

Impact of Social Anxiety on the Subjective Assessment and Somatosensory Processing at Spinal and Supraspinal Levels of Affective Touch

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Professor Doutor Alberto Jacobo González Villar

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Agradecimentos

"Entre o estímulo e a resposta existe um espaço. Nesse espaço reside o nosso poder de escolher a resposta. E nessa escolha está a nossa liberdade e o nosso crescimento" (Viktor Frankl). Este trabalho representa o culminar de um longo caminho, trilhado com muita sede de conhecimento e descoberta, mas onde esse espaço de escolha nem sempre se mostrou acessível.

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Impacto da Ansiedade Social na Avaliação Subjetiva e no Processamento Somatossensorial aos Níveis Espinhal e Supraespinhal do Toque Afetivo

Resumo

A Perturbação de Ansiedade Social (PAS) caracteriza-se por um medo excessivo da avaliação social e evitamento de situações interpessoais. Tem sido demonstrado que indivíduos com ansiedade social (IAS) apresentam um processamento alterado de estímulos sensoriais e sociais. O toque afetivo (TA) é uma modalidade tátil de natureza social, neurobiologicamente mediada por fibras C-táteis (CT) não mielinizadas, que desempenha um papel central na regulação emocional e na vinculação interpessoal, embora a sua modulação na ansiedade social (AS) permaneça pouco compreendida. O presente estudo investigou o impacto dos sintomas de AS na avaliação subjetiva e nas respostas neurofisiológicas ao TA, ao nível espinhal (potenciais somatossensoriais evocados [PSEs] N13) e supraespinhal (PSEs N20-P25, N1-P1, N2-P2), em participantes do sexo feminino saudáveis. As participantes foram expostas a três condições de toque: toque discriminativo, estimulação CT-ótima realizada por um robô e estimulação CT-ótima realizada por um humano, enquanto eram registados os PSEs. Os resultados revelaram que participantes com níveis elevados de AS relataram menor agradabilidade e apresentaram amplitudes N13 mais negativas durante o toque discriminativo, sugerindo um processamento espinhal alterado. Uma correlação positiva entre AS e a amplitude N13 durante a estimulação CT-ótima por robô indicou uma resposta espinhal alterada ao estímulo afetivo. Ao nível supraespinhal, as participantes com AS elevada exibiram amplitudes N2 inferiores durante a estimulação CT-ótima por humano. Estes resultados sugerem que os sintomas de AS modulam precocemente o processamento somatossensorial, mesmo em contextos neutros, salientando a necessidade de replicação destes resultados em amostras mais amplas e diversificadas.

Palavras-chave: ansiedade social, toque afetivo, processamento somatossensorial, avaliação subjetiva.

Impact of Social Anxiety on the Subjective Assessment and Somatosensory Processing at Spinal and Supraspinal Levels of Affective Touch

Abstract

Social Anxiety Disorder (SAD) is characterized by excessive fear of social evaluation and avoidance of interpersonal situations. It has been shown that socially anxious individuals (SAI) exhibit altered processing of sensory and social signals. Affective touch (AT) is a social tactile modality, neurobiologically mediated by unmyelinated C-tactile (CT) fibers, that plays a central role in emotional regulation and interpersonal bonding, though its modulation in social anxiety (SA) remains poorly understood. This study examined the impact of SA symptoms on subjective assessment and neurophysiological responses to AT at spinal (N13 somatosensory evoked potentials [SEPs]) and supraspinal (N20-P25, N1-P1, N2-P2 SEPs) levels in healthy females. Participants experienced three touch conditions: discriminative touch, CT-optimal stimulation by a robot, and CT-optimal stimulation by a human, while SEPs were recorded. High SAI reported lower pleasantness and showed more negative N13 amplitudes during discriminative touch, suggesting altered spinal processing. A positive correlation found between SA and N13 amplitude during CT-optimal stimulation by a robot indicated altered spinal responsiveness to affective input. At the supraspinal level, high SAI exhibited lower N2 amplitudes during CT-optimal stimulation by a human. These findings suggest that SA symptoms modulate early somatosensory processing even in neutral contexts, underscoring the need for replication with broader diverse samples.

Keywords: social anxiety, affective touch, somatosensory processing, subjective assessment.

Table of Contents

Introduction 10

Objective and Hypotheses 14

Materials and Methods 15

Participants 15

Self-Report Measures 16

Socio-demographic questionnaire 16

Social Phobia Inventory (SPIn) questionnaire 16

Electrophysiological Recording 16

Experimental Procedure 17

Data Analysis 18

EEG and ESG Processing 18

Statistical Analyses 19

Results 19

Associations between SA and Subjective Assessment by NRS scores 22

Associations between SA and Somatosensory Processing in ESG and EEG outcomes 22

Discussion 25

Limitations and Further Research 27

Conclusion 28

References 30

List of Figures

Figure 1. *Representation of the experimental procedure.* 17

Figure 2. *Grand-averages of the somatosensory evoked potentials for all the participants obtained during four experimental conditions (recorded at the spinal SC6, and scalp C4 and FCz channels).* 21

Figure 3. *Subjective pleasantness ratings across touch conditions: (A) linear correlations between SA levels measured by SPIn scores and mean NRS scores, and (B) the mean NRS scores for low versus high SA levels groups.* 23

Figure 4. *Relation between N13 SEPs amplitude measured at the SC6 ESG channel across touch conditions and SA levels: (A) linear correlation between SA levels measured by SPIn scores and N13 SEPs, and (B) the mean N13 SEPs values for low versus high SA levels groups.* 24

Figure 5. *Mean N2 SEPs values measured at the FCz EEG channel across touch conditions for low versus high SA levels groups.* 25

List of Tables

Table 1. *Mean and standard deviation (SD) values of the total sample and of both SA levels groups for SPIn, NRS scores and SEPs for each condition.* 20

Impact of Social Anxiety on the Subjective Assessment and Somatosensory Processing at Spinal and Supraspinal Levels of Affective Touch

Introduction

Since the initial works on phobia subtypes, Social Phobia has evolved into a distinct diagnostic entity (Lépine & Lellouch, 1995), with the terms Social Phobia and Social Anxiety Disorder (SAD) used interchangeably (Lecrubier et al., 2000). Although neglected by the medical community in the early years, further studies about the condition have increased since then (Stein & Stein, 2008; Stein, 1996).

Integrated in the scope of Anxiety Disorders, SAD is currently characterized by a marked fear or apprehension about one or more social situations in which individuals are exposed to possible scrutiny by others, or that they will act in a way or show anxiety symptoms that will be negatively evaluated or judged, provoking an avoidance response of such social or performance situations (American Psychiatric Association [APA], 2022). Cognitive-behavioral models of social anxiety (SA) suggest that socially anxious individuals (SAI) can show impairments in detection, modulation or interpretation of sensory stimuli, leading to specific behavioral responses to those stimuli, which contribute to the emergence and maintenance of the disorder (Clark & Wells, 1995; Green & Ben-Sasson, 2010). This indicates that there is a link between sensory information processing and SA (Jerome & Liss, 2005), demonstrating that SAI, particularly individuals with a generalized subtype of SAD, are innately more sensitive to sensory information. Some studies suggest evidence for the earliest age of onset of this subtype of the disorder, contrary to non-generalized subtype, with some researchers considering this higher sensitivity as a temperamental risk factor for SAD transmission (Hofmann & Bitran, 2007). Furthermore, this higher sensitivity is particularly relevant within the tactile domain (Ludlow et al., 2015).

