cortex is related to action preparation and execution (Azañón, Longo, Soto-Faraco, Haggard, 2010).

It is worth noting that the described pathway concerns discriminative touch receptors and that the CT-afferents have a slightly different pathway. For example, CT touch has a more direct projection onto the posterior insula, and caresses that optimally stimulate the CT afferents activate the insula more than CT-nonoptimal touches and are judged as more pleasant (Olausson et al., 2002). Due to this bottom-up¹ (i.e., driven by the features of the stimulus) influence, the CT touch is sometimes considered to be the primary form of social touch (e.g., Morrison, Löken, & Olausson, 2010; Olausson, Wessberg, Morrison, McGlone, Vallbo, 2008). However, CT touch is only one of many forms of interpersonal touch. Therefore, interpersonal touch should be considered as a complex combination of various physical, contextual, and personality-level features with a constant interplay between bottom-up and top-down (context-driven) influences (see Willemse, 2018).

¹ In perception, bottom-up refers to perceptual processing based on stimulus features captured by the sensory receptors (e.g., mechanoreceptors of the skin or the rods and cones of the eye). Top-down processing, in turn, refers to processing sensory information based on what is already driving the higher levels of cognitive processing (activated memory traces or attention).

1.3.2.2 Touch in emotional communication

Touch serves communicative functions that are very similar between different social species. For instance, among non-human primates, touch is used mainly in sexual interactions, to relieve stress after an aggressive conflict, to comfort distressed offspring, or to establish group hierarchies (Hertenstein, Verkamp, Kerestes, & Holmes, 2006). The only consistent difference between non-human primates and humans is that in humans touch is used in communication primarily in hedonistic contexts, for instance, when signaling love and affiliation (Hertenstein et al., 2006). Indeed, when requested to choose between body postures, facial expressions, and touch to communicate distinct emotions, people favour touch over other channels for communicating love and sympathy (App, McIntosh, Reed, & Hertenstein, 2011).

It thus seems that touch can be used to convey several distinct emotions but is preferred over other nonverbal channels when communicating hedonistic states. Perhaps due to its association with pleasure and safety, touch has many positive social influences. One of the established influences is the Midas Touch effect, according to which a slight touch from a passer-by elicits generosity, helping, and compliance in the recipient (Gallace & Spence, 2010). The effect was initially documented by Crusco and Wetzel (1984), who found that waiters who touched their customers while giving the bill got larger tips as compared to waiters who did not touch. Later, Guéguen and Fischer-Lokou (2003) found that bus drivers who were touched by the passenger were more likely to give the passenger a free ride. The Midas Touch effect has since been replicated in various field and laboratory settings (see Gallace & Spence, 2010) and has been suggested to arise from the strong sense of proximity and connectedness induced by physical contact (e.g. Haans & IJsselsteijn, 2006).

While it is true that touch is generally associated with positive social effects, there is evidence also suggesting that the effects depend critically on the situation. For instance, being touched by one's partner reduces stress (Ditzen et al., 2007), but receiving an uninvited touch from a stranger can be perceived as an offensive breach of personal space (Sussman & Rosenfeld, 1978). Even the intrinsically pleasant CT touch does not evoke prosocial behaviour if the situation does not offer additional social cues to justify such an intimate type of touch (Rosenberger, Ree, Eisenegger, & Sailer, 2018). Aversion to tactile communication can also occur due to gender-related preferences and norms. This is especially the case if both interactants are males, as men are known to avoid same sex touch and feel distressed when touched by another male (Crawford, 1994; Roese, Olson, Borenstein, Martin, & Shores, 1992). More recent neuroscientific studies also suggest that the social context in which the touch is conveyed has a fundamental influence on the somatosensory processing of touch (Gazzola et al., 2012; Spapé, Hoggan, Jacucci & Ravaja, 2015). For example, in an fMRI study by Gazzola and colleagues (2012), the primary somatosensory cortex of heterosexual males responded differently to gentle stroking depending on whether they believed they were being touched by a man or a woman, although the touch was always delivered by the same female confederate (Gazzola et al., 2012). Similarly, Spapé and colleagues (2015), showed that a touch conveyed via a haptic device by a

non-located person evoked different levels of P3 amplitudes in the receiver depending on whether the sender had made an unfair or fair economic proposal before touching.

The toucher's identity, perceived gender, and prior actions may thus influence the processing of interpersonal touch in a top-down manner. It is therefore likely that nonverbal emotional cues from different sensory modalities also modulate the processing of interpersonal touch. Indeed, in natural tactile communication, a sender's visual body cues, such as facial expressions, are inseparable from tactile sensation. Unfortunately, there is very little research on such cross-modal modulation. I next review some of the earlier studies on multimodal emotional expressions, focussing on cross-modal modulations between visual and tactile emotional cues.

1.3.3 Perceiving multimodal emotional expressions from touch and face

The processing of multimodal emotional expressions may differ depending on the temporal order of the inputs, given that the first cue (e.g., facial expression) can have a top-down modulatory influence on the processing of subsequent cues (e.g., touch). A handful of studies have investigated such modulatory influences between touch and visual emotional cues. Montoya and Sitges (2006) examined the somatosensory processing of frequent and deviant tactile stimuli while presenting to participants pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997; 2008). A reduced P50 SEP component was observed in response to deviant tactile stimuli presented in the context of unpleasant visual cues. In a study by Sel, Forster, and Calvo-Merino (2014), tactile probes presented after a picture of fearful or happy facial expressions evoked enhanced SEP activity between 40 and 80 ms compared to neutral face condition. Schirmer and colleagues (2011), in turn, found that applying a gentle pressure to the participant's forearm modulated neural processing of subsequent negative versus neutral IAPS pictures (e.g., pictures of snakes, wounded bodies, and flowers). The most robust effect was present in late visual evoked positivity between 300 and 500 ms (typical range of P3 component) post-stimulus and was the same irrespective of whether the touch was conveyed by a friend, produced by the device and attributed to the friend, or produced by the device and attributed to a computer. In another study, by Schirmer and Gunter (2017), CT touch was found to amplify auditory evoked LPP to surprised vocal sounds relative to neutral vocal and non-vocal sounds. In sum, some level of cross-modal integration between visual and tactile emotional perception does occur, either in early sensory processing stages or later attention-related processing stages.

However, the aforementioned studies reveal little about the processing of interpersonal touch, which has two defining features. First, in face-to-face interaction, the tactile and visual affective cues originate from the same embodied source. This in its own right could amplify the cross-modal interference to a greater extent compared to a situation wherein the tactile and visual emotional cues are attributed to different sources. For instance, if a person is at doctor's appointment and sees the doctor smiling and then touching them gently on palm, the sensation can be completely different than

when the doctor is looking worried while touching. The same is not necessarily the case if the person looks at a poster of a happy versus a sad child while being touched by the doctor.

The immediate proximity of another person makes interpersonal touch a particularly relevant source of emotional information. Individual differences in emotional reactivity and motivational tendencies may thus have a larger role in such evocative situations. So far, it is known that people with social anxiety avoid physical contact and report feeling stressed when touched by others (Wilhelm, Kochar, Roth & Gross, 2001) and that autistic individuals exhibit diminished neural response to CT touch (Voos, Pelphrey, Kaiser, 2013). It is possible that more general personality traits likewise play a role in processing tactile and visual affective cues. One such general trait is behavioural inhibition system (BIS) sensitivity, which reflects individual differences in the tendency to avoid negative experiences. The BIS has been associated with heightened responsiveness to negative facial expressions (Knyazev, Bocharov, Slobodskaya & Ryabichenko, 2008) and stronger cardiac OR compared to other types of negatively arousing visual stimuli (Balconi, Falbo & Conte, 2012). Based on these findings, it can be assumed that people with high BIS sensitivity perceive interpersonal touch as more intense or alerting, particularly if the touch is accompanied by negative facial expression. This is one of the assumptions tested in my dissertation.

1.3.4 Multimodal emotional expressions in social decision-making

Aside from modulating the perceiver's perceptual processing, emotional expressions also influence later cognitive processes such as social decision-making. The influence of emotional expressions on social decision-making is typically approached using the emotions as social information (EASI, van Kleef, 2009) model. According to the EASI model, the emotional expressions of others provide information that shapes the observers' social behaviour via two routes: inferential processes and emotional reactions. Inferential processes refer to the observer's appraisals regarding the other's feelings and behavioural intentions. Emotional reactions, in turn, refer to the observer's corresponding (emotional contagion) or opposite affective reactions to the expression (van Kleef, 2009). Therefore, to explain, for example, why genuine smiles promote compliance to requests (Vrugt, 2007), the EASI model suggests that the communicated positive emotional state is both contagious and can be appraised as a sign of the proposer's good intentions, making a positive response more likely. Similarly, the inferential and affective mechanisms have been suggested to underlie the Midas Touch effect. First, the receiver may infer that the stranger who touches them is in genuine need of help and trusts the recipient (e.g., Rose, 1990). However, the touch itself may activate reward-related neural systems in the receiver, which, in turn, leads to prosocial behaviours (Gallace & Spence, 2010).

The EASI model is particularly useful in explaining the effects of emotional expressions on economic decision-making and negotiation paradigms. In these experiments, people have been found to make different decisions and use different negotiation strategies depending on others' emotional expressions, such as facial cues

(e.g., Pietroni, van Kleef, De Dreu, & Pagliaro, 2008; van Kleef, De Dreu & Manstead, 2006). Economic decision-making paradigms, such as the ultimatum game (Güth, Schmittberger, & Schwarze, 1982), have proven to be particularly useful in studying the regulative influence of nonverbal emotional expressions in social interactions (e.g., de Melo, Gratch, & Carnevale, 2015; Spapé et al., 2015). The game proceeds so that one player (the proposer) makes a proposal of how an amount of money should be divided between themselves and another player (the receiver). The receiver then decides whether to accept the proposal (and each person receives their share) or reject the proposal (and neither receives anything). Although the only rational choice for the receiver is to accept any kind of offers (because even a little share is better than nothing), most people tend to reject offers that are unfair to them (Bolton & Zwick, 1995). Neuroimaging research has shown that the irrational decision to reject unfair offers is associated with increased activity in the insula, anterior cingulate cortex, and dorsolateral prefrontal cortex (Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003). Researchers have also found that unfair offers enhance the medial frontal negativity (MFN) ERP component (e.g., Boksem & De Cremer, 2010) and amplify cardiac OR (Osumi & Ohira, 2009). These results, together with self-reports, suggest that the negative emotional reaction to unfair offers motivates the participant to reject the proposal despite the economic costs of the decision (Sanfey et al., 2003).

Due to the fact that people often reject unfair ultimatum offers, the game offers a great possibility of testing whether the receiver's originally low acceptance rate can be increased by the proposer's touch and facial emotional expressions. In line with this idea, Mussel, Göritz, and Hewig (2013) found that unfair offers accompanied by a smile from the proposer had a greater probability of acceptance. In a follow-up study (Mussel, Hewig, Allen, Coles, & Miltner, 2014), the researchers further showed that the unfair offers accompanied by smile evoked weaker MFN (also referred to as feedback-related negativity) than those accompanied by a neutral or angry face.²

It remains an open question, however, whether emotional expressions other than facial expressions modulate decision-making-related physiological indices. Additionally, there is no prior research on what occurs in the receiver's decision-making if the sender expresses multimodal emotional cues prior to making an offer. By presenting more than one nonverbal expression, we can investigate the relative importance of different bodily communication channels for the evaluation of different economic proposals. For instance, if the participant encounters a proposer who smiles and touches them before making a very unfair offer, does the participant process the offer differently than if the proposal were preceded by a smile alone? Ultimately, investigating the neural processing of multimodal emotional expressions in decision-making enables us to revisit the discussion on the extent to which social messages are interpreted based on the nonverbal context that accompanies them (Mehrabian, 1971).

² It is interesting to point out, however, that our lab recently failed to replicate this effect (Spapé, Harjunen, Ahmed, Giulio & Ravaja, 2019).

Further insight into the influence of multimodal emotional expressions on decision-making can be gained by examining how the receiver's personality traits contribute to the influence. In previous studies, receivers with pronounced sensitivity to unfair treatment, also referred to as justice sensitivity (JS), have been found to display an elevated likelihood to reject unfair ultimatum offers (Fetchenhauer & Huang, 2004). Conversely, persons responsive to rewards who score high on the so-called behavioural approach/activation system sensitivity (BAS) are more likely to accept ultimatum offers of all kinds (Ferguson, Heckman, Corr, 2011; Scheres & Sanfey, 2006). High BAS individuals also respond with increased positive valence to appetitive IAPS stimuli (Balconi, Brambilla, & Falbo, 2009). Therefore, people with low JS and high BAS may be more readily persuaded by the proposer's affiliative emotional expressions than people with high JS and low BAS.

Studying the perception and responses to facial emotional expressions and touch in naturalistic but highly controlled interaction settings raises numerous methodological and practical challenges that may have hindered previous research into emotion perception in naturalistic face-to-face contexts; however, recent technological developments have produced cost-effective means of doing so. In the next section, I describe how VR can be used to bypass the tradeoff between ecological validity and experimental control present in traditional experimental psychological research.

1.4 Use of VR in investigating emotion perception

According to Jaron Lanier, a computer scientist and VR pioneer, VR is "an ever-growing set of gadgets that works together and match up with human sensory and motor organs" to substitute physical reality with a computer-generated one (Lanier, 2017, pp. 48). Most modern immersive VR systems build on a headset equipped with a stereoscopic display and motion tracking sensors (Anthes, García-Hernández, Wiedemann, & Kranzlmüller, 2016). The stereoscopic display and adaptation of the visual feedback to head movements together create an impression of being within a three-dimensional visual scene (Armbrüster, Wolter, Kuhlen, Spijkers, & Fimm, 2008; Sherman & Craig, 2018, pp. 260-342). The immersive visual experience is often augmented by spatial audio stimuli matching the visual feedback and motion-tracking gloves or controllers that bring the user's body into the environment (e.g., Meyer, Applewhite, Biocca, 1992; Zahorik, 2002).

In immersive VR, the participant's body movements, orientation, and gaze have an immediate impact on the media content. The sense of being inside the rendered environment and having an influence on its events, also referred to as presence (Kim & Biocca, 1997), makes VR a particularly powerful method for psychological research (Fox, Arena & Bailenson, 2009). The person's emotional involvement becomes even more evident when introducing human characters to the environment. Representations of humans in VR vary from hyper realistic figures to cartoon-like anthropomorphic figures (e.g., Nowak & Rauh, 2008). Figures that are controlled by another human are

typically referred to as avatars, whereas those controlled by an algorithm are called as virtual agents (Bailenson & Blascovich, 2004). Both aspects, appearance and agency, influence how people respond to their emotional cues and social behaviours (e.g., de Melo, Gratch, & Carnevale, 2015; Guadagno, Blascovich, Bailenson, & McCall, 2007). According to a recent meta-analysis by Fox and colleagues (2015), the emotional expressions and decisions of human-guided avatars and supposedly human-guided agents have a greater influence on human recipient's behaviour and emotional responses than those of virtual agents, especially when the experimental task involves collaboration or competition. Furthermore, when the photorealism and emotional responsiveness of virtual agents are further increased, the social influence increases as well (Guadagno et al., 2007; Ravaja, Bente, Kätsyri, Salminen, Takala, 2018).

