Frau, L, Bruno, D, McGlone, F and Cazzato, V

Exploring the impact of gentle stroking touch on psychophysiological regulation of inhibitory control

Abstract

Touch has been shown to regulate emotions, stress responses, and physical pain. However, its impact on cognitive functions, such as inhibitory control, remains relatively understudied. In this experiment, we explored the effects of low-force, slow-moving touch—designed to optimally activate unmyelinated cutaneous low-threshold mechanoreceptor C-tactile (CT) afferents in human hairy skin—on inhibitory control and its psychophysiological correlates using the Stroop Task, a classic paradigm commonly employed to assess inhibitory control capacity. The Stroop Task was repeated twice before and once after receiving either gentle touch or no-touch. Participants were assigned to two groups: the touch group (n = 36), which received low-force, slow-moving touch on their forearms at a stroking velocity of ~3 cm/sec, and the no-touch group (n = 36), which did not receive any touch stimulation. Changes in autonomic nervous system activity were also assessed by measuring heart rate variability (HRV) and skin conductance levels before and during cognitive performance. Compared to the no-touch group, participants who received gentle, low-force, slow-moving touch demonstrated faster responses and higher HRV during the Stroop Task. Additionally, within the touch group, individuals with higher HRV exhibited even quicker performance on the cognitive task. While we cannot draw definitive conclusions regarding the CT velocity-specific effect, these results provide preliminary evidence that low-force, slow-moving touch may influence cognitive processes involved in the inhibitory control of goal-irrelevant stimuli.

Keywords: gentle, low-force, slow-moving touch; autonomic nervous system; HRV; inhibitory control; Stroop Task

1. Introduction

Touch plays a crucial role in fostering social interactions (Suvilehto et al., 2023), bonding and attachment (Duhn, 2010; Jablonski, 2021), and human development (Cascio et al., 2019). The identification of a system of unmyelinated cutaneous low-threshold mechanoreceptor (LTMR) C-fibres in human hairy skin has redefined the traditional understanding of touch as being solely discriminative in nature. These C-tactile (CT) afferents, characterised by a preference for low-force, skin temperature, caress-like stroking touch of between 1 and 10 cm/s (Ackerley et al. 2014a, 2014b; Löken et al. 2009), are not well-suited for precise tactile discrimination (see McGlone, Wessberg, & Olausson, 2014 for an extensive review). Psychophysical studies consistently show that participants find this stimulus more pleasant compared to touch delivered at slower or faster velocities (Ackerley et al., 2014b; Essick et al., 1999; Löken et al., 2009). According to the affective touch hypothesis (Morrison & Croy, 2021), these CT afferents have been found to play a key role in conveying touch's pleasant and rewarding properties (Morrison et al., 2010; Löken et al., 2009; Vallbo et al., 1999). It also reduces negative emotions (e.g., social exclusion; Oya & Tanaka, 2023; von Mohr et al., 2017), buffers physical pain (Gursul et al., 2018; von Mohr et al., 2018), and increases body awareness (Crucianelli et al., 2018; Cazzato et al., 2021; Jenkinson et al., 2020).

From a physiological perspective, CT-targeted touch has been shown to regulate stress responses (Kidd et al., 2023; Morrison, 2016; Walker et al., 2022) and autonomic nervous functions (Püschel et al., 2022; Manzotti et al., 2023; Triscoli et al., 2017). For instance, maternal stroking touch has been found to increase heart rate variability (HRV) (Manzotti et al., 2023; Van Puyvelde et al., 2019). HRV, i.e., the beat-to-beat changes in heart rate, is an indirect, well-validated vagal tone index (Laborde et al., 2017). Higher levels of resting HRV, indicating increased activity of the parasympathetic nervous system (Berntson et al., 1997; Kop et al., 2011), are linked to improved emotional and behavioural regulation (Balzarotti et al., 2017; Cai et al., 2019; Mather & Thayer, 2018), as well as enhanced overall mental and physical wellbeing (Cai et al., 2019; Kemp & Quintana, 2013; Sloan et al., 2017). Changes in HRV are thought to be pivotal in maternal-infant physiological and behavioural regulation and resilience (Poehlmann et al., 2011; Porter, 2003; Suga et al., 2019). On the other hand, low levels of resting HRV have been associated with a range of mental health conditions, including anxiety (e.g., Chalmers et al., 2014; Thayer et al., 1996; Kemp et al., 2014), panic disorder (e.g., McCraty et al., 2001), post-traumatic stress disorder (Cohen et al., 1998), depression (e.g., Hartmann et al., 2019; Nahshoni et al., 2004), and suicide ideation and behaviour (Adolph et al., 2018).

While most existing research has predominantly focused on affective touch as a source of affect regulation (Fotopoulou et al., 2022; Silvestri et al., 2024), less attention has been given to its potential effects on cognitive processes, exploring the bottom-up influence of touch on top-down mechanisms. According to the "embodied cognition" framework (Gallese & Ebisch, 2013; Wilson & Golonka, 2013), bodily experiences—particularly tactile sensations—play a crucial role in shaping and influencing our cognitive functions. As such, touch is not merely a passive experience but an active process that integrates with and affects cognitive mechanisms.