Despite few studies having examined the potential relationship between SA and touch perception and processing, some evidence suggests that high SAI may react differently to the experience of touch, specifically social touch (e.g. Kashdan et al., 2017; Wilhelm et al., 2001). The emotional impact of social touch varies across individuals, and different factors may contribute to the increased fearfulness of social touch in SAI, as it can be considered culturally dependent on specific social rules (Jourard, 1966). Due to these conventions, SAI may be particularly insecure in pursuing social touch behaviors, because, for example, they can be potentially observed by the touch interaction partner and others around (Wilhelm et al., 2001) or feel awkward and unsettled due to their generally increased self-consciousness in social situations (Saboonchi et al., 1999). This supports the reported correlation between SA symptoms and negative attitudes towards social or affective touch (Barahmand et al., 2023; Lapp & Croy, 2021), with higher SAI reporting lower levels of touch comfort and higher levels of touch avoidance (e.g., Kashdan et

al., 2017). Furthermore, evidence shows that tactile sensation abnormalities are strongly associated with these avoidance behaviors from social situations more than the anxiety levels related to SAD (Ludlow et al., 2015)

Thus, to understand the impact of SA symptoms in sensorial processing, including the perception of touch, one must understand its underlying neurophysiological structures and functioning. From a neurophysiological perspective, SAD has been consistently associated with hyperactivation of neural circuits involved in threat detection and social cue processing, particularly the extended amygdala, comprising its central nucleus, the bed nucleus of stria terminalis and other forebrain structures involved in the initiation of fear and maintenance of anxiety (Fox & Kalin, 2014), which shows faster and prolonged responses to socially threatening stimuli (Blackford et al., 2011; Clauss et al., 2011). Other hyperactivated regions are the anterior hippocampus, orbitofrontal cortex, and insula, regions interconnected with the amygdala and implicated in contextual modulation, avoidance behavior, and heightened interoceptive awareness (Fox & Kalin, 2014; Schmidt et al., 2010). Structural neuroimaging studies also report cortical thinning in the fusiform and post-central gyri, as well as in temporal and insular regions, which could be related to reported impairments in facial recognition, sensory integration, and emotional processing during social interactions (Syal et al., 2012; Kucharska-Pietura et al., 2003). Importantly, comparative findings with Generalized Anxiety Disorder (GAD) patients showed distinct connectivity patterns: whereas GAD patients show stronger nucleus accumbens–thalamus connectivity, linked to dopaminergic circuits and fear generalization, SAD is characterized by reduced engagement of reward-related networks alongside somatosensory–thalamic hyperconnectivity, which can be associated with increased bodily awareness and emotional reactivity (Nagano et al., 2024; Sequeira, 2023). However, how these alterations can impact AT processing is not yet understood.

Research in somatic sensibility has viewed the senses as generally subserving a primarily discriminative role (Mountcastle, 2005). Discriminative touch is mediated by low-threshold mechanoreceptors (LTMRs), myelinated Aβ fibers, responsible for the precise perception of texture, vibration, pressure, and spatial localization, essential for object manipulation and motor control. Discriminative touch prioritizes sensory and motor functions, whereas affective touch (AT) is intrinsically linked to social bonding and emotional regulation (McGlone et al., 2014).

AT is conveyed by C-tactile (CT) fiber activity and involves complex ascending-descending pathways across the nervous system (Schirmer & McGlone, 2022). These fibers are composed of LTMRs, unmyelinated afferent neurons located in hairy skin but absent in glabrous skin of humans and other mammals (Olausson et al., 2010) with a general distribution (Johansson et al., 1988; Vallbo et al., 1993;

as cited in Olausson et al., 2010). CT receptors respond vigorously to tactile stimuli perceived as pleasant, such as slow and gentle stroking (Olausson et al., 2010). It has been shown that AT is most pleasant and socially meaningful when delivered at a slow, gentle speed, typically between 1 and 10 cm/s (Essick et al., 2009), which overlaps with the optimal parameters for the activation of these LTMRs. Particularly, stroking the forearm at around 3 cm/s with light pressure, especially using a soft brush, optimally activates CT afferents (Taneja et al., 2019).

CT fibers terminate in lamina II and III of the dorsal horn of the spinal cord, where they modulate tactile inputs through complex interneuron connections (Abraira & Ginty, 2013; Marshall, 2022). Studies with rodents suggest that CT afferents synapse in the lamina I of the dorsal horn of the spinal cord and ascend via the spinothalamic tract within the anterolateral system (Marshall, 2022). However, evidence in humans, such as the presence of preserved pleasant touch perception after spinothalamic tract ablation, implies alternative pathways like the dorsal column or input convergence, although alternative ascending pathways are not easily delineated in humans (Marshall, 2022; Marshall & McGlone, 2020).

Particularly, spinal reflexes have been shown to offer valuable insights into the central nervous system and its interaction with psychological processes. Emotional stimuli, for instance, can enhance spinal reflexes, suggesting that spinal cord responsiveness is modulated by higher-order brain functions (Both et al., 2003; Smith & Kornelsen, 2011). Individuals with GAD exhibit altered spinal cord reflexes, especially in cervical and thoracic segments, characterized by increased neural and autonomic activity (Kolesar, 2021). Although no studies to date have directly examined the spinal processing of tactile stimuli in SA, evidence from other psychiatric conditions such as autism spectrum disorder (ASD), psychosis, and attention-deficit/hyperactivity disorder (ADHD) has revealed significant alterations in somatosensory perception (e.g. Tasnim et al., 2024; Parush et al., 2007; Salamone et al., 2025; Zanini, 2024). In humans, tactile perception deficits have been consistently associated with ASD, particularly in the form of hyperreactivity to social touch and aberrant responses to affective tactile stimuli (Bennet et al., 2014; Ujiie & Takahashi, 2022). Importantly, Ludlow et al. (2015) demonstrated that in a non-clinical female population, the relationship between SA and tactile sensation abnormalities is fully mediated by the level of autistic traits. Their findings suggest that individuals with elevated autistic traits exhibit heightened sensitivity to tactile stimuli, which in turn correlates with increased social avoidance and anxiety (Ludlow et al., 2015).

At the supraspinal level, somatosensory areas S1 and S2 play a crucial role in the discriminative touch processing (Olausson et al., 2010; Ackerley et al., 2012). However, although the exact brain areas responsible for AT processing remain unclear (Khorev et al., 2024), AT seems to activate both the anterior

cingulate cortex (Case et al., 2016), especially by altering the connectivity between the left anterior pulvinar thalamus and the right pregenual anterior cingulate cortex (Khorev et al., 2024), and the insular cortex (Craig, 2002). For example, Schirmer and McGlone (2022) showed that lesions in the right insula, such as those resulting from right hemisphere strokes, disrupt the perception of touch pleasantness. Similarly, Kirsch et al. (2020) found that insular damage reduces tactile pleasantness sensitivity. Activity in the right insula also appears to mediate interoceptive awareness and social fear (Terasawa et al., 2013), being activated during the anticipation of touch rather than the tactile sensation itself and predicting the perceived intensity of the expected touch (Lovero et al., 2009).