Whether the agent is an avatar or virtual agent, their nonverbal behaviour and emotional expressions influence emotional responses and decisions in a manner similar to that of real humans (Garau, Slater, Pertaub, & Razaque, 2005). For example, people maintain personal space (Bailenson, Blascovich, Beall, & Loomis, 2001; 2003), exhibit social inhibition (impairment of performance in company of others; Hoyt, Blascovich, & Swinth, 2003), and regulate their emotional facial expressions when interacting with virtual agents (Ravaja et al., 2018).

The use of virtual agents in immersive VR opens up new methodological possibilities to human affective neuroscience and brings the research of nonverbal emotional communication closer to real life scenarios. For example, rather than showing people pictures or videos of facial expressions, we can immerse them in an environment wherein a high-fidelity human figure approaches them and expresses emotions. The agent's nonverbal cues can be defined to the precision of millimetres and milliseconds and repeated hundreds of times to obtain reliable event-related physiological measurements. In addition, the exact same body movements can be presented originating from multiple different senders. In the real world, such precision and repetition is impossible.

Like visual human bodies, interpersonal touch can also be transferred to VR. Social touch technologies refer to haptic actuators that are used to emulate interpersonal touch in computer-mediated communication (Haans & IJsselsteijn, 2006). Perhaps the most commonly used actuators are vibrotactile actuators and motors that activate the mechanoreceptors by vibrating or by applying pressure to the user's skin (Ahmed, Harjunen, Jacucci, Hoggan, Ravaja, Spapé, 2016; see Willemse, 2018, for a review).

Mediated social touch has been shown to elicit similar socio-emotional and behavioural influences on real physical contact (Gallace & Spence, 2010; Haans & IJsselsteijn, 2006). For instance, receiving a mediated social touch has been shown to reduce the receivers' physiological stress (Cabibihan, Zheng, and Cher, 2012) and increase their likelihood to help the sender in subsequent helping scenario (Haans, de Bruijn, & IJsselsteijn, 2014). Spapé and colleagues (2015) found that mediated touch conveyed during online ultimatum game increased the receiver's economic proposals. Similar to real human touch, mediated social touch can also be used to convey arousal

and valence-related emotional information between interactants (e.g., Rantala, Salminen, Raisamo, Surakka, 2013).

Together the results suggest that mediated and unmediated, regular touch are very similar in terms of their psychological influences. It should be noted, however, that in almost all previous studies on social touch technologies, touch was presented without any visual bodily cues of the sender. As suggested earlier, bodily cues such as facial expressions and reaching gestures are crucial in anticipating and interpreting the emotional relevance of the touch in natural face-to-face interaction. To take this multimodal nature into account, social touch technologies should be integrated into immersive visual displays to present virtual human figures expressing emotions via both channels. This is exactly what our team did to allow the investigation of multimodal emotion perception in face-to-face interaction.

1.5 Aims

The present thesis had two general aims. The first one was to investigate at which point of perceptual and attention-related neural processing sequentially presented touch-facial emotional expression begin to integrate. The second aim was to examine how sequentially presented touch and facial emotional expressions influence the recipient's social decision-making. Four studies with event-related electrophysiological measures were conducted to address the aims. In addition to the general aims, five study-specific research questions were investigated.

In Study I, we examined whether and when a sender's facial expressions of emotion modulate the perception of interpersonal touch (RQ1). Tactile perception was measured using EEG recordings of early and late somatosensory evoked potentials and using self-reported touch intensity and pleasantness ratings. Participants were asked to passively observe a virtual human agent expressing an emotion on its face (angry, fearful, sad, happy, and neutral) and then to touch the participant's hand projected into VR. Upon contact, a tactile stimulus with varying intensity and type was delivered to the participant's real hand. In earlier studies on contextual modulation of tactile perception, visual emotional contextual primes have been found to modulate tactile perceptual processing in the primary somatosensory cortex (Gazzola et al., 2012) and in latencies as early as 40 ms (Montoya & Sitges, 2006; Sel et al., 2014). Moreover, Montoy and Sitges (2005) reported P50 SEP to be affected by the valence of the preceding visual affective image. Here, we sought to study whether similar visual-to-tactile modulation occurs in more naturalistic stimuli scenario, namely, during face-to-face interaction. Based on the mentioned observations, we expected the sender's facial emotional expressions to modulate SEPs to subsequent interpersonal touch. To complement previous findings, a larger set of visual emotional stimuli representing multiple dimensions and categories of emotion were used to allow the examination of which dimensions and appraisal factors best explained the modulatory influences. Both early and late SEPs were examined in a data-driven manner to determine at which point of cognitive processing the modulatory influence occurs.

In Study II, we examined whether individual differences regarding behavioural inhibition system sensitivity and gender contribute to the modulatory influence of facial emotional expressions on touch perception (RQ2). Touch perception was measured using self-reported tactile intensity and pleasantness ratings, as well as touch-related cardiac OR. Persons with high BIS were assumed to respond to the agent's touch with stronger OR and perceive it as more intense and less pleasant than persons with low BIS, especially if the agent expressed negative emotions while touching. The assumption was based on previous findings demonstrating that BIS is related to heightened responsiveness and stronger cardiac OR to negative facial emotional expressions and other types of aversive visual stimuli (Knyazev et al., 2008; Balconi et al., 2012). In addition, the participant's gender was supposed to influence touch perception. More precisely, we expected that the male participants would report a male agent's touch as less pleasant than female participants, given that males have

previously been shown to report aversion towards same-sex touch (e.g., Roese et al., 1992; Gazzola et al., 2012).

Study III investigated whether being touched via a tactile interface influenced the processing of subsequent emotional facial expressions (RQ3). Both autonomic (ECG, fEMG) and central (EEG) nervous system activity was measured to capture the effect of touch on emotional face processing. The touches, presented as vibrotactile primes delivered to the participants' hands, were contrasted to condition without any prime and to auditory prime condition to see whether touch has an unique modulatory influence on emotional face processing. The facial expression stimuli were pictures presented on a regular computer screen and depicting angry, disgusted, fearful, or happy faces. In each trial, participants were asked to classify a face picture as belonging to one of four emotion categories. Since in previous studies human and machine touches were found to similarly amplify the processing of emotional versus neutral pictures and vocal sounds (Schirmer et al., 2011; Schirmer & Gunter, 2017), we hypothesized a machine-produced vibrotactile prime to uniquely modulate emotional face processing when contrasted to auditory and no-prime condition. Comparing the modulatory influence on both high arousal and low arousal negative and positive face stimuli allowed us to examine whether the touch influenced the visual processing of specific affective features (e.g., valence of the stimulus).

Table 1. Summary of the studies.

<i>Study</i>	<i>Task / Stimulus</i>	<i>Measures</i>	<i>Focus</i>
I	Passive viewing in a face-to-face context / VR, mediated touch	Tactile perception ratings, SEPs	RQ1: Effect of emotional facial expressions on tactile perception of virtual interpersonal touch
II	Passive viewing in a face-to-face context / VR, mediated touch	Tactile perception ratings, cardiac OR, trait measures	RQ2: Individual differences in the affective modulation of virtual interpersonal touch
III	Emotion recognition / facial expression pictures, vibrotactile touch	Recognition rates, ERPs (VEPs), cardiac OR, fEMG	RQ3: Modulatory effects of touch on emotional face processing
IV	Ultimatum game / VR, mediated touch	Game behaviour, cardiac OR, trait measures	RQ4 and 5: Effects of virtual touch, emotional facial expressions, and personality on social decision-making

In Study IV, the focus was directed to the secondary aim, of investigating the influence of multimodal emotional expressions on social decision-making. This study examined whether a sender's facial expressions and touch have a persuasive influence on a receiver's economic decisions (RQ4) and whether individual differences in the perception of fairness and motivational tendencies moderate this (RQ5). Here, behavioural data collected in the decision-making task were complemented by

measures of the offer-related cardiac OR. An iterative version of the ultimatum game was used in which the participant played the game in VR as a responder or proposer with eight virtual agents (proposers). The game trials were repeated multiple times, with different nonverbal cues presented prior to the offer-response sequence. Prior to making an offer, the agents first showed a facial emotional expression (happy, angry, or neutral) and then either touched or did not touch the participant. Since the proposer's smile and touch have been shown to increase the responder's compliance to unfair ultimatum game offers (Mussel et al., 2013; 2014; Gallace & Spence, 2010; Spapé et al., 2015), we predicted that the same would be observed here. Moreover, we expected the offer-related cardiac ORs to be amplified in response to unfair offers compared to fair ones. However, the increasing effect of unfairness was assumed to be smaller in those unfair offers accompanied by touch or smile or both. Finally, as people differ in their responsiveness to emotional expressions (e.g., Knyazev et al., 2008) and willingness to comply with unfair economic proposals (Fetchenhauer & Huang, 2004), it was predicted that BIS, BAS, and JS would influence the extent to which touch and facial expressions promote compliance to the proposer's offers. More precisely, we predicted that people with low BIS, low JS, and high BAS would be more prone to the compliance-promoting effects of touch and smile than people with high BIS and JS and low BAS.

2 Methods

2.1 Participants

The participants were healthy undergraduate students, postgraduate students, and staff members of the University of Helsinki and Aalto University. Participation was restricted to persons with normal or corrected-to-normal vision and no history of neurological or psychopathological disorders. Given that the handedness of the participant may influence the amplitude and latency of ERP components (Hoffman & Polich, 1999), only (self-reported) right-handed participants were recruited for Studies I, II, and III.

Table 2 shows the sample sizes and the age and gender distributions of each sample. As seen in the table, most of the participants were young adults. The gender distribution varied slightly across samples, but all samples contained male and female participants in the samples. For Studies I, II, and III, samples of 39–40 participants were collected. The data of Studies I and II were based on the same sample of 43 individuals. That is, all the data were collected within a single VR experiment, but Study I focusses on the ERP results, while Study II concentrated on the role of individual differences in affective touch perception. Differences in sample sizes between Studies I and II resulted from data exclusion due to artefactual physiological recordings or technical problems.

Table 2. Summary of samples in the four experiments.

<i>Study</i>	<i>n</i>	<i>Females/Males</i>	<i>Mean age (SD)</i>
Study I	40 ^a	17/23	25.0 (4.0)
Study II	39 ^a	17/22	25.4 (4.0)
Study III	40	16/24	24.7 (3.9)
Study IV	55	32/24	25.0 (5.0)

Note. ^a = based on the same sample of 43 participants.

In Study IV, 66 participants completed the experiment, but the data of ten participants had to be excluded due to a systematic response style in the decision-making task or technical problems in the VR system. When debriefed at the end of the session, nine of the participants reported knowing the decision-making game and how to play it in order to maximize gains. Data from these individuals were excluded.

All the experiments were conducted following the guidelines of the National Advisory Board on Research Ethics in Finland and approved by the Research Ethics Committee of Aalto University (Studies I–III: minutes 16.10.2014/3.5§, Study IV:

minutes 11.2.2016/3.2§). Participants were always briefed on the experimental procedure, its purpose, and their rights to withdraw from the experiment at any time without offering any explanation. Before leaving the lab, participants were thanked and compensated with movie tickets or money.

2.2 Procedure, apparatus, and design

2.2.1 Studies I and II

In Studies I and II, participants' task was to watch a series of animations in VR wherein they were first touched by a virtual male agent expressing an emotion on his face and then asked to report how they perceived the touch or the facial expression. The participants were first seated at a desk equipped with a glass table and motion tracking sensors. They were assisted in putting on a head-mounted display (HMD; Oculus Rift Developer Kit 2) and custom-made tactile glove (see Figure 2, Panel A). While immersed in VR, they could see a virtual replica of their right hand resting on a table (Figure 2, Panel B, Step 1). The hand movements were tracked using a Leap Motion controller that was placed below the glass table on which participants held their hand.

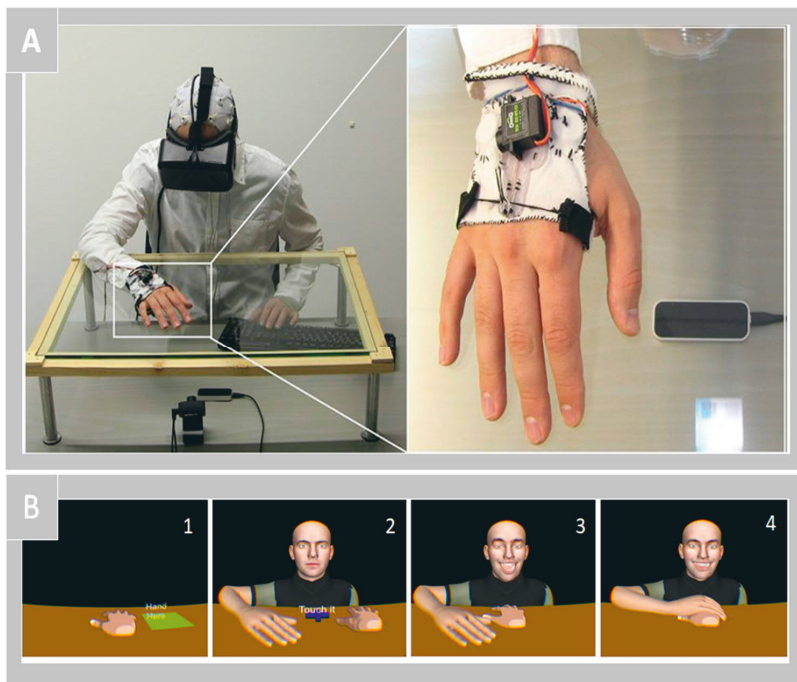


Figure 2. Panel A shows the experimental setup. On the left, one can see the participant wearing an HMD, a glass table placed on desk, and a hand-tracking device underneath the glass table. The tactile glove, presented on the right, was used to deliver the touches. Panel B presents the trial structure with the virtual agent presented showing a facial expression and then touching the participant's virtual hand.