To date, only a few studies have focussed on how interpersonal touch affects the neurocognitive processes that underlie flexible goal-directed behaviour involved in cognitive control (Dydenkova et al., 2024; Saunders et al., 2018). In particular, the study by Saunders and colleagues (2018) recruited romantic partners, with the active partner performing a speeded inhibitory control task modified version of a Go-no-Go Task while either holding (touch condition) or not holding their partner's hand (no-touch condition), whilst Electroencephalography (EEG) activity was also recorded throughout. The results demonstrated that touch (handholding) enhanced cognitive control, as evidenced by reduced error rate on the task and increased error-related negativity amplitudes, which reflect the neural response to recognising mistakes and potentially triggering cognitive control mechanisms to correct or adjust behaviour. Additionally, holding the partner's hand elicited positive emotional responses, including increased happiness, suggesting that interpersonal touch can enhance cognitive control through modulation of emotional and neural mechanisms. A possible explanation for these findings is that human proximity can enhance personal efficacy (Coan & Sbarra, 2015), helping individuals reduce their tendency to ignore or minimise negative feedback signals (e.g., error monitoring), which may, in turn, lead to exert inhibitory control over interference. While the study's findings suggest a potential link between touch and the cognitive/neural monitoring processes underlying flexible goal-directed behaviour, several issues might limit the conclusions of this investigation. The (handholding) interpersonal touch manipulation used in the study by Saunders and colleagues (2018) could not disentangle the specific effects of social (interpersonal proximity and interaction) versus affective (pleasant) touch on cognitive control. Additionally, it cannot determine whether changes in autonomic nervous system (ANS) activity may mediate psychophysiological regulation of inhibitory control. In light of this, we adopted a touch condition involving gentle, low-force, slow-moving touch to the skin specifically designed to activate CT afferents, which are thought to regulate stress response in rats (Walker et al. 2022) and in certain individuals (Kidd et al., 2023; Morrison, 2016) as well as a more controlled method (Löken et al., 2009; Wijaya et al., 2020). Furthermore, to mitigate potential order effects associated with a within-subject design (as used by Saunders and colleagues, 2018), we chose to employ a between-subjects design to compare low-force, slow-moving touch with no-touch conditions. Importantly, our study aimed to explore whether and how interpersonal touch enhances cognitive control via emotional regulation. Specifically, we sought to account for the potential role of vagal activity in supporting response inhibition, as highlighted in prior research (e.g., Thayer & Lane, 2006). As an important hallmark of executive functions, primarily regulated by the prefrontal regions of the brain, inhibitory control refers to the capacity to suppress automatic responses and irrelevant information (Bari & Robbins, 2013; Cristofori et al., 2019; Grafman, 2002). According to the Neurovisceral Integration Model (NIM; Thayer et al., 2009a; Thayer & Lane, 2000), prefrontal cortex engagement during inhibitory control is crucially associated with vagally-mediated high-HRV (parasympathetic activity) and reduced sympathetic activation. Research highlights the significance of high-frequency (HF) HRV as an index of parasympathetic activity in assessing the autonomic regulation linked to demanding tasks (Forte et al., 2019; Forte & Casagrande, 2025). HF-HRV is particularly valuable because it is sensitive to short-term fluctuations in autonomic tone, making it highly responsive to potentially stressful stimuli that require rapid autonomic adjustments (Thayer & Lane, 2000). Conversely, heightened sympathetic activation, as indicated by galvanic skin response (Kim et al., 2023), appears to result from lower prefrontal cortex activation and impaired cognitive control mechanisms (Boberg et al., 2022; Clark et al., 2018). This leads to disinhibition and altered cognitive performance (Thayer & Lane, 2000). Hence, the ANS activity, as indexed by increased vagal tone, is proposed to reflect attentional regulation and overall adaptive and flexible behavioural strategies in response to high-cognitive tasks or demands (Colzato et al., 2017; Grol & De Raedt, 2020; Hovland et al., 2012; Park & Thayer et al., 2014; Thayer & Lane, 2000). These findings are further supported by studies showing that autonomic reactivity, particularly as indicated by changes in HF-HRV in healthy adults, is heightened during demanding tasks measuring inhibition (e.g., Stroop Task; Stroop, 1935) or executive functioning, thus confirming a strong connection between ANS function and cognitive performance (Forte et al., 2019; Forte & Casagrande, 2025; Huang et al., 2021; Renaud & Blondin, 1997; Thayer et al., 2009). Therefore, an outstanding research question is whether the ability to inhibit a response can be influenced by manipulating the ANS activity through gentle, low-force, slow-moving touch. Most touch-based interventions have been found to benefit mental and physical health (Alp et al., 2021; McGlone et al., 2024). However, the specific impact of gentle, low-force, slow-moving touch on autonomic regulation during cognitive inhibition is poorly understood.

This study investigated whether gentle, low-force, slow-moving touch, specifically through stimulation designed to activate CT-targeted touch preferentially, could enhance inhibitory control during a Stroop task. The Stroop Task is a standard test that measures participants' abilities to suppress cognitive interference and to examine the efficiency of attentional control, processing speed, and overall executive processing abilities. During the Stroop Task, the capacity to overcome reaction conflict caused by the intentional suppression of irrelevant and incompatible information may elicit physiological stress that can involve the sympathetic nervous system (responsible for fight or flight response) and the parasympathetic nervous system (responsible for recovery and rest) (Hoshikawa & Yamamoto, 1997; Mathewson et al., 2010; Vazan et al., 2017; Waxenbaum et al., 2023).

Importantly, in this study, participants completed the Stroop Task whilst indexes of the sympathetic and parasympathetic activity, including Electrodermal Activity (EDA) and Electrocardiogram (ECG), were collected to measure Skin Conductance Level (SCL) and HRV for HF-HRV power, respectively. Physiological indexes were obtained before and after receiving gentle, low-force, slow-moving touch or without receiving any touch at all. We expected that participants who received gentle, low-force, slow-moving touch stimulation would perform better on the Stroop Task than those who did not receive any touch stimulation (Saunders et al., 2018). Accordingly, touch stimulation might modulate participants' physiological states (Mazza et al., 2023; Pawling et al., 2024; Triscoli et al., 2017), aiding in the implementation of flexible and adaptive control over conflicting information during prefrontal task performance (Thayer et al., 2009a). In agreement with the NIM model (Thayer & Lane, 2000, 2009a,2009b), and following touch stimulation, we also anticipated increased HF-HRV levels (parasympathetic activity) during Stroop Task performance compared to SCL (sympathetic activity).

2. Methods

2.1 Participants

The sample size calculation was determined using G*Power 3.0.10 (Faul et al, 2007) based on the outcome measures of RTs and accuracy. Calculations indicated a minimum of 27 participants per group (touch vs no-touch) and Time (pre- vs post-manipulation) for a small effect size (f2 = 0.25), with 95% power and an α level set at 0.05, using a mixed design. A total of 72 participants took part in this study, with 36 adults (23 females, mean age = 42.78yrs, *SD* = 21.90) assigned to the touch group and 36 adults to the no-touch group (22 females, mean age = 45.03yrs, *SD* = 21.65). Participants were recruited from external sources, including poster advertisements in public places, social media, and personal contacts of the researcher, as well as internally through the Liverpool John Moores University (LJMU) Psychology SONA system. Participants were free of neurological diseases and psychiatric disorders, skin conditionsor nerve impairment, and visual-perception disorders (e.g., colour blindness). The study was carried out in accordance with the Helsinki Declaration of ethical standards. The study protocol was approved by the LJMU's University Research Ethics Committee (UREC, 22/PSY/019). All participants gave their written informed consent totake part in the study. Participants were rewarded with a £5 shopping voucher or SONA credits if they were LJMU students.

2.2 General procedure

A schematic representation of the general procedure is presented in Figure 1.