Somatosensory evoked potentials (SEPs) and event-related potentials (ERPs) are electrophysiological responses that reflect the sequential activation of neural structures following a sensory or cognitive event, recorded respectively through electrospinography (ESG) and electroencephalography (EEG). Each component is named according to its polarity, positive (P) or negative (N), and the number refers either to its approximate latency in milliseconds or its order of appearance in the signal, with components of similar latencies often representing opposite deflections of the same underlying cortical activity, reflecting excitatory and inhibitory phases of synchronized postsynaptic potentials within corresponding neural generators (Allison et al., 1991; Cruccu et al., 2008). Particularly, SEPs are time-locked electrophysiological signals that follow electrical stimulation of the median nerve (Macerollo et al., 2018), a technique used to explore central and peripheral nervous structures. We used this technique to explore the dorsal somatosensory system (MacDonald et al., 2019), which conveys neural information that ascends through the dorsal column and is transmitted via the lemniscal pathway to thalamic structures (Cruccu et al., 2008; MacDonald et al., 2019). It is suggested that the N13 component reflects the segmental postsynaptic response of wide dynamic range (WDR) neurons in laminae IV-V of the dorsal horn of the spinal cord (Desmedt & Cheron, 1982; Restuccia & Mauguière, 1991). WDR neurons receive convergent input from nociceptors and tactile receptors (Bouhassira et al., 1992), and it is thought that they perform complex processes (Boehme et al., 2019). Using ESG, the N13 component can be recorded at the sixth cervical vertebra (SC6) after median nerve stimulation (Cruccu et al., 2008; Bailey et al., 2024).

Early ERP components, such as N20-P25, indicate the transmission of sensory information through primary somatosensory pathways, whereas later ERP components, including N1-P1 and N2-P2, represent higher-order cortical processing associated with perception and affective evaluation (Schupp et al., 2003). Thus, these electrophysiological markers provide a temporal map of neural activity across spinal and supraspinal levels of processing.

Using electrophysiological techniques, Ravaja and colleagues (2016) found an amplified P25 activity after angry and happy face expressions, suggesting that affective modulation of somatosensory processing starts already at a subcortical level, reporting similar findings showing that visual and auditory stimuli elicit modified processing in the thalamus (McAlonan et al., 2008; Woldorff et al., 1993; *as cited in* Ravaja et al., 2016). Furthermore, evidence has been shown that this early component, as well as N20, is generated from somatosensory area S1 (Ravaja et al., 2016), and that they are a mark of primary sensory cortex activation (Rossini et al., 1999).

At the cortical level, a review by Schulz and colleagues (2013) reported ERPs differences between SAI and healthy controls in P1 component to the visualization of different facial expressions with different valences, and heightened P2 and P3 components associated with SA but not with trait anxiety when individuals are exposed to angry faces (e.g. Rossignol et al., 2012). In fact, early ERP components, such as P1, are typically recorded over occipitoparietal or temporoparietal scalp regions (e.g. Rossignol et al., 2012), with P1 component, peaking around 100 ms post-stimulus, reflecting early sensory encoding of visual stimuli and being sensitive to attentional modulation (Hillyard & Münte, 1984). In SAI, enhanced P1 amplitudes to emotional faces, particularly angry expressions, suggest a hypervigilant perceptual bias toward socially threatening stimuli (Mueller et al., 2009; Rossignol et al., 2012).

In contrast, later ERP components, such as P2, reflect more elaborate cognitive and affective processing, as this component, typically observed over frontocentral regions around 200 ms, is associated with sustained perceptual processing (Schupp et al., 2003), stimulus evaluation (Carretié et al., 2001) and emotional categorization (Kolassa et al., 2009). In SAI, increased P2 amplitudes to angry faces suggest sustained attentional capture by emotionally salient stimuli (Rossignol et al., 2012).

Later positive ERP components have been associated with emotion regulation and motivational processes, reflecting sustained attentional engagement with emotionally salient stimuli (Hajcak & Foti, 2020; Harrewijn et al., 2018). Regarding AT, research has shown that this type of touch is responsible for changes in late positive ERPs over frontal scalp locations, rather than early positive ERPs over centroparietal areas, particularly when individuals are exposed to angry facial expressions (Schienle et al., 2022; Hajcak & Foti, 2020).

Objective and Hypotheses

This study aimed to identify how varying levels of SA symptoms are associated with differences in the neurophysiological and subjective domains of AT processing. By examining three touch conditions - discriminative touch, CT-optimal stimulation by a robot, and CT-optimal stimulation performed by a human - we explored how SA impacts the subjective pleasantness perception of AT (analyzing the scores

of the numeric rating scale [NRS] with verbal anchors given by the participants) and the AT modulation of somatosensory processing by CT-optimal stimulation at early spinal (through the analysis of the N13 component amplitude evoked by electrical stimuli) and supraspinal levels (analyzing the N20-P25, N1-P1 and N2-P2 components amplitude after electrical stimuli). Particularly, this study aimed to investigate the influence of bottom-up mechanisms in somatosensory processing of AT, as measured by earlier SEPs components (spinal and supraspinal), as well as top-down mechanisms, as individuals with higher SA levels could show heightened involvement of brain areas associated with emotional and social cognition activation (Morrison et al., 2011; Olausson et al., 2010) or the amygdala (Pessoa & Adolphs, 2010), particularly when touched by the experimenter, as shown by research reporting shortened SEPs latencies during touch by others comparing to self-touch (Boehme et al., 2019). For these purposes, the following hypotheses will be raised: 1) higher levels of SA are associated with lower pleasantness perception in the subjective assessment of AT by CT-optimal stimulation and discriminative touch by vibration, evaluated by the scores given by the participants on a NRS with verbal anchors; 2) higher levels of SA are associated with increased amplitudes of N13 and N20-P25, N1-P1 and N2-P2 components of the ESG and EEG outcomes, respectively, during AT modulation of somatosensory processing of electrical stimuli by CT-optimal stimulation, as well as increased amplitudes during discriminative touch by vibration, at both spinal and supraspinal levels.

Materials and Methods

Participants

The sample consisted of 13 participants aged between 19 and 26 (M=20.38; SD=1.805). All participants were female students at University of Minho, recruited through a research participation credit platform, which rewards students with academic credits, with high school as education qualification. Only one participant (7.7%) reported not having Portuguese nationality. Exclusion criteria included history of chronic pain, lesions in the arms, hands or legs, neurological conditions, diagnosis of Major Depression Disorder, Anorexia Nervosa or ASD, and being mainly left-handed. For preparation, the participants should have loose, dry and product-free hair, eat between one to three hours before the procedure, not drink alcohol in the last 24 hours, not drink coffee in the previous hour, smoke or wear neck-covered clothes, and they should bring wide shorts. Participants were informed about the experimental procedure and provided written informed consent before the experiment began. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee for Social and Human Sciences of the University of Minho (ref. CEICSH 030/2022). In this sample, only one participant reported a history of diagnosis of GAD with no symptoms in the last two years before participating in this study.