Each trial was launched by touching a green area. Touching it made a virtual agent appear on the other side of the table (Figure 2, Panel B, Step 2). At the same time, a blue crosshair was presented. The avatar was initially shown with a neutral facial expression, but touching the blue cross launched a 5,000 ms animation of an emotional facial expression (Figure 2, Panel B, Step 3). Following an interval of 1,000–3,000 ms (randomized), the agent reached out and touched the participant's right palm (Figure 2, Panel B, Step 4). The reaching gesture lasted for 1,000 ms, and upon contact, a tactile stimulus of 500 ms was delivered by the glove. The agent remained in view for another 500 ms, whereafter either a questionnaire was presented (in the first 20 trials of each block) or the next trial launched. In the questionnaire, participants were either asked to indicate how pleasant and intense the touch was or to identify what emotion the agent expressed (a more detailed description of the scales can be found in the measures section).

The virtual agent's face was based on the default male head model of Faceshift software, and the body was designed with the Fuse modelling tool of the Mixamo platform (Adobe Systems, San Jose, CA). The agent's expressions were obtained by recording dynamic expressions enacted by a professional actor, who was instructed to express seven different emotions (anger, fear, happiness, surprise, disgust, sadness, and neutrality as a contrast category) to a Microsoft Kinect depth camera. Based on a pre-test of the expression recognition, five emotion categories (angry, fearful, sad, happy, and neutral) were selected for the final study design. The Unity software was used to present and trigger the visual stimulus and collect the behavioural data.

The touch was delivered using a custom-made haptic glove that delivered two types of tactile stimuli: vibrations and pressure. Vibrations were delivered by two TEAX14 C02-8 audio exciters (Tectonic Elements Ltd., Cambridge, United Kingdom) placed dorsal to the middle of the metacarpal bones of right hand that sent square wave sinusoids with 500 ms stimulus duration and constant amplitude. Pressure, in turn, was produced using a OmG 9 g micro servo motor (RC OMG, Shenzhen, China) that stretched two elastic tapes over the volar of the hand. In both cases, the intensity of tactile stimuli varied between hard and soft. Vibrations were soft at a frequency of 35 Hz and hard at 100 Hz. Pressure was soft when the pulling lever of the servo motor rotated 120° and hard when it rotated 180°. Auditory cues produced by glove were masked by playing white noise throughout the experiment.

The complete experiment consisted of five blocks, each of 100 trials. Each block had five segments of 20 trials within which all possible combinations of two touch types (vibration vs. mechanical), two intensity levels (soft vs. hard), and five facial expressions of emotions (angry, happy, sad, afraid, and neutral) were presented in a randomized order.

2.2.2 Study III

In Study III, participants' task was to view facial expressions shown on a regular computer screen and, after 1,000 ms of presentation, promptly classify them as one of four emotion categories (angry, disgusted, afraid, or happy). Sometimes the

expressions were preceded by a vibrotactile or auditory prime. Each trial proceeded as illustrated in Figure 3. First, a central fixation cross was presented on a grey background for 400 ms. The cross was replaced by an image of a face wearing a neutral expression. Following an interval of 300–600 ms, a vibrotactile or auditory prime was presented while still showing the neutral face image on the screen. After a stimulus onset asynchrony of 150–500 ms (randomized), the neutral expression was replaced by the same person wearing an emotional expression. The expression image remained in view for 1,000 ms. After the image disappeared, the participants had to indicate the emotion of the face by using specific letter keys of a keyboard. The response mapping between the keys and the emotion categories was randomized between blocks to avoid the confounding effects of lateralized activity.



Figure 3. Study III trial structure with happy expression condition. The fixation cross was shown for 400 ms following a neutral face stimulus. After a 300–600 ms stimulus onset asynchrony, an auditory or tactile prime with a duration of 500 ms was presented alongside the neutral face stimulus. The neutral face was replaced by the same face image wearing an emotional expression 150–500 ms after the prime offset. The emotional expression remained in view for 1,000 ms, whereafter the participants were asked to indicate which emotion it had depicted.

Both auditory and vibrotactile primes were based on the same waveform source file: a 100 Hz square wave of 500 ms with a gradual 10 ms fade-in part and 350 ms fade-out part. The content of the audio source file was converted to vibration using a C-2 tactor (Engineering Acoustics Inc, Florida, U.S.). A speaker positioned to the right of the screen delivered the waveform as an auditory cue at a level of ca. 50 dB. The face images were obtained from the Pictures of Facial Affect (Ekman & Friesen, 1976) database. Finally, the E-prime 2.0.10.353 (Psychology Software Tools Inc, Sharpsburg, PA) software, running on Windows XP, was used to present the stimulus, record the responses, and send triggers to the EEG amplifier.

In total, participants went through four blocks of 120 trials. Participants were given four training trials in the beginning of each block to get used to the new response mapping. Trials with too fast (before disappearance of the expression stimulus) and too slow (> 2,000 ms) responses were excluded from the analysis. Finally, a 3 (prime: touch, tone, or silent) x 4 (expression: angry, disgusted, afraid, or happy) x 10 (repetitions) x 4 (blocks) within-subject design was employed, resulting in 40 trials per each prime-expression combination.

2.2.3 Study IV

In Study IV, the participants were immersed in VR with the task of playing an economic decision-making game with eight virtual agents whose decisions and non-verbal behaviours were guided by a computer algorithm. The experimental procedure was similar to that used in Studies I and II, but the nonverbal expressions were followed by a segment of the ultimatum game wherein participants had to either respond to an offer or make an offer to the agent (see Figure 4, Panels A, B, and C). The purpose of switching the roles (participant as the proposer or responder) was to avoid repetitiveness and increase the meaningfulness of the experience. However, only the data from responder trials were analysed, given that the responder behaviour fully captured the phenomenon of interest, that is, compliance to the proposals.

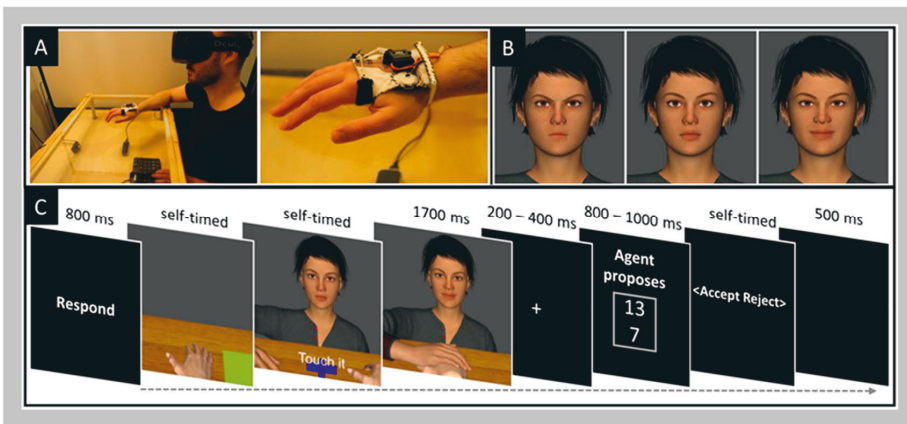


Figure 4. Panel A presents the VR system equipped with HMD, leap motion tracking device, and the haptic glove. Panel B shows the angry, neutral, and happy expressions created for the experiment. In Panel C, the trial structure is illustrated, with timing of each step depicted above.

Figure 4 (Panel C) shows the complete structure of the responder trials. Initially, the participants could see their virtual hand resting on a table. They launched the trial by touching a green area, which caused a blue crosshair and virtual agent to appear. Touching the blue crosshair was followed by delay, whereafter the agent's emotional facial expression began. In visual and visuo-tactile touch conditions, the agent reached the participant's right hand 0–200 ms after the onset of the expression. It took 1,000 ms to establish a contact, whereupon 500 ms of tactile feedback was sent by a haptic glove to the participant's right hand. However, no reaching gesture or no tactile feedback was presented in the no touch condition, and in one condition type (visual touch), no tactile feedback was delivered, although the reaching gesture was shown. After the nonverbal part, the participants saw a fixation cross presented for 200–400 ms. In the role of responder, they were next shown the agent's offer as two numbers within a grey frame. The upper number referred to the agent's share and the lower to the participant's share. The proposal was shown for 800–1,000 ms, whereafter the participants were requested to either reject or accept the offer by pressing either the

right or the left arrow key. Responding to the offer resulted in a 500 ms intertrial interval with a blank screen, whereafter the next trial was started.

The Oculus Rift HMD was used to present agents and the virtual environment. The agents were created based on male and female Genesis 2 characters offered by Daz Studio (Daz3D, Salt Lake City, UT). To increase diversity in the agents' appearance, we manually morphed the Genesis 2 characters to create four pairs of male and female agents with each pair possessing features of a specific ethnic background (African, Caucasian, East Asian, and South Asian; images of each agent can be found in the appendix of the original publication). Surrounding objects, such as the table and cues, were created using Unity 3D software, and the participant's virtual hand was the default hand model of Leap Motion's Unity 3D package. This time, the expressions were created within the Unity 3D software by manually adjusting face-contained action units defined using the Facial Action Coding System (FACS, Ekman & Rosenberg, 1997) in accordance with the six basic emotions as defined by Ekman and Friesen (1976). The resulting expression animations were validated by a separate sample of 13 participants. Although all the emotions were well recognized, only the neutral, happy, and angry expressions (Figure 4, Panel B) were selected for the study, as they were considered most suitable to the task. The recognition accuracies were 70% for anger, 98% for happiness, and 100% for neutral (i.e., well above the chance level of 14.29%).

Participants completed a total of 594 trials during the session of around 150 minutes. The trials were organized in nine blocks, so that the first orientation block consisted of 18 trials and the following eight blocks contained 72 trials each. Within each complete block (72 trials), the trials were organized into four series of 18 trials, three for the responder trials and one for the proposer trials. Across repeated responder trials, agent gender, ethnic appearance (African, Caucasian, East Asian, and South Asian), touch type (no touch, visual, visuo-tactile), facial expression (angry, neutral, happy), and offer fairness (very unfair [€2–6 for the participant | €18–14 for the agent], somewhat unfair [€7–8 | €12–13], fair [€10 | €10], and generous [€11–15 | €5–9]) were randomly varied. The agents' decisions (types of offer sent to the participant) were defined by a simple selection algorithm whose function was based on Boksem and De Cremer (2009), who designed an approach to approximate human behaviour in the ultimatum game. A detailed description of the algorithm can be found in the appendix of Study IV. After each block, participants could see how much money they had earned so far in the game. The amount presented at the end of the session was going to be paid to the participants. In addition to the default compensation of €35, participants could earn up to €35 extra, depending on their behaviour in the game. Before launching the VR system, it was made clear to the participants that their decisions in the VR would influence their actual monetary compensation for participation.

2.3 Physiological recordings

In all four studies, electrophysiological data were recorded. The signals were obtained at a 1,000 Hz sample rate using a QuickAmp USB (BrainProducts GmbH, Gilching, Germany) amplifier. A set of 32 Ag/AgCl electrodes were used for EEG acquisition, and these were attached to an elastic EEG cap (EasyCap, GmbH, Herrsching, Germany) to position them over FP1, FP2, F7, F3, Fz, F4, F8, FT9, FC5, FC1, FC2, FC6, FT10, T7, C4, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, O1, Oz, and O2. The AFz worked as the ground. The EEG recordings were accompanied by horizontal and vertical electro-oculographic (EOG) recordings that were obtained using bipolar electrodes placed 1 cm lateral to the outer canthi of the left and right eye and 1 cm above and below the left eye. In addition, an ECG was obtained in Studies II, III, and IV. The signal was recorded using two disposable electrodes (H93SG, size: 42 mm x 24 mm; Kendall, Minneapolis, MN), one placed over the upper sternum (manubrium) and the other over the second lowest left-hand rib. Finally, in Study III, three bipolar electrode pairs were used to record the facial electromyogram (fEMG). The electrodes were positioned over three left-sided facial muscle regions: the zygomaticus major (ZM), corrugators supercilii (CS), and levator labii superioris alaeque nasi (LN).

2.4 Pre-processing of the physiological signals

Data filtering and artefact correction procedures varied slightly across studies. The EEG and EOG signals were first pre-processed offline using a high-pass filter at either at 0.1 or 0.2 Hz. Artefact correction of the EEG data was carried out using independent component analysis (ICA) based on the infomax algorithm implemented in the EEGLAB (Delorme & Makeig, 2004). The preprocessing of ICA-processed EEG data was continued in Brain Vision Analyzer 2 (BrainProducts GmbH, Gilching, Germany). Here, the data was again filtered (between 0.2 Hz and 40 Hz) and segmented into epochs which were time-locked to the onset of targeted stimulus (the epoch length is reported in the measures section). Subsequently, an artefact-rejection procedure was carried out to remove trials with greater than 35–40 μV (varied between studies) absolute amplitude and $> 55\text{--}60 \mu\text{V}$ difference between the maximum and minimum amplitude. Finally, the cleaned continuous EEG data were segmented to epochs which were time-locked to specific stimuli. The epoch lengths and quantification of specific ERPs are described in Section 2.5.

Continuous ECG signals were first band-pass filtered between 2 and 100 Hz whereafter a notch filter between 46 and 54 Hz was applied. A MATLAB-based peak detection algorithm (available at cognitology.eu/source/mig_ContECGToIBI.m) was then used to detect latencies of R-peaks in the ECG and to interpolate peaks that were not detected. The algorithm was also used to interpolate R-peak latencies to a continuous IBI signal. The continuous EMG data was filtered with a 7 Hz high-pass filter, then rectified using the Hilbert transform (Myers et al., 2003), and finally log-transformed to reduce the influence of outliers. Both the continuous EMG and ECG

data were segmented into epochs, which were time-locked to target stimuli. The following section includes details of the epoch lengths and quantification of the autonomic responses.

2.5 Measures and analysis

2.5.1 Study I

Three questionnaires presented in separate blocks were used to measure participants' tactile (pleasantness and intensity of touch) and visual (pleasantness and intensity of avatar's expression) experience and emotion recognition. The questionnaires were always filled out after the first 20 trials of each block. In the first block, participants were asked to evaluate the pleasantness and intensity of the virtual agent's facial expression (e.g., "Was the emotional expression pleasant / friendly / intense / forceful / humanlike?"), indicating their answers on continuous Likert scales (1: "not at all", 5: "very much"). In the second block, questions of touch pleasantness, intensity and naturalness were asked (e.g., "Was the touch pleasant / friendly / intense / forceful / humanlike?"). Pleasantness and friendliness ratings were positively correlated ($r = .48$) and were thus combined by calculating an average of the two to be used as an index of the hedonic value of the stimuli. Items of forcefulness and intensity were also strongly correlated ($r = .68$), for which reason an average of the two was used to measure the stimulus intensity. The measurement approach was equivalent to that used in Ellingsen et al. (2014). In the last three blocks, in the end of first 20 trials, participants were requested to classify the agent's emotion (angry, happy, sad, afraid, or neutral). The percentage of correctly classified expressions was used to measure emotion recognition.