On the day of testing, participants gave written consent and were asked to fill out a questionnaire concerning demographic details (i.e., gender, age, education), the Positive and Negative Affect Schedule (PANAS; Watson, 1988) for rating positive and negative emotions, and the Depression anxiety stress Scale-21 (DASS-21; Lovibond & Lovibond, 1995) to provide a measure of anxiety, depression, and stress levels. Then, all participants were asked to perform the Stroop Task at Time 1 (T1). At Time 2 (T2), the touch group received gentle, low-force, slow-moving touch stimulation delivered at a velocity of ~3 cm/sec—a speed typically perceived as pleasant and optimal for activating the CT system (Löken et al., 2009)—before performing the Stroop Task for the second time. The interval between the two times was about 7 minutes, consistently maintained across groups and participants. After receiving manual stroking through a cosmetic soft brush applied over their ventral forearm, participants were required to report their pleasantness on a Visual Analogue Scale (VAS, e.g., Bellard et al., 2023; Sacchetti et al, 2021). Participants assigned to the no-touch group underwent the same procedure except for the touch stimulation. Participants in the no-touch group were instructed to remain quietly without being engaged in stimulating activities to prevent any sensory/affective input that could potentially influence the Stroop Task performance for a time equal to that of the participants receiving touch stimulation. In this case, the experimenter maintained a non-intrusive presence, staying two metres away from the participant to minimise engagement and prevent heightened arousal. In the touch condition that closely mirrored this setup, participants were invited to remain still, calm, and away from the tactile stimulation. We implemented a standardised interaction script for the experimenter during the touch stimulation. This script reduced variability in non-verbal cues, such as body language and tone of voice, ensuring that every participant experienced the same level of engagement. Additionally, both groups were exposed to the same ambient lighting and room temperature settings to avoid sensory differences that could influence arousal levels. All participants were randomly assigned to either the touch or no-touch condition to ensure that any physiological and cognitive differences observed were attributable to touch rather than pre-existing differences between participants. Participants were informed in the participant information sheet that they might receive touch during the experiment, although the timing was not specified. On the testing day, participants were informed about their group allocation (whether they would receive touch or not) after the first Stroop Task (T1) and just before they performed the task again (T2) to minimise biases and anticipatory effects that might arise from knowing about the touch stimulation.

EDA and ECG signals were measured throughout the experiment to evaluate sympathetic and parasympathetic activity, respectively. During this time, participants were instructed to maintain regular breathing and minimise body movements during the physiological recording before performing the task. At the end of the experiment, they were asked to fill out the PANAS a second time. Overall, the testing procedure lasted approximately 45 minutes.

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2.3 Material and measures

2.3.1 Stroop Task

The colour word Stroop Task (Stroop, 1935) was performed using Millisecond software (Inquisit 6; Draine, 1999; https://www.millisecond.com). This task measures the ability to inhibit automatic responses by requiring participants to ignore the meaning of a word and focus on naming the colour of the word's ink. In this study, participants were asked to type specific keys corresponding to the colour of the word displayed on the screen [i.e., D = red, F = green, J = blue, and K = yellow)] as quickly and accurately as possible. Each word was displayed until one of the four keys was pressed. The task included 84 trials [4 colours × 3 stimuli (congruent, incongruent, control) × 7 repetitions]. This resulted in 28 congruent trials (word and colour match), 28 incongruent trials (word and colour do not match), and 28 control trials (coloured rectangles), randomly presented (Parkin et al., 2017). Prior to the start of the task, participants were trained with a short practice consisting of 12 practice trials (4 for each trial type). If the response was correct during the experiment, the subsequent trial started immediately. A red X was flashed on the screen if an incorrect response was made. Accuracy was determined by the percentage of correct responses (Tot correct/Ntrial) with a score of 1 for correct and 0 for incorrect answers. RTs were recorded by measuring the time lapse between the presentation of the stimulus and the participant's response on the keyboard. We calculated the mean latency of congruent or incongruent trials (in milliseconds) to assess RTs for our analyses. Data from the practice and control trials were not included in accuracy and RTs performance counts.

2.3.2 Touch stimulation

Participants received manual gentle strokes on the ventral forearm using a soft brush (No7 cosmetic brush, Boots UK; Cazzato et al., 2021; Pawling et al., 2024; Sacchetti et al., 2021) for two minutes (Della

Longa et al., 2021; Ree et al., 2019) before performing the Stroop Task a second time. This interval length is sufficient for obtaining accurate measures of physiological arousal (Della Longa et al., 2021; Munoz et al., 2015). The brush was employed for tactile stimulation as materials perceived as soft are typically rated as pleasant (Tarvainen et al., 2014; Wijaya et al., 2020). Following the procedure adopted in a study previously published by our research group, each stroking was applied at a velocity of ~3 cm/s on the ventral forearm (Sacchetti et al., 2021). The rationale for this choice was that this velocity preferentially activates CT afferents, a type of nerve fibre that typically responds to gentle, slow stroking touch (Löken et al., 2009; Olausson et al., 2010; Vallbo et al., 1999), triggers pleasant feelings (Löken et al., 2009; Triscoli et al., 2017) and buffers stress (Morrison, 2016). Accordingly, we delivered 12 strokes, each separated by a 6-second interval, in a single session to account for CT-afferents' tendency to fatigue after repeated exposure to tactile stimuli (Schirmer & McGlone, 2022; Vallbo et al., 1999). Strokes were delivered at a constant pressure of 22 gr/cm^2 on about 9 cm long by a (female) research assistant trained to deliver the strokes on a scale to replicate the same movements on participants' forearms during the experiment. A visual metronome was programmed on PsychoPy (Peirce, 2007) to guide the research assistant in delivering the strokes. During the touch manipulation, participants were asked to look at a blank screen presented on the computer in front of them. After touch manipulation, a VAS was used to evaluate the pleasantness of touch. The VAS consisted of a horizontal line measuring 20 cm. Participants were instructed to make a mark on the line using a pen, indicating the level of pleasantness experienced during the touch. The scale ranged from -10 to +10, representing unpleasant, neutral, and pleasant touch.

2.3.3 Physiological arousal

A Biopac System, Inc., MP36 was utilized to record electrocardiogram (ECG) signals from which High-Frequency Heart Rate Variability (HF-HRV; variation in time between each heartbeat for high power frequency) was taken. HF-HRV (HRV in the 0.15-0.4 Hz band range) was used for assessing vagal tone as an index of the parasympathetic nervous system activity (Laborde et al., 2017; Shaffer et al., 2014).

During the experiment, three sensors were applied to the torso to reproduce Einthoven's triangle (i.e., one electrode on each shoulder and one on the left hip). Then, these were connected to The Biopac Student Lab Pro 3.7 software. The software was programmed to filter real-time data using a band-pass of 0–35 Hz and .5-35 Hz, respectively. The sampling rate for data acquisition was set at 2000Hz. The recordings were interspersed with 30s breaks. To facilitate data recording, we configured a graphical template in the Biopac Student Lab software allowing us to manually add markers for precise visualisation of time intervals within the software's dialogue box (e.g., beginning and end of resting state; start and end for HRV during Stroop task, etc.).