Self-Report Measures

Socio-demographic questionnaire

This questionnaire included questions about socio-demographic information (e.g. sex, age, nationality, etc.) and eligibility questions for participation in this study (e.g. current medication, medical history, time of sleep, consumption of substances, etc.).

Social Phobia Inventory (SPIn) questionnaire

The Portuguese version of SPIn, in its reduced version of seven questions (Ferreira, 2022), adapted from the original English version (Connor et al., 2000), was applied after the experimental procedure. This questionnaire assesses the intensity of anxiety-related problems in social situations in the previous week, with a five-point Likert scale, ranging from 0 (Not at all) to 4 (Extremely), with the possibility of total scores ranging between 0 and 28. According to the author, this questionnaire presents two factors, with four questions assessing avoidance of social situations (Factor 1) and three questions about physiological symptoms of SA (Factor 2). For Factor 1, the four items present strong levels of internal consistency, with Cronbach's alphas between .84 and .77; for Factor 2, the three items present strong to moderate levels, with Cronbach's alphas between .75 and .64. For the entire questionnaire, the author reported an adequate level of internal consistency ($\alpha > .70$; Ferreira, 2022).

Electrophysiological Recording

The EEG and ESG were recorded using a BioSemi ActiveTwo system (Biosemi, Amsterdam, The Netherlands). Participants wore one nylon cap on the head fitted with 47 active Ag/AgCl scalp electrodes, and one nylon patch on the back of the neck equipped with 17 active Ag/AgCl cervical electrodes positioned according to the international 10-10 system. In addition to the scalp and cervical electrodes, one active electrode was placed at the glottis, used as reference for the ESG, and another at the tip of the nose, used as reference for the EEG. The signals were referenced to the Common Mode Sense (CMS) and Driven Right Leg (DRL) electrodes from the BioSemi system. Before recording, electrode offsets were confirmed to be below 30 mV. Electrophysiological signals were sampled at a rate of 2048 Hz, with an online high-pass filter of 0.01 Hz.

To measure the differences in the somatosensory processing of electrical stimuli after CT-optimal stimulation at the spinal and supraspinal levels, the following measures were used for neurophysiological data collection: recording of SEPs with electrical stimulation of the median nerve in the arm at 1) the spinal level, the N13 component, especially with recordings at the level of the sixth cervical vertebra (SC6), and at the supraspinal level, 2) the N20-P25 components, particularly recorded at the C4 location (contralateral to the left hand) and 3) the N1-P1 and N2-P2 components, particularly recorded at the FCz

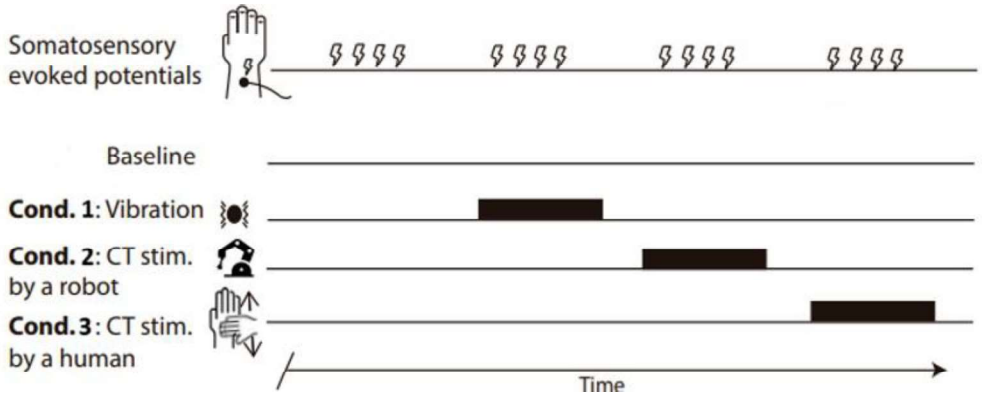
location (central pre-frontal locations).

Experimental Procedure

The experiment, whose procedure is represented in Figure 1, evaluated how the stimulation of CT fibers affects somatosensory processing at spinal and supraspinal levels. For this purpose, electrical stimuli to elicit SEPs were delivered over the median nerve of the left hand under three different conditions: 1) discriminative touch by vibration; 2) CT-optimal stimulation performed by a robot; 3) CT-optimal stimulation performed by a human. The order of conditions was counterbalanced among participants. CT-optimal stimulation in condition 2 was administered to the participants' left dorsal forearm using an in-house robotic arm equipped with a cosmetic brush (a laboratory-created device capable of reliably but neutrally performing CT fiber stimulation). The brushing movement covered a 12 cm strip of the forearm, applied at CT-optimal speeds (4 cm/s). To prevent visual feedback, participants could not see the movement of the robotic arm, as the brush was inside a box.

Figure 1

Representation of the experimental procedure.



The third condition of the experiment (i.e., CT-optimal stimulation performed by a human, who, in this case, was the experimenter) was designed to clarify the role of top-down or bottom-up mechanisms by comparing indices during touch performed by a human and by a robot. To match the CT-optimal stimulation parameters between the robot and the human, the experimenter was informed about the stimulation area and the start and end time of the touch through headphones.

Discriminative Touch (Vibrotactile) was delivered using two linear resonant actuator vibration motors controlled by the DVR2605L haptic module at a frequency of approximately 200 Hz. The motors were housed in a PLA plastic plate (6 cm x 2.5 cm) attached to the skin with adhesive tape, positioned immediately adjacent to the brushed area on the medial forearm. To control external variables such as

vibration, sound, and electrical noise, the robotic arm and the experimenter performed the same movement across all conditions. Before the experiment, participants were instructed to adjust the intensity of the vibratory stimulus to match the perceived intensity of the brushing. They used a visual analogue scale on a computer screen to increase or decrease the vibration intensity, while the brushing speed and pressure remained constant. The final vibration intensity used during the experimental task was calculated as the average of three calibration trials.

Electrical stimulation was administered using a Digitimer DS7A constant current stimulator controlled by the Psychopy software (Peirce, 2007). A surface stimulation electrode was placed on the wrist crease (anode) with the cathode positioned 2 cm proximal to the wrist crease. Prior to the experiment, the intensity of the electrical stimulus was calibrated for each participant. The intensity was increased by 2 mA until the experimenter observed involuntary twitches of approximately 1 cm in fingers innervated by the median nerve (M = 14.1 mA; SD = 0.7 mA). A total of 864 electrical pulses were delivered to each participant across 6 counterbalanced blocks (2 blocks of 144 stimuli per condition), for a total of 288 trials per condition. The electrical stimuli were presented at a rate of 4 Hz at the intensity established during the calibration phase.