As no previous research used the same tactile stimuli in an EEG setting, we identified ERP components based on a data-driven approach. The inspection revealed three early components within the first 60 ms, followed by a later positive component peaking around 250–350 ms. To define latency windows for the early SEPs, the first 60 ms of the grand average voltage activity was divided by its standard error, whereafter a peak detection procedure was carried out on the standardized activity to define window borders for each peak. The first early peak was detected at the range of 22–29 ms, which was most pronounced in Cz. This was followed by another centrally located but negative peak at 36–66 ms. These peaks were referred to as P25 and N50, respectively. Another positive peak was observed over C3, temporally between P25 and N50 at 24–41 ms, showing a different topography compared to the other two components. This component was referred to as the P30. For the latency windows of P25, P30, and N50, we first defined latencies of the local maximum and minimum amplitudes and then extracted the voltage values at those time points from four sites overlying the sensorimotor areas (CP5, C3, C4, CP6) and two overlying the fronto-central areas (FC1, FC2). For the P25 and P30, peak voltages were used to

index components. In contrast, for the N50, a peak-to-peak difference between P25 and N50 was used.

The later, longer-lasting component was similar to the somatosensory P200 and P300 obtained in earlier studies (e.g., Montoya & Sitges, 2006). Rather than defining exact measurement windows for these components and increasing the risk of type-I error, we used six bins spanning the breadth of the P200, P300, and later positive activity to analyse differences in this later stage. Visual inspection of the grand average ERP waveform revealed high amplitudes, particularly over the centro-parietal areas, for which reason amplitude averages over the Cz, CP1, CP2, P3, Pz, and P4 sites were entered into the statistical analyses.

To test the effect of emotional facial expressions on self-reported tactile perception, four separate full-factorial, repeated-measures ANOVAs were conducted, setting emotional facial expression (neutral, angry, happy, fear, sad), touch type (vibration, mechanical) and touch intensity (soft, hard) as factors and pleasantness and intensity of touch or expression as the dependent variables. For early SEPs, the previous ANOVA model was accompanied by the factor of the electrode (CP5, C3, FC1, FC2, C4, CP6) to run four-way repeated-measures ANOVAs separately for each peak amplitude (P25, P30, and N50). For late SEPs, a single repeated-measures ANOVA was conducted with average amplitude as the dependent variable and emotional expression, touch type, touch intensity, electrode (CP1, CP2, Cz, P3, Pz, P4), and time (100–200, 200–300, 300–400, 400–500, 500–600, 600–700 ms) set as factors.

2.5.2. Study II

Given that Studies II and III were based on the same experiment, the self-reported measures of tactile and visual experience were the same. Therefore, here, I describe the results regarding touch evoked cardiac activity and personality-level analyses.

Touch related deceleration in cardiac cycles (i.e., cardiac OR) was measured to investigate touch-induced changes in parasympathetically mediated sensory intake (Bradley, 2009). Visual inspection of the grand average (across conditions) IBI response was used to define temporal window for the OR. The IBI signal was found to peak between 1 and 3 s, in accordance with the literature (Bradley, 2009), and this window was used to detect the local maximum of the IBI signal. The trial-based max IBI values were averaged to obtain a single OR value for each condition and for each participant.

To determine whether individual differences in behavioural inhibition tendency influence the way affective interpersonal touch is perceived, we measured the participants' BIS sensitivity using the BIS subscale of the BIS/BAS scale (Carver & White, 1994). The scale consists of seven statements to which participants give their responses using a four-point Likert scale (1 = very false for me, 4 = very true for me). The Cronbach's alpha for the BIS scale was 0.80.

The effect of affective touch on touch-related OR was investigated using repeated measures of ANOVA with touch type, touch intensity, and emotional expressions set

as factors and touch-evoked OR as dependent variable. Given that cardiac OR tends to habituate after repeated stimuli (Bradley, 2009), the additional factor of phase (500 trials divided into three levels, each consisting of 167–166 trials) was included in the model. To further specify the effects of emotional expression on cardiac OR, planned pairwise comparisons between emotional expressions and the neutral control were conducted.

To investigate the effect of individual differences on perceiving touch, we analysed the moderating influences of behavioural inhibition and gender on self-reported touch perception. The moderation was analysed testing cross-level interactions between the agent's expression and the receiver's BIS and gender using multilevel linear modelling (MLM). Multilevel linear modelling allows the investigation of cross-level interaction (e.g., between BIS and expression) as, contrary to the analysis of covariance, there is no assumption of homogeneous regression slopes (Hoffman & Rovine, 2007). Since we expected male and female participants to respond differently to the male agent's touch, the effect of gender was also included in the model. Consequently, three separate mixed models were conducted for tactile intensity, pleasantness, and OR. The main effects of expression, touch type, intensity, gender, and BIS, as well as the interaction effects of expression, gender, and BIS were included in each model. In case a significant interaction was found between expression and BIS, the effect was further inspected using a simple slope approach (Preacher, Curran, & Bauer, 2006).

2.5.3 Study III

In Study III, early and late ERPs, fEMG, and cardiac OR evoked by the face stimuli were measured to examine whether receiving a touch modulates emotional face processing.

To quantify the early ERP components, local maximum and minimum peaks were first detected from the standardized (mean/SE voltage at every 10 ms) grand average ERP waveform, and the window borders around them were then defined based on points at which the standardized ERP waveform reached a threshold value of $T(40) > 4$. This window detection procedure revealed a N1 component in frontal sites being most enhanced at 110–120 ms. In the same time range but in a lateral-temporal and occipital site, a positive P1 component was found. The obtained N1/P1 was thus defined as the local minimum and maximum between 90 and 130 ms. The N1/P1 component was followed by VPP/N170, peaking between 170 and 180 ms. The VPP/N170 was most positive over frontal sites (VPP) and most negative over lateral posterior sites (N170). The window for VPP/N170 was therefore defined as the maximal or minimal value between 150 and 210 ms. A centro-parietal P2 component was observed slightly after the N170, peaking between 210 and 220 ms and being most enhanced in the Cz channel. Therefore, a maximum value between 180 and 250 was used as an index of P2. The aforementioned windows were used to extract amplitudes from all electrodes separately.

In contrast to the peak localization approach to the early components, we used a windowed averaging approach for late components based on previous literature by

Eimer, Holmes, and McGlone (2003). In their study, mean amplitudes between 220 and 315 ms for P2, 320–495 ms for P3, and 500–700 ms for LPP were used to measure late positive activity. Similar to Study I, the late ERP activity was statistically analysed adding the time range as a factor to the ANOVA model. Finally, means for IBI and EMG activity were calculated at four 1,000 ms bins following the emotion onset, while subtracting the average baseline activity of 1,000 ms prior to the expression onset.

The statistical analysis was done using repeated-measures ANOVAs conducted separately for early and late ERPs, EMG, and cardiac activity. All the models included emotional expression (anger, disgust, fear, happiness) and prime (silent, audio, touch) as factors. As an extension of this basic design, the analysis of ERPs included the factor of area (i.e., the average across electrodes within frontal [F3, Fz, F4], central [C3, Cz, C4], parietal [P3, Pz, P4], lateral posterior [P7, P8] and lateral occipital [O1, O2] regions). Because both the N1/P1 and N170/VPP had components with parallel latency but opposite polarities and distinct topography, all the areas were included in the factor as levels when analysing these two temporal windows. In contrast, for the P2 window, only central (C3, Cz, C4) and parietal (P3, Pz, P4) areas were included. Analysis of the late components was done conducting a four-way ANOVA with expression, prime, area (all five regions), and time (220–315, 320–495, and 500–700 ms) as factors.

To analyse changes in cardiac OR, a repeated-measures ANOVA was conducted with prime, expression, and time (1st, 2nd, 3rd, 4th s) as factors and average IBI as the dependent variable. The effect of time was added as a factor only when cardiac OR was examined, given that OR behaves in a time-locked manner (Graham & Clifton, 1966). In turn, the timing of fEMG responses varied between muscle areas, for which reason the EMG activity could be better distinguished in terms of its localization than its timing. Consequently, the factor of time was replaced by that of area (CS, LN, ZM) in the ANOVA model conducted on EMG. Whenever a significant interaction between the prime and facial expression was found, the effect was further examined using Bonferroni corrected pairwise comparisons.

2.5.4 Study IV

In Study IV, compliance to economic offers, offer-related cardiac ORs, and responders' BIS, BAS, and JS were measured. Compliance to the agents' economic offers was operationalized as the binary decision to reject or accept the agent's offer.

The cardiac OR was quantified by first segmenting the continuous IBI signal into 9-s epochs with 1,500 ms of baseline activity. The epoched data was time-locked to offer feedback onset, and an average of baseline activity was subtracted from the post stimulus IBI activity. Visual inspection of the baseline-corrected grand average (across conditions) IBI signal revealed a brief increase in IBIs occurring 1000–3000 ms after offer feedback, as expected based on literature (Bradley, 2009). Consequently, trial-based cardiac OR was calculated averaging the baseline corrected IBI activity between 1000 and 3000 ms post offer stimulus. These trial-based values were used in statistical testing.

Similar to Study II, the BIS/BAS scale was used to measure individual differences in behavioural activation and inhibition systems. Only the BAS-reward responsiveness (four-item) and BIS (seven-item) subscales were used in the present study. The items of the reward responsiveness subscale measure a person's sensitivity to rewarding experiences. According to Taubitz, Pedersen, and Larson (2015), this subscale captures individual differences in approach motivation better than the other two BAS subscales. Both the BIS and the BAS-reward responsiveness scales resulted in an acceptable level internal consistency, as indicated by the Cronbach's alphas (α BAS = .73 and α BIS = .75). Individual differences in JS was measured using the justice sensitivity questionnaire (Schmitt, Gollwitzer, Maes, & Arbach, 2005), whose validity and reliability has been proven in several previous studies (see Schmitt, Baumert, Gollwitzer, & Maes, 2010). The questionnaire consists of three subscales, but in the present study, only the JS_{victim} subscale was used, since only this measured a person's proneness to experience injustice toward oneself. The scale has 10 statements, and participants can indicate their agreement to each using a five-point Likert scale (1 = disagree strongly, 5= agree strongly). The Cronbach's alpha for the 10-item subscale showed acceptable internal consistency (α = .76). Averages of each subscale item's ratings were calculated, and standardized average values were used as an index of the trait measures.

All the statistical analyses were based on a five-way factorial repeated measures design with agent gender, ethnic appearance (African, Caucasian, East Asian, and South Asian), touch type (no touch, visual, visuo-tactile), facial expression (angry, neutral, happy), and offer type (very unfair, somewhat unfair, fair, generous) varying between trials. The included predictors were the same irrespective of the outcome variable. The models included main effects of all the five factors as well as the two-way interactions between expression and offer type and touch and offer type. In addition, two-way interaction between expression and touch as well as the three-way interaction of expression, touch, and offer were tested in all models.

To statistically test whether the virtual agent's expression and touch influenced participants' acceptance or rejection rates, the binary outcome data was modelled using the generalized estimating equation (GEE; `geepack` in R; Halekoh, Højsgaard, & Yan, 2006) with the binary logistic link function. The GEE suited this analysis purpose well, as it is used in the analysis of clustered data with binary outcome variables (Liang & Zeger, 1986).

To examine whether touch and expression influenced responders' post-offer cardiac OR, MLM was used. The model included the same set of main and interaction terms as was used in the GEE. However, to control for the commonly observed habituation effect in cardiac OR (Bradley et al., 1993), a binary factor of time (first vs. last half of the session) was also included. Based on preliminary inspection, the IBI amplitudes and habituation trends of cardiac OR varied substantially across participants. Therefore, the participant ID was assigned to a random intercept, and the factor of time was set as a random slope. To measure the proportion of explained variance by each model, the so-called pseudo- R^2 was calculated. Moreover, the

proportion of residual variation explained by individual predictors was measured using the Ω^2 index (Xu, 2003).

The final phase of the analyses investigated whether the responders' JS, BAS, and BIS trait covariates moderated the effects of touch and expression on offer acceptance. Consequently, three separate GEE models (one for each covariate) were built to accompany the described situational factors by the trait covariates. The covariates were tested in separate models to avoid overly complex model structures or multicollinearity between the covariates. Therefore, each model included the main and interaction effects of the previously described situational factors, the main effect of the trait covariate, and the two- and three-way interactions between and among touch, expression, offer type, and trait.

3 Results

The purpose of this section is to answer the five research questions presented in Section 1.5 by summarizing the key findings of all four studies. A more detailed description of the preliminary and complementary observations can be found in the original publications.

3.1 Study I

The results of self-reported tactile and visual experiences are illustrated in Figure 5. As can be seen, the intensity and pleasantness of the agent’s facial expression was evaluated differently depending on the emotion category (expression intensity: $F(3.14, 125.64) = 43.79, p < .001, \eta_p^2 = .52$; expression pleasantness: $F(2.58, 103.32) = 47.78, p < .001, \eta_p^2 = .54$). More precisely, facial expressions of anger, fear, and happiness were rated as more intense expressions than sadness and neutral state (p ’s $< .001$ of Bonferroni adjusted pairwise comparisons). The ratings regarding expression pleasantness revealed that expressions depicting negative emotions were rated as less pleasant than expressions of positive emotions (p ’s $< .03$ for all comparisons).

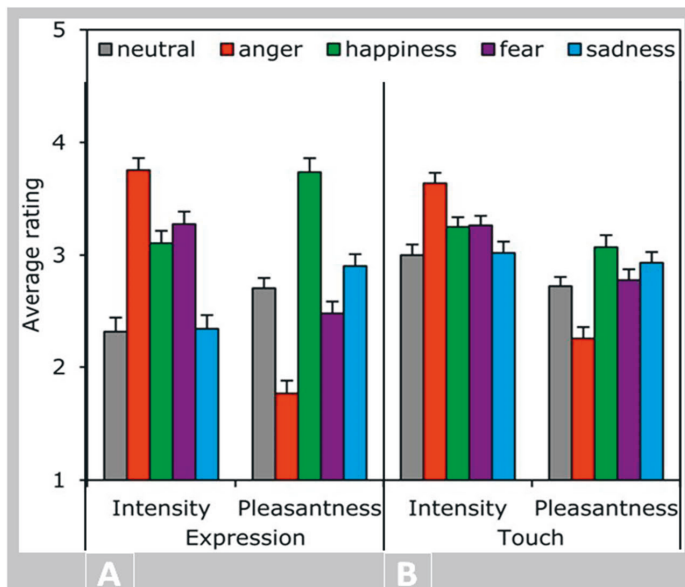


Figure 5. Self-reported intensity and pleasantness ratings regarding the agent’s facial expressions (Panel A) and touch (Panel B). Error bars indicate standard errors of means.