ECG signals were first visually inspected to remove artifacts and subsequently imported into Kubios HRV software (Tarvainen et al., 2014) to obtain the frequency domain measure of the High-Frequency band (i.e., 0.15-0.4 Hz). The software retrieves the interbeat (or RR) intervals from the original ECG signal and applies the smoothness prior's method to remove the low-frequencybaseline trend component. The normalised HF-HRV units were acquired through frequency domain estimation employing powerspectrum density. This estimation method involved Welch's periodogram method, which leverages the fast Fourier transformation.

ECG signals were captured in conjunction with electrodermal activity (EDA) signals, as shown in previous studies investigating the link between touch and ANS activity (Chatel-Goldman et al., 2014; Sacchetti et al., 2021). EDA signals, which refer to the electrical activity of the skin resulting from variations in sweating, were used for calculating Skin Conductance Level (SCL), a measure of the tonic arousal regulated by the sympathetic nervous system (SNS; Dawson et al., 2007; see Braithwaite et al., 2015, a guide for analysing SCL). When the sympathetic system is activated, the electrical activity of the skin results in increased sweating and, thus, increased SCL (Gordan et al., 2015).

While arousal levels were recorded throughout the experiment, our analysis focused on changes in HRV and SCL during two distinct phases: resting (pre task) and during task performance. These phases were analysed at two different time points, i.e., time 1 (T1) and time 2 (T2). Therefore, the study design resulted in a total of four recordings for each participant, as follows:

- Pre-Task at T1: before participants performed the Stroop Task during the first session;
- During task at T1: during Stroop Task performance in the first session;
- Pre-Task at T2: prior to touch stimulation (touch group) or task performance in the second session;
- During task at T2: during Stroop Task performance in the second session.

Notably, for resting state measurement, participants were instructed to remain still and relaxed with their eyes open for 3 minutes, a sufficient time interval length for obtaining accurate measures of physiological arousal (Della Longa et. al., 2021; Munoz et al., 2015; Ree et al., 2019). The rationale for recording physiological arousal before the task was to ensure that any differences observed during the tasks were not influenced by pre-existing group differences in the arousal levels (Liang et al., 2009; Pendleton et al., 2016). Moreover, real-time assessments of the HF-HRV/SCL levels during the task contributed to examining specific changes in arousal linked to task engagement (Culver et al., 2012; Liang et al., 2009; Pendleton et al., 2016), particularly in relation to touch stimulation.

2.3.4 Self-report questionnaires

2.3.4.1 The Depression, Anxiety, and Stress Scale (DASS-21)

DASS-21 (Lovibond & Lovibond, 1995) is a self-report scale of mood that consists of 21 items divided into three subscales assessing depression (e.g., lack of interest/involvement in activities, anhedonia, etc), anxiety (e.g., restlessness, and physiological arousal associated with anxiety), and stress (e.g., being easily upset/agitated, irritable/over-reactive, etc). Participants are asked to rate the presence and intensity of their symptoms over the past week on a 4-point Likert scale. Each item can be rated from “0” which indicates the symptoms were not experienced at all to “4” which indicates that the symptoms were experienced most of the time.

2.3.4.2 Positive and Negative Affect Schedule (PANAS)

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was used to evaluate positive and negative emotions before and after completing the Stroop Task. Participants were asked to respond to a 20-item self-report using a 5-point scale with 10 items assessing positive affect and 10 items assessing negative affect. Each item can be rated from “1” (very slightly or not at all) to “5” (extremely). Scores ranged from 10 to 50 on each scale, with higher scores on the positive affect scale indicating a more pronounced positive mood (e.g.,“enthusiast”) whereas items with higher scores on the negative affect scale indicate a more pronounced negative mood (e.g., “nervous”).

2.4 Data handling

Statistical analyses were conducted using IBM SPSS 26 (SPSS Inc., Chicago, IL). A series of independent sample t-tests were performed to determine whether there were any baseline statistically significant differences in the demographics (e.g., age and education), DASS-21 subscales, PANAS scores, and HF-HRV/SCL levels between the two groups (touch vs. no-touch group). For the analysis of Stroop Task performance, we calculated the mean of response times (RTs) in msec and the % of correct responses for assessing the accuracy for each word category (congruent and incongruent). To assess changes in Stroop Task performance, two separate mixed-design two-way ANOVAs were performed, with Group [touch vs. no-touch] as a between-subjects factor, and Congruency [congruent vs. incongruent words] as a within-subjects factor, using RTs or Accuracy as a dependent variable.

Then, we ran two one-way ANOVAs using Group [touch vs no-touch] as a between-subjects factor and HF-HRV or SCL as a dependent variable to assess changes in the parasympathetic and sympathetic activity respectively. Prior to these analyses, we calculated the difference (Δ) in mean scores between

T1 and T2 for HF-HRV and SCL measurements. For both HF-HRV and SCL measures, we considered two temporal windows, i.e., recordings before and during the Stroop Task.

To account for a potential trade-off between accuracy and speed, we calculated an inverse efficiency score (IES) by taking the ratio of the percentage of correct responses (expressed as a decimal) to the mean latency for both congruent and incongruent trials. This calculation was carried out separately for T1 and T2, for each group. We conducted a 2 Group [touch vs no-touch] × 2 Time [T1 vs T2] mixed ANOVA to assess changes in the IES.

An additional 3-way mixed design ANOVA was performed with Group [touch vs no-touch] as a between-subjects factor, and Time [T1 vs T2] and Valence [positive vs negative emotions] as within-subjects factors to assess changes in emotions based on the PANAS questionnaire scores from T1 to T2.

A series of Pearson correlations were performed to explore the relationship between physiological arousal (SCL and HF-HRV) and cognitive outcomes (RTs and Accuracy) obtained from the Stroop Test within each touch/no-touch group. For our analyses, we calculated the Δ difference in mean scores between T1 and T2 for RTs and Accuracy (for congruent and incongruent words). Similarly, to establish the change indices for arousal levels, we calculated the change (Δ) in mean scores for HF-HRV and SCL between T1 and T2 across two phases: resting state (before the task) and during task performance. After obtaining the Δ change index values for all variables, we proceeded to examine the correlations.

Before performing the ANOVAs, all dependent variables were tested for homogeneity of variance and sphericity assumptions. To follow-up all significant interactions, we conducted a series of independent sample t-tests to examine differences between the touch and no touch groups. P-values were corrected using the Bonferroni method to account for multiple comparisons (Rogers & Weiss, 2009). A significance threshold of $p < .05$ was set for all effects. Effect sizes were estimated using partial eta square (η^2_p) and Cohen's d.

3. Results

3.1 Descriptive statistics

Overall, participants in the touch group reported the touch stimulation as relatively pleasant (Mean = 12.95cm; SD = 3.5). Baseline descriptive statistics for demographics, mood (DASS-21), emotions (PANAS), and physiological measures (HF-HRV and SCL) for each group (touch vs no-touch) are reported in Table 1. Overall, we observed no significant differences when comparing baseline measurements between the two groups. Therefore, the two groups were comparable in all measures.