After every two blocks, participants rated the sensation produced by the previous ten electric stimuli on a NRS with verbal anchors (0 - no sensation; 10 - noticeable sensation; 20 - mildly painful sensation (i.e., pain threshold); 30 - very weak pain; 40 - weak pain; 50 - moderate pain; 60 - slightly strong pain; 70 - strong pain; 80 - very strong pain; 90 - nearly intolerable pain; and 100 - unbearable pain). Electrophysiological recording took place in a soundproofed, electrically shielded room with controlled lighting.

Data Analysis

EEG and ESG Processing

EEG and ESG data were analyzed using the EEGLAB v2025.0.0 toolbox for Matlab (Mathworks® version R2024b). Segments containing major muscular or other artifacts were manually removed. To reduce artifacts caused by electrical stimulation, samples from approximately -2 ms to 8 ms after stimulus onset were zeroed. Signals were filtered offline using a high-pass FIR filter with a cut-off frequency of 0.01 Hz. Electrodes exhibiting poor recording quality were removed and reconstructed using spherical spline interpolation. Epochs were extracted from continuous ESG and EEG data within time windows of -10 ms to 25 ms and -100 ms to 250 ms, respectively, relative to the onset of electrical stimuli, with a baseline correction applied from -8 to -2 ms and -40 to -20 ms, for the ESG and EEG respectively. For the EEG, extended Infomax Independent Component Analysis (ICA) was used to correct ocular artifacts.

Components associated with eye movements, muscle activity, and poor signal quality were rejected with the assistance of the EEGLab plug-in "ICLabel" for component classification and removal, improving the overall data quality (Pion-Tonachini et al., 2019).

The EEG and ESG data were re-referenced to an average reference and waveforms were computed by averaging all trials for each condition. Negative and positive peak amplitudes were identified within different time windows: for N13 within the 0-10 ms window, for N20 and P25 within the 10-30 ms, for N1 and P1 within the 50-150 ms window and for N2 and P2 identified within the 150-250 ms window.

Statistical Analyses

Before the analyses, exploratory data assessments were conducted to detect potential outliers, as well as descriptive statistics (means, medians and standard deviations), to characterize the sample and guide the selection of appropriate statistical tests. All statistical analyses were carried out using IBM® SPSS® Statistics software (version 29.0.0.0, build 241; IBM Corp. ©, 2022). Non-parametric statistical methods were employed due to the limited sample size to ensure the robustness of the results (Siegel, 1957). Spearman's correlations were conducted to explore associations between variables and test both hypotheses.

To further examine potential group differences based on SA levels, Mann–Whitney U tests were also performed (Mann & Whitney, 1947). For this purpose, participants were categorized into two groups - high and low SA levels - based on a median split of the SPIn scores (Median = 17.00), which served as a cut-off point. This allowed for the comparison of distributions of dependent variables (e.g., SEP amplitudes, NRS scores) between participants with higher versus lower SA levels (Siegel & Castellan, 1988; for a discussion: Conover, 1999). A significance level of 5% was adopted for all non-parametric tests, with p-values below .05 considered statistically significant. Additionally, effect sizes (r) were calculated for each Mann–Whitney U test, where values of .10, .30, and .50 represent small, medium, and large effects, respectively (Cohen, 1988).

Results

Table 1 shows the descriptive statistics for the total sample and each group of SA levels. Figure 2 shows the waveforms of the mean values of the different SEPs in all touch conditions.

Table 1

Mean and standard deviation (SD) values of the total sample and of both SA levels groups for SPIn, NRS scores and SEPs for each condition.

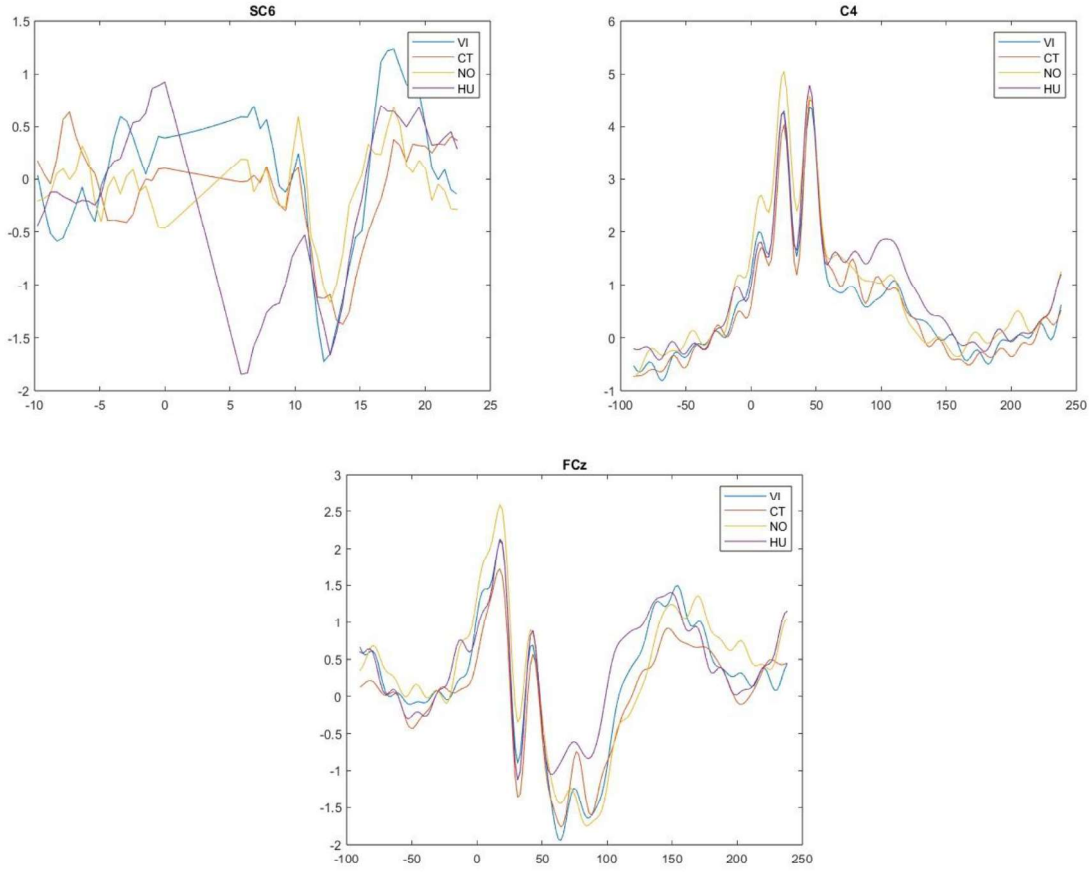
	Total Sample		Low SA Level Group		High SA Level Group	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
SPIn	18.31	4.211	14.86	2.116	22.33	1.033
NRS						
VI	46.346	16.772	55.036	16.216	36.208	11.425
CT	70.346	13.186	68.679	8.935	72.292	17.693
HU	71.808	14.763	67.500	10.608	76.833	18.215
N13						
VI	-2.081	1.898	-1.289	1.122	-3.005	2.287
CT	-2.098	1.306	-2.535	1.433	-1.588	1.024
HU	-1.805	1.550	-1.649	1.147	-1.988	2.028
N20						
VI	1.348	1.757	0.826	2.078	1.956	1.183
CT	1.208	2.176	0.647	2.298	1.863	2.019
HU	1.317	1.516	0.942	1.447	1.753	1.605
P25						
VI	4.783	3.050	5.023	3.820	4.503	2.154
CT	4.456	3.115	4.496	4.014	4.408	1.986
HU	4.662	3.487	4.827	4.493	4.470	2.207
N1						
VI	-2.707	2.104	-2.937	2.005	-2.438	2.375
CT	-2.973	2.192	-3.393	1.703	-2.484	2.742
HU	-2.287	2.220	-2.824	1.962	-1.661	2.518
P1						
VI	2.111	1.499	1.857	1.290	2.408	1.789
CT	2.000	1.150	2.162	1.049	1.811	1.332
HU	2.441	1.388	2.210	1.427	2.710	1.422
N2						
VI	-0.713	0.907	-0.914	1.121	-0.479	0.585