More interestingly, and in response to RQ1, receiver’s ratings of touch intensity and pleasantness varied depending on the sender’s emotional facial expression (tactile intensity: $F(2.05, 81.79) = 16.30, p < .001, \eta_p^2 = .29$; tactile pleasantness: $F(1, 40) = 60.87, p < .001, \eta_p^2 = .60$). The mean ratings in each expression condition can be

observed in Figure 5 (Panel B). As can be seen, touches accompanied by angry expression were perceived as more intense than touches accompanied by any other expression (p 's < .001). In addition, touches paired with happy and fearful expressions were perceived as more intense than those paired with sad and neutral face (p 's < .02). With regard to tactile pleasantness, touches accompanied by a happy or sad expression were rated as the most pleasant, while touches paired with angry, fearful, and neutral expressions were perceived as less pleasant (p 's < .05).

Figure 6 (Panel A) shows the grand average ERP waveforms presented as a function of touch types (vibration and mechanical pressure) and intensity levels (low and high). As can be seen, the early components were clearly present when evoked by vibration but almost entirely smeared out in the mechanical touch condition. This was supposed to be due to random latency differences in the pressure device resulting from the more gradual onset of the mechanical pressure stimuli giving rise to multiple overlapping early components or skewed latency distribution. Consequently, the mechanical stimuli data were omitted from the further analysis of the early, though not the late, SEPs.

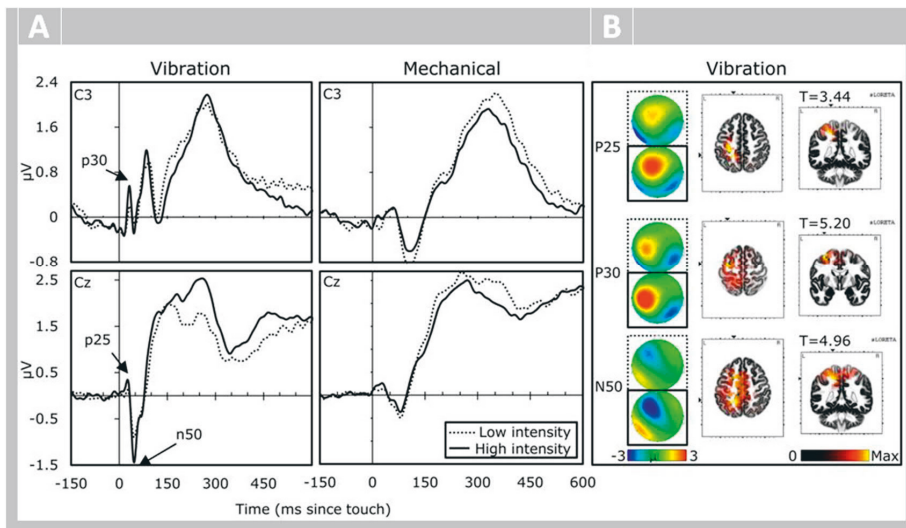


Figure 6. Panel A shows the grand average ERPs resulting from low (dotted line) and high (solid line) intensity vibration (left column) and mechanical (right column) touch stimuli. The early SEPs have been indicated by arrows. Panel B (left column) presents the topography of the current source density from all 32 channels. In the right column of Panel B, one can see the source localization results produced with the eLORETA software back projecting statistically significant differences (the range of t-values presented as black to yellow colour range) between low and high intensity vibration conditions.

Inspection of the grand average waveforms at C3 and Cz revealed the early components being more enhanced in high than low intensity vibrations (Figure 6, Panel A, left side). The current source density images (Figure 6, Panel B, left side) and the exact low-resolution brain electromagnetic tomography (eLORETA) revealed that the components were more enhanced in electrode sites over the contralateral

sensorimotor region (including the somatosensory cortex). The difference between high and low intensity vibration at P25 was found to be most enhanced over the somatosensory cortex in the left Brodmann Area 5 (BA5) and extending to BA3. The maximum P30 activity was more anterior, with peak difference being found in the left BA6. Similarly, the peak difference of N50 was found in BA5, but the activity extended to a wider area, including left BA6, BA7, and BA40.

When testing whether the three early SEPs were affected by the agent's facial expressions, it was found that P30 was insensitive to the facial expression (p 's > .15), but P25 and N50 were both affected by the facial expression, as indicated by similar three-way interactions among tactile intensity, electrode, and expression in both ANOVAs (P25: $F(8.28, 323.08) = 2.78, p = .005, \eta_p^2 = .07$; N50: $F(6.94, 269.71) = 2.62, p = .01, \eta_p^2 = .06$). Post hoc analyses revealed that the hard vibration caused more contralateral amplification of P25 and N50 when the touch was preceded by happy, angry, or sad facial expressions than when preceded by fearful or neutral expressions (see Figure 7, Panels A and B).

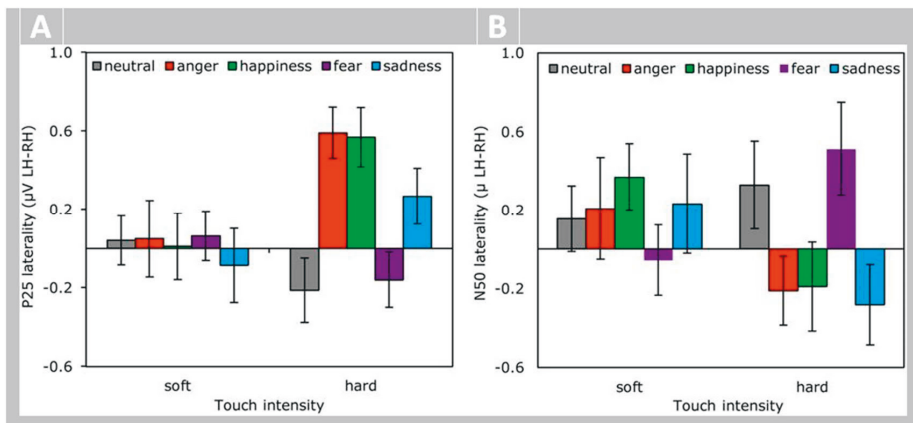


Figure 7. Lateralization of the P25 (Panel A) and N50 (Panel B) SEP components as a function of the agent's facial expression (colours) and touch intensity (soft touch on the left side and hard touch on the right side of each panel). Lateralization values were calculated on the basis of CP5, C3, FC1, FC2, C4, and CP6 channels, subtracting the average voltage activity on the left (ipsilateral) hemisphere from the corresponding right-hemisphere activity. Error bars indicate standard errors of mean.

Analyses of late SEP activity revealed that the differences between expressions evolved over time, as indicated by a significant time-expression interaction, $F(8.71, 339.71) = 3.82, p < .001, \eta_p^2 = .09$. Follow-up analyses of the interaction revealed that the amplitudes of angry expressions were significantly higher compared to those of neutral expressions already at 200–300 ms ($p < .01$), while the difference between happy and neutral expressions became significant only later, at 400–500 ms ($p = .01$). Overall, the late SEP activity was characterized by increasingly high voltage values in angry expressions and increasingly low values in happy expressions. This pattern can also be seen in Figure 8 (Panel A).

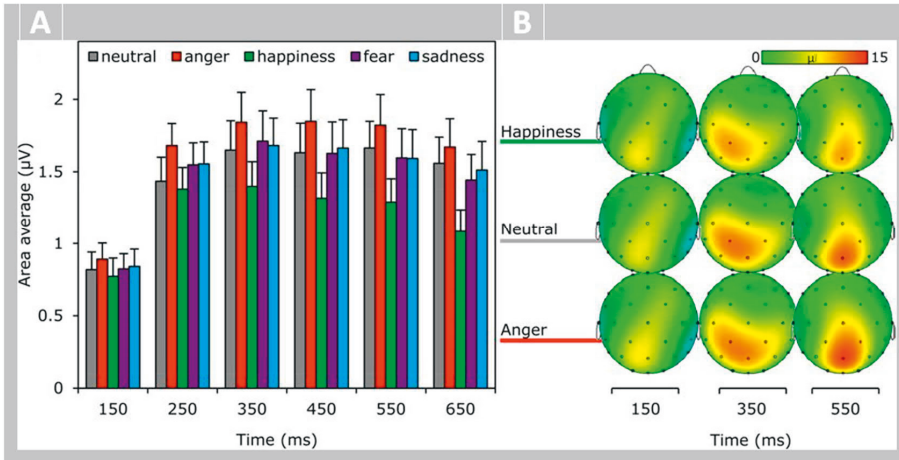


Figure 8. Panel A presents average voltage activity over centro-parietal electrode sites (Cz, CP1, CP2, P3, Pz, P4) at six 100 ms time intervals and in each facial expression condition. Panel B shows the topography of current source density at three time intervals and three selected expression conditions.

In answer to RQ1, the results of Study I revealed that the participants rated the agent’s touch differently and exhibited differing early and late SEP activity depending on the accompanied emotional facial expression. The pattern obtained in early SEPs, in turn, revealed that contralateral voltage activity, which was sensitive to the touch type and intensity, was more enhanced in response to touches preceded by angry, happy, and sad expressions than to those preceded by neutral and fearful facial expressions. Finally, the late SEP activity, that was spatially and temporally more broadly distributed showed a dissociation between touches with angry and happy facial expressions, with the angry expression increasing and the happy expression decreasing the amplitudes.

3.2 Study II

When examining the effects of facial expressions on touch-related cardiac OR, a significant interaction between touch type and facial expression was found, $F(4, 152) = 4.78, p = .001, \eta_p^2 = .11$. Testing the effect of expression on OR in both touch types separately revealed that only the cardiac ORs in the vibration condition varied as a function of the accompanied facial emotional expressions, $F(4, 152) = 8.67, p < .001, \eta_p^2 = .19$. As the Figure 9 presents, ORs were most enhanced in response to vibrations paired with the sad expression and lowest in response to those paired with the happy expression, with responses to neutral, fearful, and angry expressions falling in between.

Multilevel linear modelling, conducted to test the moderating effect of BIS and gender on touch intensity ratings, revealed a three-way interaction among expression, BIS, and gender, $F(5, 141.59) = 7.34, p < .001$. Follow-up analyses were conducted separately for females and males, revealing a significant interaction of expression and

BIS in males ($p < .001$) but not in females ($p = .96$). Subsequently, the interaction effect in males was further inspected using the simple slope analysis. As shown in Figure 9 (Panel B), high-BIS males perceived the same touch as more intense if paired with fearful, happy, or angry expressions. In other words, the effect of these emotional expressions on touch intensity ratings was enhanced in males with high inhibition system sensitivity. The MLM conducted on touch pleasantness ratings did not reveal any interactions between the expression and BIS (p 's $> .61$).

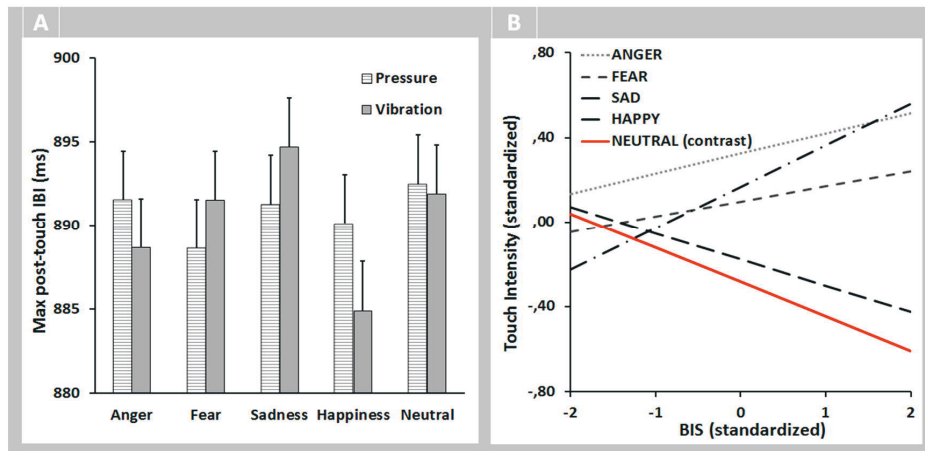


Figure 9. In Panel A, touch-evoked cardiac orienting response (max post-touch IBI) is presented as a function of the agent's facial expression and touch type. Panel B shows the interaction effect of the agent's facial expression and BIS on tactile intensity ratings in males. Simple slope analysis was used to plot separate regression slopes for each expression condition.

Then, investigating the role of gender and BIS in touch-evoked cardiac OR revealed that the males' autonomic responses to the agent's touch were also different compared to females, $F(1, 35) = 14.39$, $p = .001$; that is, males had greater cardiac ORs (959.01 ± 138.33 ms) than females (827.38 ± 166.80 ms) in all touch-expression conditions. Further explorative analysis revealed that, irrespective of the agent's expression, high ratings of BIS predicted enhanced cardiac OR in males, $F(1, 20) = 7.95$, $p = .01$ but not in females ($p = .17$).

Taken together, the findings of Study II demonstrated that approximating the touch with vibration resulted in enhanced touch-evoked OR, especially if the agent's facial expression was neutral or sad while touching. Thus, as an answer to the RQ2, males with high BIS perceived the agent's touch as particularly intense when accompanied by angry, fearful, or happy facial emotional expression, and they exhibited enhanced cardiac OR when touched by the agent.

3.3 Study III

The purpose of Study III was to examine whether receiving a touch modulates the processing of subsequent emotional facial expressions (RQ3). To test whether touch

modulated the effect of expressions on autonomic activity, ANOVAs were conducted. Significant interaction between muscle area and expression was obtained, $F(1.64, 63.95) = 15.48, p < .001$, indicating a stronger CS and lower ZM muscle activity in response to angry, fearful, and disgusted faces than to happy expression images (see Figure 10, Panel A). Contrary to our expectations, however, the prime type had no influence on the expression-related EMG responses (p 's $> .30$). The same was the case with cardiac OR: Expression significantly interacted with time, $F(3.24, 126.51) = 4.83, p = .003$, the effect reflecting a stronger OR 3 s after the expression onset in response to anger compared to other expressions. However, the expression-related cardiac OR was not affected by whether a touch, tone, or no prime was presented (p 's $> .50$). The main effects of prime type on each autonomic measure are presented in Figure 10 (Panel B). As can be seen from the figure, LN muscle activity is strongly affected by touch, which was found to be the case because touch induced a sudden increase in LN activity in the baseline, meaning that the decline observed in the figure is merely a result of baseline correction.