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3.2 PANAS analysis

The 3-way mixed ANOVA on mean scores obtained at the PANAS for positive and negative emotions revealed a significant main effect of Valence [$F(1, 70) = 363.61$, $p < .001$, $\eta^2p = .84$], which was corroborated by a significant interaction of Time × Valence [$F(1, 70) = 21.15$, $p < .001$, $\eta^2p = .09$]. In both groups, post-hoc tests revealed that positive emotions significantly increased, $t(71) = 3.02$, $p = .004$, $d = .35$, whereas negative emotions decreased at T2, $t(71) = 3.08$, $p = .003$, $d = .36$. However, there was no variation in PANAS scores across the touch and no-touch groups from T1 to T2, suggesting that positive and negative emotions did not differ between the two groups before and after completing the Stroop Task.

3.3 Stroop Task outcomes

3.3.1 *Response times (RTs)*

Findings revealed significant main effects of Group [$F(1, 70) = 11.09$, $p <.001$, $\eta^2p = .14$] and Congruency [$F(1, 70) = 11.09$, $p <.001$, $\eta^2p = .14$]. These effects were further qualified by a significant

Group × Congruency interaction [$F(1, 70) = 8.39$, $p = .005$, $\eta^2 p = .11$]. As shown in Figure 2, an independent sample t-test revealed a greater reduction in RTs in the touch group for congruent trials (Mean = 284.60 msec, SD = 69.22) compared to the no-touch group (Mean = 98.14 msec, SD = 153.94), $t(70) = 6.63$, $p < .001$, Cohen's d = 1.03. Similarly, a greater reduction in RTs was observed in the touch group for the incongruent trials (Mean = 168.22 msec, *SD* = 113.70) compared to the no-touch group (Mean = 90.04 msec, SD = 103.69), $t(70) = 3.05$, $p = 002$, Cohen's d = .72.

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To summarise, these findings indicate that the group receiving gentle, low-force, slow-moving touch exhibited faster processing in both congruent and incongruent trials, compared to the no-touch group.

3.3.2 Accuracy

The analyses did not yield a significant main effect of Congruency [$F(1, 70) = .98$, $p = .33$, $\eta^2 p = .02$]. Similarly, there were no significant effect of Group [$F(1, 70) = 3.88$, $p = .05$, $\eta^2 p = 0.05$] or the Group × Congruency interaction [$F(1, 70) = 3.39$, $p = .07$, $\eta^2 p = 0.05$].

3.3.3 Inverse efficiency score (IES)

The results showed a significant effect of Time [$F(1, 70) = 297.90$, $p < .001$, $\eta^2_p = .81$], and a significant Time × Group interaction [$F(70) = 51.55$, $p < .001$, $\eta^2_p = .42$], as shown in Fig. 3.

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T-test results revealed no significant difference between the touch and no-touch groups at T1 (touch group: Mean = 18.02, SD = 2.48; no-touch group: Mean = 17.54, SD = 2.93), t(70) = 0.76, p = .45, Cohen's d = .18. However, at T2, there was a significant difference between the two groups (touch group: Mean = 14.87, SD = 2.18; no-touch group: Mean = 16.24, SD = 3.06), t(70) = 2.18, p = .03, Cohen's d = 0.51. In line with our main results, results suggest that the touch group showed better performance at T2, with faster responses while maintaining high accuracy, as indicated by the significantly lower IES at T2.

3.4 High-Frequency Heart Rate Variability (HF-HRV) outcomes

HRV during task

When looking at the HF-HRV during the task, results revealed a significant main effect of Group [F(1, 70) = 48.55, $p < .001$, $\eta^2 p = .41$], indicating a difference in HF-HRV levels between groups. As shown in Figure 4, an independent sample t-test revealed a significant difference in the change of HF-HRV between groups, t(70)= -6.96, $p < .001$, Cohen's d = 1.64. Specifically, HF-HRV was significantly greater in the touch group (Mean = -6.13, SD = 3.92) than in the no-touch group (Mean = -1.22, SD = 1.56).

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Overall, these results showed a greater increase in HF-HRV in the touch group compared to the no-touch group.

3.5 Skin conductance level (SCL) outcomes

We did not observe any significant main effect of Group [F(1, 70) = 1.72, p = .20, η2p = .03] for SCL during the Stroop Task performance.

3.6 Correlations analyses: physiological arousal and cognitive outcomes

Correlational analyses between measures of physiological arousal (HF-HRV and SCL pre and during task) and Stroop outcomes (RTs and Accuracy) were performed for each group. In the touch group, we observed a significant and negative association between HF-HRV during task and RTs for incongruent words ($r = -.36$, $p = .02$) but not for congruent words ($p = .36$). However, no significant correlations were found between physiological measures during task and accuracy (all $ps \geq .40$). Moreover, when looking at the no-touch group, we did not observe any significant association between physiological measures during the task and Stroop outcomes (all $ps > .33$).

Lastly, no significant correlations were found between HF-HRV or SCL pre-task and cognitive outcomes within each group. Specifically, in the touch group, the p-values ranged from above 0.40 to 0.80. Similarly, the no-touch group also exhibited no significant correlations, with p-values ranging between 0.40 and 0.90. These results suggest that the physiological state at rest did not relate to cognitive performance.

4 Discussion

CT afferents contribute to affective touch processing and the regulation of social behaviours (Huzard et al. 2022), including modulating stress response and resilience (Walker et al. 2022). This study explored the effects of touch, specifically gentle, low-force, slow-moving touch, designed to optimally activate CT afferents on physiological arousal and cognitive performance, with a particular emphasis on inhibitory control of goal-irrelevant stimuli. We hypothesised that touch stimulation would positively influence participants' physiological states, enhancing their ability to manage conflicting information during a cognitive task. Although Saunders and colleagues (2018) were the first to examine the impact of touch (i.e., handholding with a romantic partner) on cognitive functioning (i.e., error monitoring), to our knowledge, this study is the first to explore the beneficial effects of gentle, low-force, slow-moving touch on inhibitory control ability through the modulation of psychophysiological reactivity. Our findings suggest that participants receiving gentle, low-force, slow-moving touch exhibited increased physiological arousal, as evidenced by higher HF-HRV, and reduced RTs during the Stroop Task, compared to those who did not receive touch. These results may point to a potential link between gentle, low-force, slow-moving touch and cognitive performance, particularly in a task involving inhibitory control. However, further research is necessary to fully elucidate the nature of this relationship and determine the specific underlying mechanisms involved.