CT	-0.920	1.139	-1.135	1.150	-0.669	1.179
HU	-0.746	1.335	-1.335	1.379	-0.060	0.973
P2						
VI	2.004	1.360	1.670	0.842	2.393	1.802
CT	1.820	1.061	1.818	0.997	1.822	1.228
HU	2.157	1.108	1.900	0.839	2.456	1.378

Note. SPIn = Social Phobia Inventory, NRS = Numeric Rating Scale, VI = Discriminative touch by vibration, CT = CT-optimal stimulation by a robot, HU = CT-optimal stimulation by a human. Values represent descriptive statistics only; inferential analyses are presented separately.

Figure 2

Grand-averages of the somatosensory evoked potentials for all the participants obtained during four experimental conditions (recorded at the spinal SC6, and scalp C4 and FCz channels).



Note: VI – Discriminative touch by vibration; CT – CT-optimal stimulation by a robot; HU – CT-optimal stimulation by a human; NO – No touch delivered (not considered in this study).

Associations between SA and Subjective Assessment by NRS scores

For the first hypothesis, Spearman correlations between the SA levels and the mean values of NRS scores show significant statistical negative correlation between SA and the subjective assessment of discriminative touch by vibration ($r = -.734$, $p = .004$; see Figure 3A), although no significant correlations were found for the AT conditions (CT-optimal stimulation by a robot: $r = .125$, $p = .685$; CT-optimal stimulation by a human: $r = .382$, $p = .197$). Also, Mann-Whitney U tests show a significant statistical difference between high and low SA levels for the vibration condition ($U = 6.00$, $p = .032$, $r = -.594$) with the high SA level group showing lower levels of pleasantness to the discriminative touch ($M = 36.208$, $SD = 11.425$; comparing to low SA level group: $M = 55.036$, $SD = 16.216$; see Figure 3B). However, despite no significant differences were found for both AT conditions, high SA level group presented higher mean values of pleasantness in these conditions than low SA level group, as shown in Figure 3B (CT-optimal stimulation by a robot: $M = 68.679$, $SD = 8.935$ for low SA level group and $M = 72.292$, $SD = 17.693$ for high SA level group; CT-optimal stimulation by a human: $M = 67.500$, $SD = 10.608$ for low SA level group and $M = 76.833$; $SD = 18.215$ for high SA level group).

Associations between SA and Somatosensory Processing in ESG and EEG outcomes

For the second hypothesis, the sample shows a significant positive correlation between SA and the N13 component of the ESG for the CT-optimal stimulation by a robot condition ($r = .590$, $p = .034$), indicating an attenuated spinal response for high SA levels (see Figure 4A). Regarding group comparison, in spite of the reduced N13 observed for the high SA level group ($M = -1.588$, $SD = 1.024$ for high SA level group, and $M = -5.535$, $SD = 1.433$ for low SA level group; see Figure 4B), Mann-Whitney U tests did not show significant group differences during CT-optimal stimulation by a robot ($U = 12.00$, $p = .199$, $r = -.357$).

Mann-Whitney U tests also found significant differences for the N13 component during discriminative touch by vibration ($U = 5.00$, $p = .022$, $r = -.634$), indicating differences in the spinal response between high and low SA levels during discriminative touch, with high SA level group showing a more negative N13 component ($M = -3.005$, $SD = 2.287$ for high SA level group, and $M = -1.289$, $SD = 1.122$ for low SA level group; see Figure 4B), although no significant correlation was found between both variables ($r = -.388$, $p = .190$). Post-hoc pairwise comparisons indicated that the N13 component differed significantly from almost all the other components of the vibration condition, except for the N1 component, as mean amplitude values showed that N13 and N1 presented a heightened negative peak for high SA level group (See Table 1).

Figure 3

Subjective pleasantness ratings across touch conditions: (A) linear correlations between SA levels measured by SPIn scores and mean NRS scores, and (B) the mean NRS scores for low versus high SA levels groups.