Modulatory effects of touch on early ERPs were then tested with three separate repeated measures ANOVAs with area (frontal, central, parietal, and occipital), expression, and prime as factors and average amplitudes in P1/N1, N170/VPP, and P2 time ranges as the outcomes. A significant interaction between area and expression was obtained in the range of P1/N1, $F(5.55, 216.26) = 4.04, p = .001$, indicating amplified negativity over central electrodes (N1) and amplified positivity in occipital sites (P1) in response to disgusted expression stimuli (see Figure 10, Panel C). While the prime type was also found to interact with area, $F(3.19, 124.35) = 7.07, p < .001$, (touch amplifying and tone attenuating the N1 amplitude in fronto-central sites; see Figure 10, Panel D), there was no interaction between the prime type and expression, which implies that touch did not modulate the effect of emotional expression, although it had a unique enhancing effect on early visual processing of all face stimuli.

Inspection of the N170/VPP time range revealed a significant interaction between area and expression, $F(4.56, 177.66) = 14.33, p < .001$. The N170 was found to be localized at lateral temporal sites and was most amplified in response to fearful and happy expressions. The same was the case with frontally localized VPP (see Figure 10, Panel C). In addition, the auditory and tactile primes were found to amplify the localized N170 and VPP effects compared to the no-prime condition, which implies that receiving any kind of prime prior to the face amplifies later face-specific visual processing (Figure 10, Panel D). Nevertheless, the prime type did not modulate the effect of expression in this time range either (p 's $> .60$).

The same pattern of results was also found in the temporal range of P2, as demonstrated in significant interaction between expression and area, $F(2.78, 108.43) = 6.88, p < .001$, as well as between prime and area, $F(1.96, 76.48) = 5.93, p = .004$. In central sites, the P2 amplitude was higher in the fearful compared to other expressions, whereas at parietal electrodes, the activity was enhanced in all negative expressions (especially in anger) compared to happiness (see Figure 10, Panel C). With regard to primes, tone was found to result in higher P2 amplitudes at central sites

than touch and no-prime (Figure 10, Panel D). Similar to earlier time ranges, there were no modulatory influences of prime on the effects of expression on P2 amplitude, which suggests that receiving a brief, computer-generated touch does not modulate emotional face processing. Inspection of the later ERP components, namely, P3 and LPP, lent further support to this conclusion, showing that in neither these later stages was the effect of expression modulated by the prime (p 's $> .30$). The main effects of expression and prime on P3 and LPP can be seen in Figure 10 (Panels C and D, respectively).

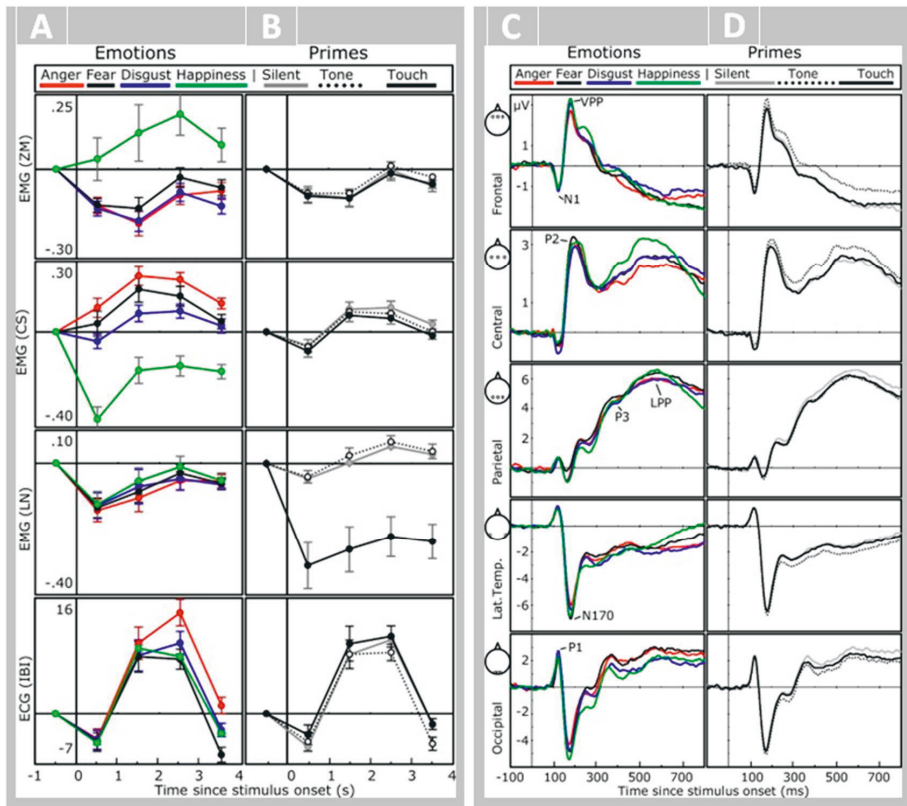


Figure 10. Panels A and B show averaged post-face EMG and ECG activity at four 1-s time bins. In Panel A, the effect of emotional expression is presented, whereas Panel B depicts the effect of the prime. Panels C and D present grand average ERP waveforms at five cortical locations time-locked to facial expression onset. Panel C depicts the effects of facial expressions on average voltage activity, whereas Panel D shows the effect of the prime on the same post-face ERP activity.

Taken together, Study III replicated the earlier observations of emotional face processing but gave also strong evidence against the assumption that receiving a computer-generated touch modulates the processing of subsequent facial emotional expressions.

3.4 Study IV

Study IV was conducted to investigate whether touch and facial expressions affected compliance to economic offers made by virtual agents (RQ4) and whether the receiver’s personality modulated the persuasive effect of the agents’ non-verbal cues (RQ5). A large number of results were reported in the original publication, but, for the sake of brevity, I report only the key findings here.

Table 3. Means and standard deviations of the probabilities of participants accepting agents’ offers and offer-related cardiac orienting responses (OR) at each level of offer fairness (N = 56).

Offer type	P(accept)		Cardiac OR	
	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>
Very unfair	.20	.40	32.78	54.13
Somewhat unfair	.69	.46	30.88	54.92
Fair	.94	.24	29.44	54.85
Generous	.94	.24	28.27	54.77

Note. P(accept) refers to the mean probability of the participant accepting the agent’s offer. Cardiac OR refers to average increase in interbeat intervals (IBIs) after the presentation of the offer compared to pre-offer IBI activity (baseline).

As seen in Table 3, there was substantial variation in the participants’ acceptance rates depending on the offer fairness, as the fair and generous offers were almost always accepted and the very unfair offers in only 20 percent of cases. Touch and expression were also found to influence participants’ acceptance rates, but the effects were further dependent on offer fairness, as reflected in the significant two-way interactions between touch and offer fairness, $\chi^2(6) = 18.07, p = .006$, and expression and offer fairness, $\chi^2(6) = 22.71, p = .001$. Along the lines of previous field experiments on non-verbal persuasion, it was hypothesized that happy and neutral expression as well as visuo-tactile touch would result in higher compliance than when an angry expression was displayed or no touch was delivered by the agent. As seen in Figure 11 (Panels A and B), this was indeed the case.

The participants were less likely to accept the agent’s offers if they were accompanied by an angry expression. While the trend was the same across all offers, the difference between happy or neutral compared to angry expressions varied depending on offer fairness (fair: p ’s < .001, Odds ratios ≤ 4.83 ; generous: p ’s < .001, Odds ratios ≤ 4.04 ; somewhat unfair: p ’s < .001, Odds ratios ≤ 2.06 ; very unfair: p ’s < .001, Odds ratios ≤ 1.63). The participants were also 1.20 times more likely to accept a very unfair offer if a visuo-tactile touch preceded the offer than if no touch was delivered ($p = .03$, Odds ratio = 1.20, 95% CI [1.16, 1.28]). Although this Midas Touch effect reached statistical significance only in the very unfair offers, the same trend was also present in somewhat unfair offers ($p = .06$, Odds ratio = 1.13).

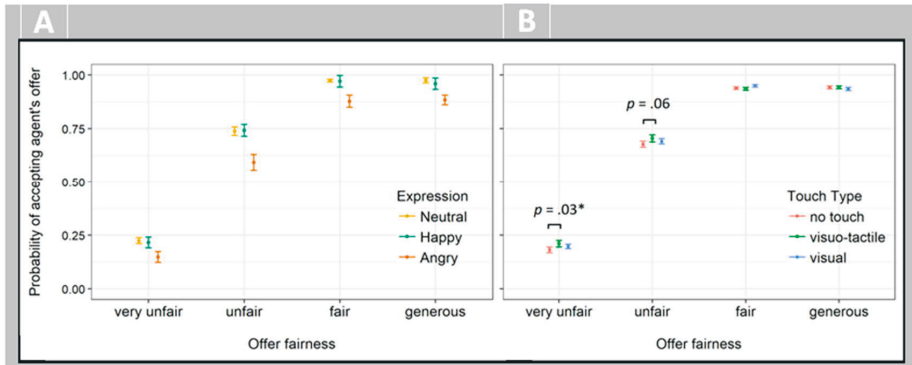


Figure 11. Probability of accepting the agent's offers at each level of offer fairness. Panel A shows the acceptance rates as a function of fairness level and facial expression, and Panel B presents the acceptance rates as a function of fairness level and touch type.

We had assumed the persuasiveness of touch to depend on the accompanying expression. However, instead, the effect of touch on compliance was found to be constant over the different conditions, as indicated by the non-significant interactions between expression and touch, $\chi^2(4) = 8.34, p = .08$, and among expression, touch, and offer fairness, $\chi^2(12) = 10.69, p = .55$.

The MLM analyses on offer-related cardiac OR revealed an increase as a function of offer type (i.e., unfairness of the offers), $\chi^2(3) = 23.60, p < .001$. However, we found no support for the hypothesis that touch and expression moderate the fairness-related cardiac activity (p 's $> .10$ for all main and interaction effects). Careful inspection of the MLM revealed that the full MLM was able to explain only 6.7 % of the entire variation in touch-evoked cardiac OR. This observation and the fact that no significant correlation between cardiac OR and compliance was found ($r = -.12, p = .39$) suggested that the OR did not offer a precise picture of the decision-making process.

Examining the influence of the responder's personality on compliance revealed that persons with high BAS generally accepted more offers than people with low BAS, $\chi^2(1) = 5.32, p = .02$. In answer to RQ5, BAS was also found to moderate the relation between offer fairness and touch as reflected in the statistically significant three-way interaction between the three variables, $\chi^2(6) = 14.24, p = .03$. Further inspection of the effect revealed that people scoring low in BAS (-2 SD below mean) were more than 1.5 times more likely to accept a very unfair offer if they were being touched than if not being touched by the proposer (Odds ratio $_{\text{visuo-tactile vs. no touch}} = 1.74, 95\% \text{ CI } [1.68, 1.81]$, Odds ratio $_{\text{visual vs. no touch}} = 1.54, 95\% \text{ CI } [1.50, 1.58]$). The same was not the case with high BAS individuals, who showed higher acceptance rates in all levels of offer fairness irrespective of the preceding non-verbal cues (see Figure 12, Panel A). Moreover, no significant interactions were found between facial expression and BAS (p 's $> .10$), which suggests that BAS was not moderating the persuasiveness of facial expressions.

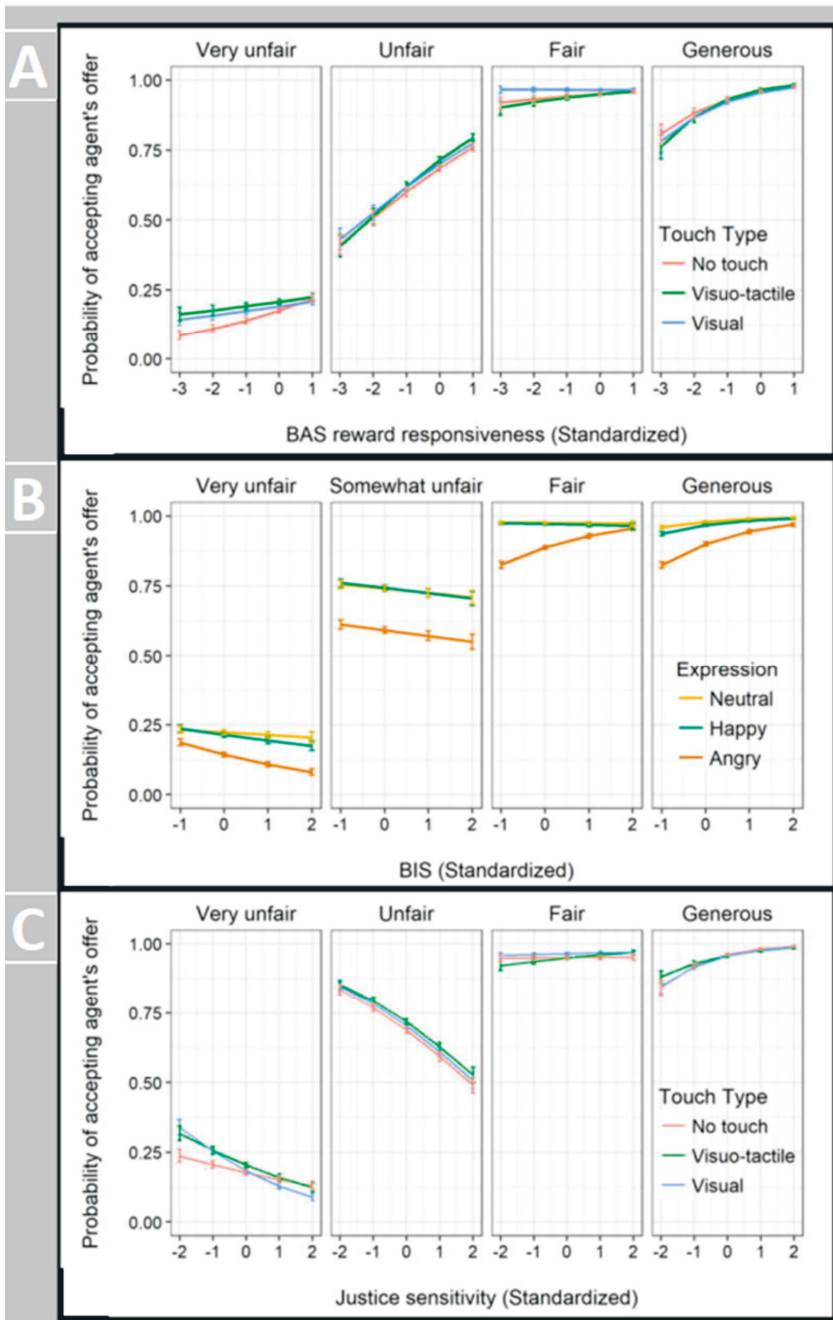


Figure 12. Moderating effects of responder's personality traits on the effects of touch and facial emotional expressions on compliance to Ultimatum game proposals. Panel A presents the moderating effect of BAS on the persuasive influence of touch in four offer types. Panel B depicts a similar moderating effect of BIS on facial expression. Panel C, in turn, shows the moderating effect of justice sensitivity on the persuasive influence of touch. The personality scores have been standardized around zero.