It is important to note that a practice effect was observed in both groups, with a greater reduction RTs in the touch group, suggesting that touch may play an active role in cognitive processing, potentially extending its influence beyond mere repeated exposure. These findings seem to align with the "embodied cognition" framework, which proposes that sensory experiences, including tactile sensations, could play a significant role in bolstering cognitive processes (Gallese & Ebisch, 2013; Wilson & Golonka, 2013).

The mechanism for the increased cognitive performance, as indicated by reduced RTs, may also be grounded in the homeostatic and allostatic regulation properties of affective touch (Fotopoulou et al., 2022). It is possible that in our study, the touch manipulation could have facilitated an increase in internal control (e.g., heightened body awareness; “homeostatic mechanism”), which might have contributed to the regulation of affective and physiological states (“allostatic mechanism”) (Burleson & Quigley, 2021; Fotopoulou & Tsakiris, 2017; Fotopoulou et al., 2022). This effect may be amplified when touch involves the activation of CT afferents, as is the case with affective/pleasant stimulation (e.g., Ree et al., 2019; Silvestri et al., 2024; Van Puyvelde et al., 2019). Affective regulation is crucial in achieving optimal goal-directed behaviour (Cardinale et al., 2019; Rónai et al., 2024). It can be speculated that integrating sensory information from gentle, low-force, slow-moving touch with higher-level cognitive control activity might have enabled participants to regulate task-induced negative emotions (Ellingsen et al., 2016; McRae et al., 2012), which could have helped them to cope with inhibitory control mechanisms (Gliga et al., 2019; McCabe et al., 2008). Although speculative, this interpretation resonates with the findings of the Saunders et al. study (2018), which suggest that touch between romantic partners can increase self-reported positive emotions and buffer against the threat of negative information, possibly making people more open to negative signals or processing negative, affectively charged events (e.g., impulses and mistakes) during a conflict task performance. Furthermore, touch is known to have significant implications for the regulation of the Hypothalamic-Pituitary-Adrenal (HPA) axis (Yachi et al., 2018), a critical system involved in stress management (Smith et al., 2006). Although this study did not explicitly test this hypothesis, it is possible that the type of touch used in our study may have stimulated the release of oxytocin (Portnova et al., 2020; Walker et al., 2017), a hormone associated with stress reduction (Lee et al., 2009). This release might contribute to lower cortisol levels by influencing the hippocampus and other brain regions that regulate the HPA axis (Matsushita et al., 2019). Consequently, gentle, low-force, slow-moving touch may promote a more adaptive stress response, facilitating a timely deactivation of the HPA axis and supporting overall physiological homeostasis (Kidd et al., 2023; Lupien et al., 2009; McEwen, 2007).

Another potential mechanism to support the findings observed here may be attributed to changes in physiological arousal following touch manipulation. Participants in the touch group exhibited a more pronounced increase in HF-HRV compared to the no-touch group. According to the NIM (Thayer & Lane, 2000, 2009a), this effect might reflect a boost of flexible and adaptive responses to increasingly cognitive demand. One crucial component of this flexibility could be inhibitory control, which involves a series of feedback loops between frontal brain areas in the central nervous system, and the ANS, which in turn regulates heart rate, as indexed by HRV (Thayer & Friedman, 2002; Thayer, 2006). It is reasonable to suggest that enhanced physiological reactivity, supported by increased HRV levels—potentially fostered by gentle, low-force, slow-moving touch (Triscoli et al., 2017; Van Puyvelde et al., 2019)—might have contributed to participants' quicker reactions during the Stroop Task performance (Pallak et al., 1975). These mechanisms could include increased allocation of anticipatory attentional resources (Bastiaansen & Brunia, 2001; Weiss et al., 2018), cognitive control over conflicting and irrelevant information (Banich et al., 2019), and error monitoring (Saunders et al., 2018). Supporting this idea, neuroimaging studies revealed that, in particular being gently stroked, activates a brain network including, e.g., the orbitofrontal, insular, and cingulate cortices, all of which are involved in interoception, autonomic regulation, and high-level cognitive processes (e.g., Craig, 2002, 2008; Fotopoulou et al., 2022; Gordon et al., 2013; McCabe et al., 2008; McGlone et al., 2012).

It should be noted that even the no-touch group showed an improvement in HF-HRV levels. We speculate that participants' expectations regarding the upcoming tasks may have heightened their arousal levels in preparation for the next phase of the experiment (Knutson & Greer, 2008). Another possible explanation is that repeated exposure to the tactile stimulus may have led to sensitization, where initial arousal during the first Stroop task primes the nervous system for increased arousal in later sessions (Stevens & Bruck, 2019). Presumably according to the NIM (Thayer & Lane, 2000), an increase in parasympathetic activity is typically expected to enhance executive functioning, even in the no-touch group. However, the lack of a significant correlation between Stroop performance and HF-HRV suggests a more complex relationship between physiological measures and cognitive outcomes, particularly in the context of CT-targeted touch. In the absence of touch stimulation, this relationship could be weaker.

Partially consistent with NIM (Thayer & Lane, 2000), the changes observed in physiological responses during the Stroop Task may have been driven by parasympathetic activity, as indicated by significant changes in HF-HRV levels. Accordingly, we did not observe any significant difference in sympathetic activity as measured by SCL levels across the two groups. One possible explanation for the divergence between SCL and HRV effects is that during cognitive challenges, individuals might experience increased sympathetic activation that does not correspond to changes in SCL. This could be due to a “feedback loop” from cognitive engagement that enhances parasympathetic activity (i.e., increased HRV) while inhibiting sympathetic activation (i.e., lower SCL) (Knight et al., 2021). This concept further highlights that dimensions of arousal may not be uniform and affect all physiological parameters (like SCL and HRV) (Dickman, 2002).

Nevertheless, our findings revealed that in the touch group, higher HF-HRV levels were linked to faster reaction times compared to the no-touch group, but no changes were observed in levels of SCL. This finding could be consistent with a relationship between parasympathetic activity and cognitive performance (Lazaridi et al., 2022; Nicolini et al., 2024), particularly under increased cognitive demands, as evidenced by the highest HRV levels observed during incongruent trials (Solhjoo et al., 2019). These findings may imply that HRV could serve as an indicator of an adaptive stress response (Thayer et al., 2012), where greater mental effort may contribute to improved performance, especially in more complex tasks (Solhjoo et al., 2019). Indirect support for this idea comes from findings that CT mediated touch may have a regulatory effect on the parasympathetic nervous system (i.e., as reflected in increased HRV), as observed in previous research (Manzotti et al., 2023; Triscoli et al., 2017; Van Puyvelde et al., 2019).