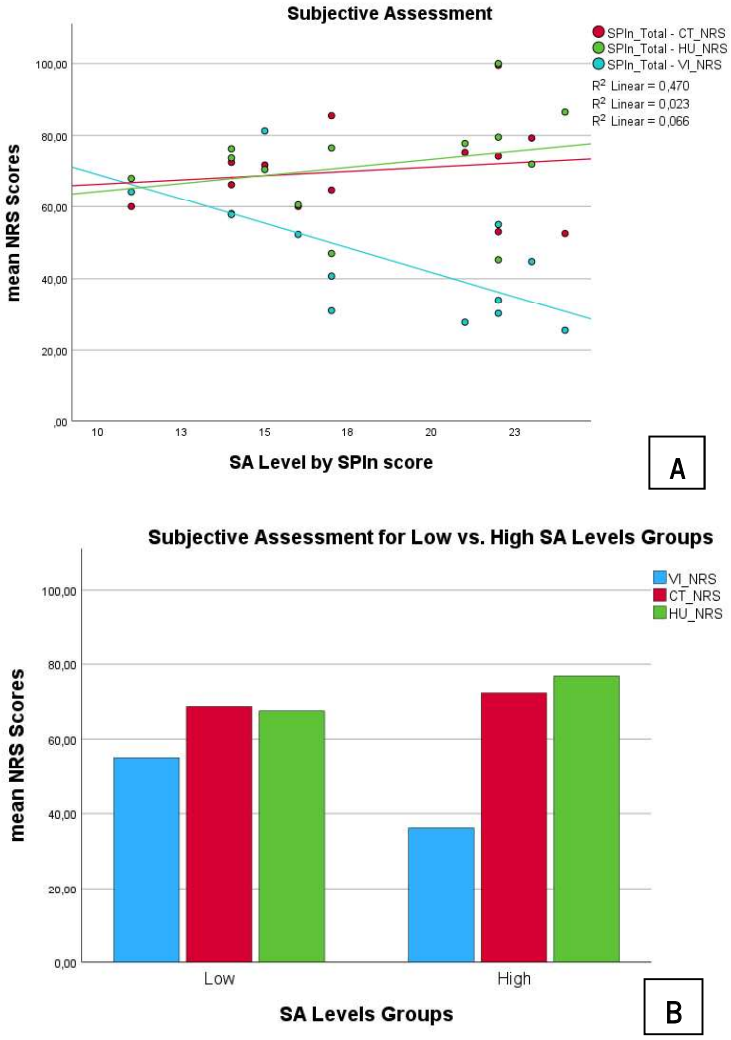
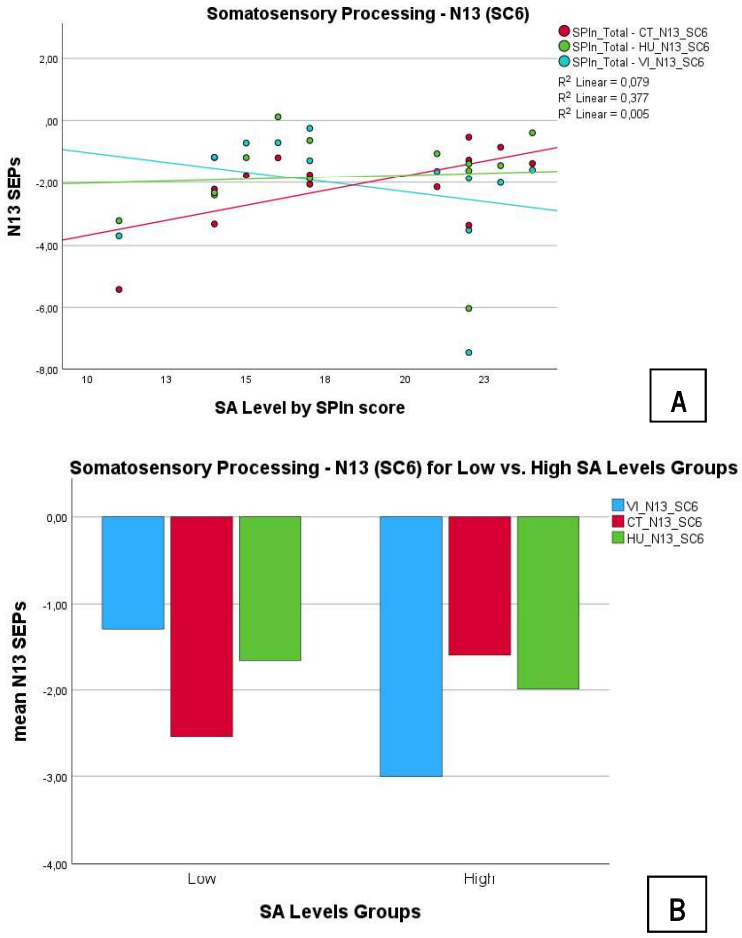


Figure 4

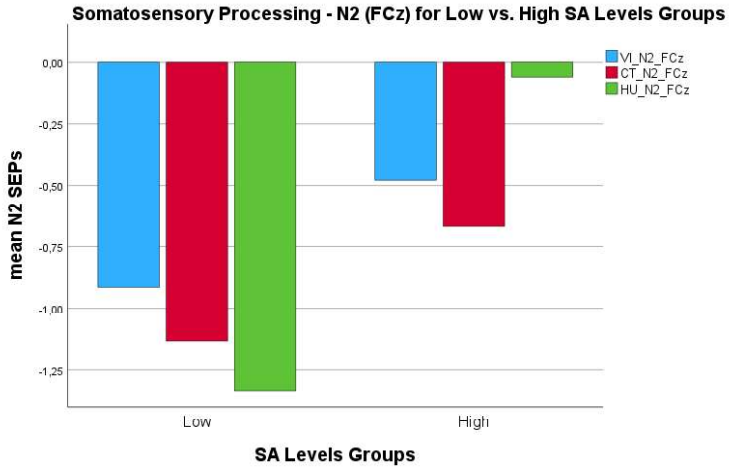
Relation between N13 SEPs amplitude measured at the SC6 ESG channel across touch conditions and SA levels: (A) linear correlation between SA levels measured by SPIn scores and N13 SEPs, and (B) the mean N13 SEPs values for low versus high SA levels groups.



A significant difference in the amplitude of the N2 component was observed during CT-optimal stimulation by a human (U = 7.00, p = .046, r = .555), with high SA level group showing lower amplitudes of this component (M = -.060, SD = 0.973 for high SA level group, and M = -1.335, SD = 1.379 for low SA level group; see Figure 5), although no significant correlation was found for this condition (r = .518, p = .070). No additional significant correlations or group differences were observed in the remaining components studied.

Figure 5

Mean N2 SEPs values measured at the FCz EEG channel across touch conditions for low versus high SA levels groups.



Discussion

This study aimed to investigate the impact of different levels of social anxiety (SA) in healthy young female adults on the subjective assessment of affective touch (AT), as well as on the modulatory effect of AT by CT-optimal stimulation on the somatosensory processing at spinal and supraspinal levels.

The results showed that individuals with higher SA levels perceived discriminative touch as less pleasant, with no differences for subjective ratings in the conditions of AT by CT-optimal stimulation, whether delivered by a human or by a robot. These results contradict the existing research reporting overall negative attitudes towards social or affective touch by higher socially anxious individuals (SAI; Barahmand et al., 2022; Lapp & Croy, 2021). However, no reviewed studies have examined the attitudes towards touch in an experimental design conducted in a neutral, non-threatening environment like this one. Most of the previous research evaluates those attitudes by correlations between self-report questionnaires (e.g. Lapp & Croy, 2021; Vieira et al., 2016) as well as context modeling designs with presentation of different facial expressions (e.g. Schulz et al., 2013; Schienle et al., 2022) or with an affiliative partner delivering touch (e.g. Kashdan et al., 2017). On the other hand, the neutral, non-threatening and non-social context (despite the presence of the experimenter in condition 3) of this study may have attenuated threat perception and reduced typical hypervigilance in high SAI (Heinrichs & Hofmann, 2001).

No significant differences were found for both AT conditions by CT-optimal stimulation. However,

individuals with high SA levels assessed AT pleasantness more positively, in terms of mean values, although the greater standard deviation (SD) values observed for this group. These values show the inconsistent attribution of higher or lower extreme scores by high SAI, which can justify the inexistence of significant differences. Nevertheless, this counterintuitive finding of higher pleasantness mean values in the high SA may allow us to infer well-reported latent motivational needs in high SAI, such as increased craving for affiliative contact in the absence of overt social threat. Research has shown that individuals with high levels of attachment anxiety, characterized by difficulty trusting others in relationships and worry about abandonment (Brennan et al., 1998), are more likely to seek touch (Beltrán et al., 2020). On the other hand, greater attachment anxiety has been linked to increased effectiveness of pleasant CT-optimal touch in reducing pain, and greater attachment avoidance to its reduced effectiveness (Krahé et al., 2018; Bowling et al., 2024). Attachment anxiety is strongly positively correlated with SA more than avoidant attachment style (Manning et al., 2017).

Additionally, as mentioned before, the questionnaire used to assess SA levels (the SPIn questionnaire in its Portuguese reduced version; Ferreira, 2022) presents two factors, with four questions assessing physical discomfort and three questions about avoidant behaviors, which can explain these relative results, as this structure may have captured primarily the distress component of SA, potentially masking more avoidant or fear-driven responses to touch. This may also possibly account for this relative preference for affective contact under neutral conditions.