Examining the moderating influence of BIS on non-verbal persuasion revealed an opposite pattern, as the BIS was found to moderate the interaction between offer fairness and expression on compliance, $\chi^2(6) = 23.23, p = .001$, but not that between offer fairness and touch, $\chi^2(6) = 6.39, p = .38$. Further inspection revealed that people with high BIS were more prone to reject very unfair offers that were accompanied by angry expressions than those coupled with neutral or happy expressions (Odds ratio $_{\text{neutral vs. angry}} = 2.93, 95\% \text{ CI } [2.76, 3.11]$, Odds ratio $_{\text{happy vs. angry}} = 2.42, 95\% \text{ CI } [2.29, 2.54]$). However, as can be seen from Figure 12 (Panel B), the interaction effect was more complex than this, because fair or generous offers coupled with angry expressions were more likely to be rejected by those scoring low rather than high in BIS (Odds ratios $_{\text{happy/neutral vs. angry}} > 3.44$).

Inspection of the moderating role of JS revealed a pattern similar to that of BAS, and JS was found to interact with offer fairness and touch, $\chi^2(6) = 32.27, p < .001$, but not with offer fairness and expression, $\chi^2(6) = 6.52, p = .37$. The interaction with touch was further inspected using simple slope analysis. As seen in Figure 12 (Panel C), people with low JS were overall more likely to accept unfair offers than people with high JS and 1.50 times more likely to accept very unfair offers when the agent had touched them than when no touch had been delivered (Odds ratio $_{\text{visuo-tactile vs. no touch}} = 1.50, 95\% \text{ CI } [1.48, 1.51]$, Odds ratio $_{\text{visual vs. no touch}} = 1.66, 95\% \text{ CI } [1.64, 1.67]$). The same was not the case with those with high JS who were insensitive to the touch.

To summarize the findings of Study IV, people were more likely to accept the agent's unfair offers if the agent touched or smiled before making the offer. In answer to RQ4, both touch and facial expressions influenced the receiver's compliance, but in an independent and additive manner rather than interacting with one another. Moreover, and in answer to RQ5, the persuasive effect of touch was found to be more enhanced in receivers with low JS and BAS. Conversely, the effect of BIS on compliance depended on the agent's facial expression but not on touch. All the described effects remained after controlling for the effects of the agent's gender (same vs. different-sex) and ethnic appearance.

4 General discussion

Table 4 summarizes the research questions and key findings of the dissertation work. The first aim of the dissertation was to reveal how a sender’s multimodal emotional expressions, conveyed via face and touch, integrate into the receiver’s perceptual processing during virtual face-to-face interaction. Study I revealed that both self-reported tactile perception and somatosensory-evoked potentials to sender’s touch were influenced by the sender’s facial expression. This finding was extended by Study II, which demonstrated how men with high behavioural inhibition tendencies were especially likely to perceive the sender’s touch as particularly intense when it was accompanied a facial expression indicating high arousal. In Study III, a more traditional experimental paradigm was used to study how being touched modulates subsequent emotional face processing. The results revealed that, contrary to our assumptions, receiving a computer-generated touch had no modulatory influence on subsequent emotional face processing.

Table 4. The research questions and key findings of the studies.

<i>Study</i>	<i>Research Questions (RQs)</i>	<i>Key Findings</i>
I	Do sender’s emotional facial expressions influence tactile perception of their virtual interpersonal touch (RQ1)?	The sender’s emotional facial expressions modulated self-reported tactile perception and somatosensory-evoked potentials
II	Do individual differences in behavioural inhibition system sensitivity and gender contribute to the modulatory influence of facial emotional expressions on touch perception (RQ2)?	Receiver’s gender and behavioural inhibition tendencies moderated the influence of facial expressions on tactile perception
III	Does being touched via a tactile interface influenced the processing of subsequent emotional facial expressions (RQ3)?	Touch did not modulate subsequent emotional face processing
IV	Does a sender’s facial expression and touch have a persuasive influence on a receiver’s economic decisions (RQ4)	Touch and smile increased likelihood to accept sender’s unfair economic offers.
	Do individual differences in the perception of fairness and motivational tendencies moderate this persuasiveness (RQ5).	The persuasive influence was modulated by the receivers’ justice sensitivity and reward responsivity traits

The second aim of this doctoral thesis was to examine how multimodal presentation of facial emotional expression and touch influence social decision-making and offer-related autonomic activity. In Study IV, both the sender’s facial expression and touch were found to additively influence decisions to accept the sender’s economic offers. This persuasive influence was found to be greater in

individuals with low justice sensitivity and low responsivity to rewards. In the following sections, I will discuss these findings in greater detail.

4.1.1 Modulatory influence of facial expressions on touch perception

According to the Study I findings, people perceived touches accompanied by angry, fearful, or happy facial expression as more intense than those accompanied by a sad or neutral face. In earlier studies, feelings of anger, fear and happiness have been associated with heightened emotional arousal, whereas feelings of sadness and neutrality have been linked to low emotional arousal (Gable & Harmon-Jones, 2010; Lang, Greenwald, Bradley & Hamm, 1993). Consequently, the Study I results suggest that perceived intensity of interpersonal touch varies as a function of emotional arousal manifested in the toucher's facial expression. A touch's pleasantness, in turn, was found to vary according to the expression's emotional valence (i.e., negativity vs. positivity) as only touches preceding happy expressions were considered pleasant. Similar results were previously reported by Ellingsen et al. (2014), who found that machine-generated and human touch was evaluated as more pleasant if paired with a picture of a smiling face than a frowning face.

When it came to early somatosensory-evoked potentials, Study I demonstrated two temporally and spatially distinct groups of SEPs, both of which were influenced by the sender's facial expression. The differences in latencies, topographies, and effects of facial expressions between the SEPs led to the suggestion that there were two distinct stages of affective top-down modulation. The first stage was characterized by three early SEPs, (p25, P30, and N50) peaking around 25 and 50 ms over the contralateral somatosensory cortex, of which P25 and N50 were selectively amplified by high-intensity vibrations. The facial expressions were found to modulate this intensity-related amplification, so that strong vibrations preceded by angry, happy and sad expression led to larger contralateral activity in P25 and N50 than those preceded by neutral or fearful expressions. Previous research has revealed that SEPs around 20-50 ms in the contralateral central electrodes originate exclusively from the contralateral primary somatosensory cortex (SI, see Urbano et al., 1997). Additionally, Sel and colleagues (2014) found SEPs to tactile probes being more amplified if presented after pictures of fearful or happy facial expression than after neutral face stimulus. Finally, Gazzola and colleagues (2012) demonstrated that contextual information about the toucher's gender modulated caress-evoked activity specifically in the PI. Therefore, the observed early influences of facial expressions can be assumed to reflect top-down modulation of the tactile feature encoding in the SI. In the original publication, it was suggested that P25 could have a subcortical origin, but in the light of literature reviewed above, it is more likely that both early components originate from contralateral PI.

Another interesting aspect is the difference between emotional categories in the early SEPs. The observation that both P25 and N50 had highest amplitudes in happy, angry, and sad expression conditions is in conflict with the assumption that the hedonistic value (valence) of the visual information would underlie the modulation

(Montoya & Sitges, 2006). Therefore, in the original publication, we introduced an alternative, appraisal-based explanation. Since facial emotional expressions signal the sender's affective state and intentions (Keltner & Haidt, 1999), they could also be used to predict others' motives to reach out and touch. Indeed, feelings of joy and anger are related to the motivation to approach, whereas the feeling of fear is linked to the motivation to avoid the target of one's feelings (Harmon-Jones, Gable, Peterson, 2010). While the withdrawal-approach tendency of sadness is less clear, the emotion commonly co-occurs with the seeking of consolidation and physical contact (Averill & Nunley, 1988; Gray, Ishii, & Ambady, 2011). Therefore, people may have anticipated physical contact more from a sad, angry or happy person than from a fearful or non-expressive interactant. This anticipation could have amplified the SI's response to the touch. Although more research is needed to confirm this explanation, previous studies of nociception and somatosensory spatial attention are in line with this argument (Porro et al., 2002; Schubert et al., 2008). For instance, in the study by Porro and colleagues (2002), expectations regarding the upcoming tactile stimulus amplified processing of the stimulus in the contralateral SI.

The later SEPs were likewise affected by the sender's facial emotional expression. The positive components over centro-parietal electrodes between 250 and 650 ms post-stimulus were most enhanced in response to touch accompanied by an angry facial expression, and least amplified when coupled with a happy facial expression. The topography and temporal characteristics largely resembled somatosensory evoked P200 and P3 components related to attention and memory-related semantic processes obtained in earlier studies (Conroy & Polich, 2007; Freunberger, Klimesch, Doppelmayr, & Höller, 2007; Montoya & Sitges, 2006). It is possible that the emotional relevance of the touch was encoded at this stage, producing increases in attentional and semantic processing. Although this interpretation seems plausible due to the component topography and the temporary increase voltage difference between the hostile angry touch and the affiliative happy touch conditions, it should be pointed out that Montoya and Sitges (2006) did not find that unpleasant/pleasant IAPS stimuli modulated SEPs in this time range. Of course, receiving a touch from an angry virtual agent in immersive VR is a more threatening and perhaps more meaningful experience than watching unpleasant/pleasant IAPS pictures. This might explain why a strong modulatory effect was found in our study, but not in the study by Montoya and Sitges (2006).

The differences in latency, topography and sensitivity to distinct categories of emotion between early and late SEPs indicate the modulatory influence to dissociate into two stages: the early expectation-driven and the later emotional relevance-driven stage. The stages are tentative, but resonate well with the recent developments in appraisal theories of emotion. According to the most prominent appraisal theory, the Component Process Model (Scherer, 1984), people appraise emotionally salient events sequentially. That is, a person first detects the event as emotionally relevant (as determined mainly by the suddenness and intrinsic pleasantness of the event), then evaluates its cause and implications to their goals, and finally assesses how well they

can cope with and adjust to the consequences (Sander, Grandjean & Scherer, 2005). Psychophysiological studies give support for such a processing pipeline (Gentsch, Grandjean, & Scherer, 2015a; Sander et al., 2018). Grandjean and Scherer (2008), for instance, showed participants IAPS pictures while manipulating the novelty, pleasantness and goal relevance of the picture stimuli. Topographical clustering and time–frequency EEG analyses revealed that the stimulus novelty was encoded before its goal relevance. These results were then replicated and extended by other studies, which revealed that the encoding of coping potential occurs later than the novelty and goal conduciveness check (Van Peer, Grandjean, Scherer, 2014; Gentsch, Grandjean, & Scherer, 2015b). Our results reveal similar sequential information processing in the processing of serial nonverbal emotional cues. The preceding emotional cue (facial expression) works as a contextual background for the appraisal of a subsequent nonverbal cue (touch), allowing the receiver to determine whether it is unexpected, pleasant and relevant to their goals.

If the observed modulations in SEPs reflect the described appraisal processes, they are highly reflective, requiring the binding of previous experiential knowledge to surrounding contextual cues and action tendencies. In addition to these reflective appraisals, rapid minimally reflective appraisals may also take place at the same time, but be observable only in later changes of autonomic nervous system activity, such as the orienting response (Sander et al., 2018). Indeed, in Study II, the vibrotactile touch was shown to induce deceleration in cardiac activity 1000 ms after onset. Unlike SEPs and self-reports, this cardiac OR was strongest when accompanied by a sad expression and weakest when coupled with a happy expression. Therefore, it is possible that the OR reflects yet another branch of the sequential appraisal process. For instance, the vibrotactile touch combined with a passive sad expression may have provoked a reflex-like orientation to the touch stimulus even though some sort of touch was anticipated based on the reflective appraisal of the expression. Be as it may, more research is required to better understand the differences between modulation of SEPs and cardiac OR.

4.1.2 Modulatory influence of touch on emotional face processing

The Study III results were clear cut: there was no modulatory influence of touch on emotional face processing, whether on face-evoked ERPs, fEMG or ECG. However, touch was found to have a unique amplifying effect on the face-evoked N1, irrespective of the facial emotional expression. The N170 and VPP were also larger after touch and tone than after silent prime. These influences resembled the so-called forewarning effect typical for all kinds of primes (e.g., Hackley & Vallen-Inclán, 1990; Swallow & Jiang, 2010) and were thus not interpreted as signs of exclusively tactilely modulated emotional face-processing.

Unlike us, Schirmer and colleagues (2010) found machine- and human-generated touch to modulate processing of negative IAPS stimuli at P3 time range. There are substantial differences between the experimental paradigms, which may explain the conflicting findings. For instance, Schirmer and colleagues (2010) did not measure

ERPs to facial emotional expressions, but to IAPS stimuli. Additionally, they contrasted negatively valenced pictures with neutral ones, whereas we compared different emotional expressions to each other. Finally, Schirmer and colleagues used a 3000 ms pressure stimulus to implement the touch, whereas our touch was a 500 ms vibrotactile stimulus. All these aspects could have influenced the results.

Apart from the null findings on tactile-to-visual modulations, we found that different facial emotional expressions had unique effects on autonomic activity, many of the effects being similar to previously reported observations. For example, the fEMG recordings revealed the well demonstrated unconscious facial mimicry effect (Dimberg & Thunberg, 1998) with more ZM activity in response to happy expression and more CS activity in response to angry, disgusted and fearful expressions. Also, the cardiac OR was found to be affected by emotional expressions being particularly amplified in response to angry expression. Similar observations have been reported earlier by Jönsson and Sonnby-Borgström (2003).

Inspection of the ERP responses revealed also many earlier demonstrated patterns. Similar to Hinojosa et al. (2015), for instance, we found that the N170 and VPP were amplified in response to fearful and happy expressions. Earlier it was believed that the late processing stage indexed by P3 and LPP only distinguish emotional expressions from neutral face but is not sensitive to any particular emotion (Eimer & Holmes, 2007). However, in our study as well as in the study by Luo et al. (2010), the P3 and LPP were selectively amplified by fearful expression. The conflicting findings may be due to the fact that in both studies, the neutral expression was used as a visual background the emotional expression was going to replace and not as one condition among other emotional ones (see Eimer & Holmes, 2007). It is possible that the feature encoding of the face and later semantic processing is different when the neutral/emotional facial expression stimuli are presented on a blank background than when each expression stimulus is preceded by neutral expression picture of the same face. In the latter option, also utilized in the Study III, the static configural features (identity) remain the same and only thing changes is the emotional expression for which reason the paradigm might be more sensitive to emotion specific influences on perceptual and attention-related ERP components.