4.1 Limitations

Although our findings seem to suggest that gentle, low-force, slow-moving touch may enhance cognitive performance through physiological regulation, the absence of a group receiving CT-targeted touch at suboptimal velocities (e.g., faster speeds outside the optimal CT range, such as 30 cm/s; Sacchetti et al., 2021, or static touch; Ali et al., 2023) limits our ability to draw definitive conclusions about the specific velocity effects of CT-targeted touch. Including such control groups in future research could help disentangle the unique contributions of CT-targeted touch from general tactile stimulation, providing a clearer understanding of its specific influence on cognitive processes. Furthermore, the current study did not determine whether the effects observed are specific to CT-targeted touch or could be attributed to any form of tactile stimulation such as tapping and light finger touch (non-affective touch; Della Longa et al., 2023; Lee et al., 2018a). Future research could explore this distinction to better isolate the potential contributions of CT-targeted touch to the observed effects. It is also important to highlight that gentle skin stroking activates various classes of C-fiber low-threshold mechanoreceptors (CLTM), including Aβ field low-threshold mechanoreceptors which are highly sensitive to gentle stroking but unresponsive to other types of stimuli like hair deflection (Walker et al., 2022; Watkins et al., 2021; Bai et al., 2015). Future studies should further investigate the sensory role of these mechanoreceptors, particularly in distinguishing their contributions to affective touch vs discriminative touch.

In this study, other touch properties (such as duration and manual stimulation) may have played a significant role in the interaction between autonomic regulation and task performance. Therefore, future research might consider investigating the impact of various CT-touch characteristics (e.g., velocity, temperature, skin locations; Ackerley et al., 2014a, 2014b), or non-CT touch characteristics, on both physiological and cognitive outcomes. Furthermore, we do not exclude the potential beneficial effects of different tactile texture stimuli (e.g., satin; haptic glove; Etzi et al., 2018; Terrile et al., 2021), as well as sensorial activities (e.g., light, aroma; Chamine & Oken, 2015; Siraji et al., 2023) could influence physiological patterns and cognitive processes related to inhibitory control. Including control conditions would enhance the validity of our findings, allowing to determine whether the observed effects are indeed attributable to the specific tactile or sensory modalities being tested.

It is also important to acknowledge that improvements in cognitive performance may stem from attentiveness or motivation related to social facilitation, such as the awareness or presence of other individuals (Belletier et al., 2019). To minimise contextual variability, our experimental setup consistently included both the researcher and assistant researcher across all participants. However, our effort to keep the experimenter's presence non-intrusive or at a distance from the participant in the control condition may have unintentionally drawn attention to proximity as a potential confounding factor.

Future studies could incorporate more rigorous control over proximity, such as setting fixed distances between the participant and the experimenter or using a transparent partition to control for the visual and spatial presence of the experimenter, thereby reducing its influence on the physiological-cognitive outcomes. Furthermore, we recommend an experimental design that incorporates additional conditions to isolate the effects of touch from social presence, such as using a Rotary Tactile Stimulator (RTS). The RTS allows for the delivery of precise, controlled force and velocity, potentially reducing variability introduced by human touch and establishing a control condition in which participants receive identical tactile stimuli without the influence of social context (Lee et al., 2018b). Our study utilised the HF parameter to measure parasympathetic activity in the autonomic nervous system through high-frequency bands of HRV. Future research should consider incorporating a variety of HRV measures, such as time-domain indices or additional metrics, (e.g., SDNN Index, RMSSD, NN50, and pNN50, see Shaffer & Ginsberg, 2017 for an overview) to provide a more comprehensive analysis of the cardiac vagal tone related to sensory-cognitive stimulation.

During the experiment, gentle, low-force, slow-moving touch at 3cm/sec was delivered for two minutes, which is generally sufficient to elicit physiological activation (Della Longa et al., 2021; Ree et al., 2019). Despite this, it is important to note that too high or too low arousal levels elicited can have a detrimental effect on cognitive performance (Storbeck et al., 2008; Yerkes & Dodson, 1908). Thus, further research could explore the optimal duration of touch stimulation to achieve the desired level of arousal without negatively impacting cognitive performance.

Lastly, we assessed emotional distress using the DASS-21 questionnaire and affect through PANAS before and after the experimental manipulation. These measures provided insight into participants' emotional states, which helped understand potential confounding factors, such as whether any observed changes in physiological responses or cognitive performance could be due to pre-existing emotional states. While PANAS has been previously used in studies related to affective touch (Mammarella et al., 2012; Sailer et al., 2024), we are aware that these questionnaires may not directly capture the influence of social or environmental factors.

5 Conclusion

While we cannot make definitive claims about the specific role of CT-targeted touch in enhancing inhibitory control through physiological regulation, our study provides preliminary evidence of a potential connection between gentle, low-force, slow-moving touch and autonomic regulation, as indicated by increased HF-HRV. This was accompanied by enhanced processing speed during the Stroop Task. Future research employing more rigorous control conditions is necessary to further clarify the role of CT-targeted touch in shaping physiological and cognitive outcomes.

CRediT authorship contribution statement

Loredana Frau: Writing – original draft, Writing – review & editing, Conceptualization, Resources, Methodology, Investigation, Validation, Software, Project administration, Data curation, Formal analysis. Davide Bruno: Review & editing, Validation, Supervision. Francis McGlone: Review & editing. Valentina Cazzato: Writing – Review & editing, Validation, Supervision.

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Data Availability

All the relevant data are freely available from OSF at the following weblink: https://osf.io/wbgjv/?view_only=35b5166bea004ce9974476c099dc317f. The current study and its associated data were not preregistered.

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References

Ackerley, R., Backlund Wasling, H., Liljencrantz, J., Olausson, H., Johnson, R. D., & Wessberg, J. (2014a). Human C-tactile afferents are tuned to the temperature of a skin-stroking caress. *The Journal of neuroscience*, 34(8), 2879–2883. https://doi.org/10.1523/JNEUROSCI.2847-13.2014;

Ackerley, R., Carlsson, I., Wester, H., Olausson, H., & Backlund Wasling, H. (2014b). Touch perceptions across skin sites: differences between sensitivity, direction discrimination and pleasantness. *Frontiers in behavioral neuroscience*, 8, 54. https://doi.org/10.3389/fnbeh.2014.00054;

Adolph, D., Teismann, T., Forkmann, T., Wannemüller, A., & Margraf, J. (2018). High frequency heart rate variability: Evidence for a transdiagnostic association with suicide ideation. *Biological psychology*, 138, 165–171. https://doi.org/10.1016/j.biopsycho.2018.09.006;

Ali, S. H., Makdani, A. D., Cordero, M. I., Paltoglou, A. E., Marshall, A. G., McFarquhar, M. J., McGlone, F. P., Walker, S. C., & Trotter, P. D. (2023). Hold me or stroke me? Individual differences in static and dynamic affective touch. *PloS one*, 18(5), e0281253. https://doi.org/10.1371/journal.pone.0281253;

Alp, F. Y., & Yucel, S. C. (2021). The Effect of Therapeutic Touch on the Comfort and Anxiety of Nursing Home Residents. *Journal of religion and health*, 60(3), 2037–2050. https://doi.org/10.1007/s10943-020-01025-4;

Bai, L., Lehnert, B. P., Liu, J., Neubarth, N. L., Dickendesher, T. L., Nwe, P. H., Cassidy, C., Woodbury, C. J., & Ginty, D. D. (2015). Genetic Identification of an Expansive Mechanoreceptor Sensitive to Skin Stroking. *Cell*, 163(7), 1783–1795. https://doi.org/10.1016/j.cell.2015.11.060;

Balzarotti, S., Biassoni, F., Colombo, B., & Ciceri, M. R. (2017). Cardiac vagal control as a marker of emotion regulation in healthy adults: A review. *Biological psychology*, 130, 54–66. https://doi.org/10.1016/j.biopsycho.2017.10.008;

Banich, M. T., Smolker, H. R., Snyder, H. R., Lewis-Peacock, J. A., Godinez, D. A., Wager, T.