These subjective assessment results were broadly corroborated by the significant group differences of the N13 component in the vibration condition, which could explain its less pleasantness perception, although no significant correlation was found. This may indicate that spinal somatosensory processing can be altered by discriminative touch in individuals with high SA levels. This aligns with models proposing that SA is characterized by heightened sensitivity to somatic signals and bodily states (Domschke et al., 2010; Ludlow et al., 2015), potentially as a function of enhanced bottom-up processing or reduced top-down modulation. It is known that the terminals of A-fibers, responsible for discriminative and dynamic touch processing, are located in deep laminae III-IV of the dorsal horn of the spinal cord in adult mice (e.g. Pignatelli et al., 1989), which could explain the main differences found for this type of touch in this component. This direct dorsal horn termination (Abraira & Ginty, 2013) may account for the heightened sensitivity reflected in the N13 component in high SAI, compared to affective touch conditions that rely on slower CT afferents.

Despite the higher spinal somatosensory processing alteration during discriminative touch, the significant positive correlation between SA levels and the spinal N13 component amplitude observed

during CT-optimal stimulation by a robot may indicate a reduced sensitivity to somatosensory information during AT in high SAI, although group comparison did not show significant differences in N13 amplitude between high and low SA levels. This reduced sensitivity could reflect that, in these individuals, AT captures greater attentional resources, leaving fewer available for the processing of other somatosensory inputs, or alternatively, that AT actively inhibits concurrent somatosensory processing (e.g. Morrison et al., 2009). As expected, there were no differences for AT by CT-optimal stimulation by a human in this spinal component, as it is in line with the evidence of a later and higher-order cognitive processing of this type of touch, as discussed before (e.g. Olausson et al., 2010). However, studies have shown that being touched by someone else shortens SEPs latencies already at the cervical spinal level, suggesting that descending modulation of top-down signaling alters sensory processing as early as in the dorsal horn of the spinal cord (Boehme et al., 2019).

At the cortical level, the results show differences between high and low SA levels for the N2 component in the CT-optimal stimulation by a human condition, although a significant correlation between both variables was not found. Remarkably, this component's less negative mean value in the high SA level group reflects an enhanced recruitment of emotion-processing cortical networks in response to human-delivered AT, suggesting stronger affective modulation of somatosensory processing. As mentioned before, evidence shows differences between SAD patients and healthy controls in P1, with the presentation of facial expressions of all or negative valences, as well as in late P2 and P3 components during visualization of angry faces (e.g. Schulz et al., 2013). The present study, however, was conducted in a neutral context, without emotionally salient stimuli beyond the tactile stimulation and the fixation cross and NRS scale. Even so, the increased cortical sensitivity observed in high SAI suggests that human-delivered AT may evoke a stronger affective impact, possibly due to the inherently social nature of the stimulus and its capacity to actively modulate cortical processes, particularly those involved in higher-order emotional regulation (e.g., Morrison et al., 2009; Olausson et al., 2010).

Limitations and Further Research

This study presents several limitations that should be considered when interpreting the results. First, the small size of the sample, composed exclusively of healthy young female university students, limits the generalizability of the findings. This is particularly relevant given previous evidence of gender differences, with women showing greater sensitivity to AT compared to men (Barahmand et al., 2022). Future studies should therefore include more diverse and balanced samples in terms of gender to allow broader generalization of results.

Second, the study used a reduced version of the SPIn questionnaire, which, although validated

for the Portuguese population, includes only seven items and may therefore provide a limited assessment of SA. This shortened scale does not fully capture key features of SA, such as the fear of social situations (Ferreira, 2022), which represents an important characteristic of the condition. In addition, as a self-report measure, it remains susceptible to biases such as social desirability. Future research should employ more comprehensive instruments that can differentiate between the various characteristics and dimensions of SA, and ideally include clinical samples diagnosed with SAD to clarify potential alterations in touch processing.

Third, the study's correlational analyses restrict causal inference regarding the relationship between SA symptoms and touch processing. Future studies should therefore adopt experimental designs capable of testing these causal relationships, for example, through the controlled elicitation of social fear or evaluative situations, to determine the specific impact of SA on somatosensory and affective responses. Moreover, given the scarcity of studies examining touch processing in neutral contexts, further research should compare different types of tactile stimulation without necessarily invoking socially threatening conditions.

Fourth, to deepen the understanding of the underlying neurophysiological mechanisms, future investigations should also analyze later electrophysiological components. In particular, EEG measures such as the P300 and LPP between 1000 and 6000 ms may provide insights into sustained attention and emotional evaluation of socially relevant stimuli (Schienle et al., 2022; Hajcak & Foti, 2020). Additionally, late SEPs, notably N60 and P150 components, have been linked to higher-order somatosensory and cognitive processing of tactile input (Restuccia & Mauguière, 1991; Cruccu et al., 2008), particularly reductions in P150 amplitude, as recently reported (Ribeiro-Carreira et al., 2024), reflecting differences in top-down modulation during AT.

Finally, considering that SA symptoms frequently co-occur with other psychiatric conditions, with SAD often showing high comorbidity rates (e.g., Vilaplana-Pérez et al., 2020; Alomari et al., 2022), future research should control variables such as depressive and other anxiety symptoms, autistic traits, and attachment styles. This would help clarify the specific contribution of SA symptoms to AT processing, leading to a more complete understanding of the interplay between sensory, emotional, and social processes.

Conclusion

Contrary to some previous findings, high SA levels were associated with lower pleasantness ratings only in discriminative touch, with no significant differences observed in AT perception under CT-optimal stimulation, whether delivered by a human or a robot. Nevertheless, altered somatosensory

processing was identified in high SAI at both spinal and supraspinal levels. At the spinal level, discriminative touch elicited distinct patterns of activity suggesting heightened sensitivity to peripheral somatosensory input, reflecting early modulation of tactile information within the dorsal horn pathways. At the supraspinal level, human-delivered AT was associated with enhanced cortical sensitivity and stronger affective modulation, indicating an increased recruitment of emotion-related neural networks and top-down integration processes during affective touch in individuals with higher SA levels.

These findings support the notion that SA symptoms modulate tactile processing across both spinal and cortical levels, revealing differential mechanisms according to the type and context of touch. While discriminative touch appears to evoke reduced pleasantness and altered bottom-up sensory processing, AT seems to engage higher-order emotional and interoceptive systems, eliciting stronger affective reactivity in individuals with elevated SA levels even in neutral, non-threatening conditions. Such results highlight the role of affective touch as a potential modulator of emotional and sensory integration in social anxiety.

Overall, this study contributes novel evidence to the growing field of affective neuroscience by demonstrating that SA symptoms can impact the early somatosensory and affective stages of touch processing. Understanding these mechanisms is crucial for developing somatosensory-based therapeutic strategies, particularly tactile interventions aimed at regulating affect and reducing anxiety symptoms. Given the emerging clinical potential of tactile approaches, such as Mechanical Affective Touch Therapy (MATT; e.g. Gonsalves et al., 2020), the present findings provide relevant neurophysiological groundwork for optimizing and individualizing interventions for individuals with SAD.

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