Despite this methodological strength, the Study III did not find evidence on tactile modulation of emotional face processing. It remains possible that such modulation would have been observed if a different experimental paradigm and longer naturalistic tactile primes had been used (I will discuss these possibilities with greater detail in the section 4.2). However, it is also possible that the modulatory relationship between touch and facial emotional expressions is asymmetric and being touched does not simply influence subsequent emotional face processing although seeing other's facial expressions modulates the processing of subsequent touch. The asymmetry could stem from the so-called facial primacy, that is the preferential orienting to face instead of other bodily communication channels (e.g., Itier, Villate, & Ryan, 2007; Turati, Simion, Milani, & Umiltà, 2002). In fact, the face region has particular high density of sources of socially relevant information including not only the facial muscle activity

but the static facial features (e.g., Santos, Almeida, Oliveiros, & Castelo-Branco, 2016), gaze behaviour (e.g., Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008), and facial coloration (Thorstenson, Elliot, Pazda, Perrett, & Xiao, 2018). The attentional salience of face may thus offer a plausible functional explanation why facial emotional expressions modulate touch perception while touch does not modulate emotional face processing.

4.1.3 Influence of multimodal emotional expressions on decision-making

In Study IV, the sender's facial expressions and touch were found to influence the receiver's decision-making. Receiving an offer from a smiling agent or agent with neutral expression increased the receiver's likelihood of accepting economic offers. Similarly, receiving an unfair offer after a touch resulted in a higher likelihood of compliance with the proposer. The persuasive effect of a smile, as well as the Midas touch effect, have been reported in various field experiments (Gallace & Spence, 2010; Vrugt, 2007). While there are previous indications of the Midas touch effect in computer-mediated communication as well (Haans et al., 2014; Spapé et al., 2015), our findings are unique, as they show that virtual touch also has persuasive influence when attributed to a non-human social agent.

Contrary to the assumption that the effects of touch and facial expressions would depend on each other, they were found have an additive effect, so that both nonverbal expressions increased compliance independently. Of course, it is possible that the number of repetitions in each design cell of the experiment was too small to detect a small interaction effect like this, or that the repetitive nature of the experiment, together with the fact that people knew they were interacting with non-human agents, led to the adoption of a heuristic response style (e.g., systematically rejecting offers accompanied by angry faces), diminishing the naturally occurring interaction. Be as it may, the results show that at least in the given context, the Midas touch effect is not contingent on the facial emotional expressions of the sender and vice versa.

Finally, the question of whether the sender's nonverbal emotional expressions influenced the receiver's decision-related cardiac OR was also examined. In previous studies, the cardiac OR was found to be greater in response to unfair than fair offers (Osumi & Ohira, 2009). Although this was also the case in our study, neither touch nor facial expression modulated the effect. In the original publication, it was proposed that the cardiac OR was overall too noisy an index of decision-making and that more direct electrophysiological indexes would be required to further examine the phenomenon. Indeed, in the ERP study by Mussel et al. (2014), the sender's smile was found to reduce the amplitude of unfairness-evoked medial frontal negativity.

To summarize the Study IV situation-level results, we can say that there is a systematic persuasive effect of simulated touch and facial expressions, and that the effect is additive rather than conditional. The personality-level results gave further insights into the differences between facial emotional expressions and touch, as was reported in the results and as will be discussed further in the next subsection.

4.1.4 Individual differences in emotion perception and decision-making

People are known to differ in their action tendencies and responsiveness to emotional cues (Balconi et al., 2012; Knyazev et al., 2008). In Study II, we investigated how these differences influence the integration of facial and tactile emotional expressions in order to give further insight into the cognitive processes involved in multimodal emotion perception. The results revealed that people with high BIS reported the sender's touch as more intense when coupled with a high-arousal facial emotional expression (angry, fearful, or happy), and showed higher touch-induced cardiac OR than people with low BIS, irrespective of the sender's facial expression. In earlier studies, high BIS individuals were shown to respond with heightened cardiac OR to emotionally negative and arousing IAPS stimuli (Balconi et al., 2012), and to perceive negative facial expressions as more discomforting than people with low BIS did (Knyazev et al., 2008). However, in the present study, the effects of BIS were only present in men. While it was hypothesized that men and women would indeed respond differently to the touch, gender was not expected to moderate the effect of BIS in such a complex way.

Of course, the observed relation between BIS, gender, and facial expressions could be due to the simple fact that in this study the agent was always male. Indeed, male-male touch has been shown to communicate the receiver's lower social rank (Major & Heslin, 1982). Due to the inherent status threat, men often report male touch as uncomfortable (Roese et al., 1992; Gazzola et al., 2012). In our study, the influence of (male-male) touch was particularly pronounced in men with high BIS, which is consistent with the status threat view (Major & Heslin, 1982). However, as no female agent was included in the study design, it is impossible to draw further conclusions on this respect. Further research with both female and male agents is thus required to better understand the gender-related aspects of interpersonal touch. In these studies, it could make sense to consider gender as a relational feature (same-sex vs. different-sex dyad) rather than an individual characteristic.

The last question addressed by this dissertation was whether the receiver's motivational tendencies (BIS and BAS) and justice sensitivity moderate the effect of the receiver's responses to multimodal emotional expressions. The Study IV demonstrated that people with low sensitivity to unfairness and low behavioural approach tendency were more likely to accept a very unfair offer if the sender touched them before making it. Interestingly, these traits were not found to moderate the effect of facial expressions. Moreover, there was no difference in the personality effects depending on whether the agent was of same or different sex or ethnicity. In earlier studies, justice sensitivity has been related to a lower likelihood of accepting unfair ultimatum offers (Fetchnauer & Huang, 2004) whereas BAS has been linked to an elevated likelihood to accept unfair as well as fair offers (Ferguson et al., 2011; Scheres & Sanfey, 2006). Given that the ultimatum game works by evoking a conflict between short-term economic gains and avoidance of unfair treatment (Sanfey, 2007), people who score low in their responsiveness to gains and sensitivity to unfairness are,

in principle, less influenced by the game dynamics. Therefore, the results suggest that the persuasive effect of touch is most pronounced if the accompanying request is not in stark conflict with the receiver's other (e.g., economic) interests.

Examining the moderating effect of BIS revealed a completely different pattern. While there was no difference in the effect of touch between people with high and low BIS, those with high BIS showed a pronounced tendency to reject very unfair offers from agents with angry facial expressions. Moreover, people with low BIS had a higher likelihood of rejecting fair and generous offers if those were accompanied by angry facial expressions. Although unclear, the findings may reflect BIS's role in motivating individuals to punish wrongdoers as well as avoid future negative consequences. In previous studies, people with high BIS have been shown to react more strongly to negative facial cues and perceive them as more negative (e.g., Knyazev et al., 2008). Moreover, BIS has been linked to higher risk aversion in economic decision-making scenarios (Demaree, DeDonno, Burns, & Everhart, 2008). It is thus possible that high-BIS individuals are more motivated to reject unfair offers accompanied by angry expressions when the economic gains are low, as they perceive the combination of unfair offer and angry expression more negatively than low-BIS individuals. If an offer is fair or generous, however, the decision to reject it due to the expression may be perceived as more costly and risky by high-BIS individuals. They might, for instance, anticipate that the rejection of an angry but fair proposal will result in the agent's retaliation in subsequent trials (e.g., less fair offers), which may decrease their motivation to punish the agent in this case.

To conclude, the persuasive effects of facial expressions and touch were moderated by different motivational traits. This dissociation indicates distinct socio-cognitive mechanisms underlying their persuasive effects. While the influence of facial expressions on decision-making could be related to the motivation to punish a sender for an unfair offer or hostile manners, the effect of touch may be related to an increased urge to comply with slightly unfair requests when these are not in stark conflict with the receiver's own interests

4.2 Limitations

The research questions examined in this dissertation were largely unexplored, for which reason there were a limited number of earlier findings that could be used to formulate more specific hypotheses. Consequently, the questions and hypotheses tested here were rather explorative. The downside of such explorative approach is that when something is found, there is no a priori explanation for it and the chance of inaccurate conclusions is elevated. Therefore, the tentativeness of interpretations has to be acknowledged and further hypothesis testing is inevitably required to confirm or falsify the interpretations. A good example of this limitation is our interpretation that anticipation of physical contact underlies the modulatory influence on early SEPs found in the Study I. Due to fact that the expectations were not directly manipulated or measured, there is a good chance the modulation was not due to anticipation.

Therefore, a more direct test of the assumption is still required. One could, for instance, ask people to rate their expectations regarding the probability of physical contact in each expression condition and see whether these ratings covary with the early modulation.

Other limitations that should be pointed out here relate to the methodology. First, one could argue that the use of virtual agents and social touch technologies made it unclear to what extent the findings could be generalized to real human-human interaction. For example, while accumulating evidence suggests that virtual agents' nonverbal behaviour has influences similar to real humans' nonverbal behaviour (Bailenson et al., 2001; 2003), people can feel uncomfortable when interacting with virtual agents that look almost but not fully human (Seyama & Nagayama, 2007). This "uncanny valley" effect may be elicited by our virtual agents as well. On the other hand, we do not know how the uncanniness could have accounted for the perceptual and decision-making related cognitive effects demonstrated by the studies. In addition, using immersive VR, social touch technologies and virtual agents enables us to overcome the trade-off between ecological validity and experimental control (Blascovich et al., 2002).

The highly controlled traditional paradigm with static face images was used in Study III, as it enabled examination of modulatory influences on emotional facial processing in the standardized stimulus condition. While it is possible that touch has no influence on emotional face processing, as the results suggest, it cannot be ruled out that the far-from-natural stimulus presentation was unable to evoke modulatory influences operating in natural face-to-face interactions. Along the same line of argument used in studies I and II, one could argue that seeing the touch and facial cues originating from the same embodied source intensifies integration of the nonverbal emotional cues. Indeed, in a recent study, we showed that the presence of perceiver's own virtual body is enough to enhance cross-modal interference between tactile and visual senses in a bimodal oddball paradigm (Harjunen, Ahmed, Jacucci, Ravaja, Spapé, 2017). Therefore, the contribution of bodily presence and other strengths of VR cannot be ruled out when trying to understand discrepancies between the findings of studies I and III.

The potential limitation related to human agency should be pointed out as well. It is clear that people respond differently to virtual agents and avatars, especially if the tasks involve theory of mind -related processes such as perspective taking (Fox et al., 2015). The Study IV findings could thus have been different if the participants had been told they were interacting with humans instead. Indeed, imaging studies on the ultimatum game reveal that the receiver's insula responds more strongly to unfair offers attributed to another human than to those attributed to a computer (Sanfey et al., 2003). The extent to which agency-related factors influence emotion perception may, however, depend on the cognitive process in question. For instance, whether the agent is regulated by a human or an algorithm can make a substantial difference in higher social cognition-related processes such as fairness evaluations (see Sanfey et

al., 2003), but have a much smaller influence on low-level cognitive processes such as early perception and exogenous attention (studies I and II).

Finally, limitations related to small sample sizes arise when investigating individual differences with small experimental samples. These limitations are most prominent in Study II, in which the effect of BIS was found to be further moderated by gender. The obtained findings were internally consistent, as there were many indications of gender differences, but the risk of type I error was nevertheless elevated.

4.3 Implications and future directions

Despite limitations, the present dissertation has clear implications to scientific understanding of emotions and nonverbal communication. Previous work shows that the socio-emotional context in which an interpersonal touch is conveyed modulates perceptual processing of the touch (e.g., Ellingsen et al., 2014; Gazzola et al., 2012; Spapé, et al., 2015). The current dissertation extends these findings, showing that multimodal emotional expressions conveyed consecutively via face and touch begin to be integrated at a very early stage of the perceiver's somatosensory processing, and that the integration has two qualitatively different phases.

Moreover, the findings are important as they demonstrate how nuanced the perception of interpersonal touch can be. Not only does the sender's nonverbal behaviour determine how the physical contact is perceived, but the receiver's personality and gender also contribute to the experience. While more research is required to better understand the role of gender and other individual characteristics in tactile communication, the present dissertation successfully demonstrates that interpersonal touch is a complex compound of tactile and visual bodily cues, contextual information and personality-level factors with considerable social influence.

While examining whether receiving a computer-generated touch influences processing of emotional faces, we found no evidence of the modulation. There are multiple explanations for the null finding, as noted above, but the most obvious one is that the modulatory link between emotional facial expressions and touch is asymmetrical and that the modulatory influence from touch to emotional face processing does not exist. In psychology, researchers too often report findings supporting their hypotheses while leaving opposite and null findings in the file drawer (Ferguson, & Heene, 2012). This bias is almost two times higher in social and behavioural sciences (95 % of tests supporting the hypothesis in psychology and psychiatry) than in physical and biological sciences, which may well explain the current replication crisis in our field (Fanelli, 2010). For the sake of sustainable psychological research, we should be more transparent and also report the results that do not give support for our hypotheses. Study III made large contributions to this endeavour.

When it comes to higher level cognitive processes, we show that a virtual agent's touch and facial emotional expressions influence the receiver's social decision-

making, and that the effect of the two cues is additive. Moreover, we demonstrate that there are substantial individual differences in the persuasive influences of multimodal emotional expressions, and that the influences are modulated by different personality traits. While it remains unclear to what extent the observations apply to human-human interaction, many previously demonstrated behavioural effects that were replicated in our VR setup, such as the Midas touch effect. This suggests that the results may be applicable to human-human interaction as well.

The importance of this work to the field of human-computer interaction is likewise apparent as we demonstrate how computer-mediated social touch can be enriched and contextualized using virtual embodied agents that amplify the technology's emotional relevance. Another aspect also relevant here is the potential of emotionally expressive virtual agents in persuasive communication. Algorithmic conversation agents and social robots are becoming increasingly popular (Fortunati, Esposito, & Lugano, 2015; Prendinger & Ishizuka, 2013). Here, it is shown that just a small increase in virtual agents' emotional expressiveness increases their persuasive influence. Further increases in emotional responsiveness, verbal communication repertoire and behavioural flexibility could make them even more influential and attractive to commercial use. This could have many positive outcomes, such as new job markets and economic growth, but could also lead to various ethical issues including automatized persuasion of children and elderly people who are in vulnerable position when it comes to persuasive communication. Therefore, rigorous scientific inquiry is required to determine the risks and develop ethical guidelines for this form of persuasive computing.

4.3 Concluding remarks

The present work stands out from the mass of social and affective neuroscience research on emotion perception. Using a unique combination of immersive VR, haptic technology and electrophysiological recordings, our team was able to reveal earlier unknown aspects of the complex neural dynamics of multimodal emotion perception that may operate in face-to-face interaction. In future, the same methodology can be utilized to study multimodal emotion perception from other nonverbal cues such as prosody, gaze and posture and to investigate how the processing of multimodal emotional expressions differs between neurotypical individuals and people with abnormalities in social cognition. Ultimately, the accumulating knowledge may help to improve the diagnosis and treatment of these disorders, and to develop technologies that support emotional communication in general.

5 References

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