D., & Hankin, B. L. (2019). Turning down the heat: Neural mechanisms of cognitive control for inhibiting task-irrelevant emotional information during adolescence. *Neuropsychologia*, 125, 93–108. https://doi.org/10.1016/j.neuropsychologia.2018.12.006;

Bari, A., & Robbins, T. W. (2013). Inhibition and impulsivity: behavioral and neural basis of response control. *Progress in neurobiology*, 108, 44–79. https://doi.org/10.1016/j.pneurobio.2013.06.005;

Bastiaansen, M. C., & Brunia, C. H. (2001). Anticipatory attention: an event-related desynchronization approach. *International journal of psychophysiology*, 43(1), 91–107. https://doi.org/10.1016/s0167-8760(01)00181-7;

Bellard, A., Trotter, P. D., McGlone, F. L., & Cazzato, V. (2023). Role of medial prefrontal cortex and primary somatosensory cortex in self and other-directed vicarious social touch: a TMS study. *Social cognitive and affective neuroscience*, 18(1), nsad060. https://doi.org/10.1093/scan/nsad060;

Belletier, C., Normand, A., & Huguet, P. (2019). Social-facilitation-and-impairment effects: From motivation to cognition and the social brain. *Current Directions in Psychological Science*, 28(3), 260–265. https://doi.org/10.1177/0963721419829699;

Berntson, G. G., Bigger, J. T., Jr, Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., Stone, P. H., & van der Molen, M. W. (1997). Heart rate variability: origins, methods, and interpretive caveats. *Psychophysiology*, 34(6), 623–648. https://doi.org/10.1111/j.1469-8986.1997.tb02140.x;

Boberg, E., Iacobaeus, E., Sklivanioti, M., Wang, Y., Msghina, M., & Le Blanc, K. (2021). Reduced prefrontal cortex and sympathetic nervous system activity correlate with fatigue after a HSCT. *Bone Marrow Transplantation*, 56(3), 360-369. https://doi.org/10.1038/s41409-021-01539-9;

Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2015). *A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments*.

Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham; School of Psychology, University of Warwick; Linton Instrumentation;

Burleson, M. H., & Quigley, K. S. (2021). Social interoception and social allostasis through touch: Legacy of the Somatovisceral Afference Model of Emotion. *Social neuroscience*, 16(1), 92–102. https://doi.org/10.1080/17470919.2019.1702095;

Cai, R. Y., Richdale, A. L., Dissanayake, C., & Uljarević, M. (2019). Resting heart rate variability, emotion regulation, psychological wellbeing and autism symptomatology in adults with and without autism. *International journal of psychophysiology*, 137, 54–62. https://doi.org/10.1016/j.ijpsycho.2018.12.010;

Cardinale, E. M., Subar, A. R., Brotman, M. A., Leibenluft, E., Kircanski, K., & Pine, D. S. (2019). Inhibitory control and emotion dysregulation: A framework for research on anxiety. *Development and psychopathology*, 31(3), 859–869. https://doi.org/10.1017/S0954579419000300;

Cascio, C. J., Moore, D., & McGlone, F. (2019). Social touch and human development. *Developmental Cognitive Neuroscience*, 35, 5–11. https://doi.org/10.1016/j.dcn.2018.04.009;

Cazzato, V., Sacchetti, S., Shin, S., Makdani, A., Trotter, P. D., & McGlone, F. (2021). Affective touch topography and body image. *PLoS ONE*, 16(11). https://doi.org/10.1371/journal.pone.0243680;

Chalmers, J. A., Quintana, D. S., Abbott, M. J., & Kemp, A. H. (2014). Anxiety Disorders are Associated with Reduced Heart Rate Variability: A Meta-Analysis. *Frontiers in psychiatry*, 5, 80. https://doi.org/10.3389/fpsyt.2014.00080;

Chamine, I., & Oken, B. S. (2015). Expectancy of stress-reducing aromatherapy effect and performance on a stress-sensitive cognitive task. *Evidence-based complementary and alternative medicine*, 2015, 419812. https://doi.org/10.1155/2015/419812;

Chatel-Goldman, J., Congedo, M., Jutten, C., & Schwartz, J. L. (2014). Touch increases autonomic coupling between romantic partners. *Frontiers in behavioral neuroscience*, 8, 95.

https://doi.org/10.3389/fnbeh.2014.00095;

Clark, D. J., Chatterjee, S. A., McGuirk, T. E., Porges, E. C., Fox, E. J., & Balasubramanian, C. K. (2018). Sympathetic nervous system activity measured by skin conductance quantifies the challenge of walking adaptability tasks after stroke. *Gait & posture*, 60, 148–153. https://doi.org/10.1016/j.gaitpost.2017.11.025;

Coan, J. A., & Sbarra, D. A. (2015). Social Baseline Theory: The Social Regulation of Risk and Effort. *Current opinion in psychology*, 1, 87–91. https://doi.org/10.1016/j.copsyc.2014.12.021;

Cohen, H., Kotler, M., Matar, M. A., Kaplan, Z., Loewenthal, U., Miodownik, H., & Cassuto, Y. (1998). Analysis of heart rate variability in posttraumatic stress disorder patients in response to a trauma-related reminder. *Biological psychiatry*, 44(10), 1054–1059. https://doi.org/10.1016/s0006-3223(97)00475-7;

Colzato, L. S., & Steenbergen, L. (2017). High vagally mediated resting-state heart rate variability is associated with superior action cascading. *Neuropsychologia*, 106, 1–6. https://doi.org/10.1016/j.neuropsychologia.2017.08.030;

Craig A. D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Neuroscience*, 3(8), 655–666. https://doi.org/10.1038/nrn894;

Craig, A. D. (2008). Interoception and emotion: A neuroanatomical perspective. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (3rd ed., pp. 272–292). The Guilford Press;

Cristofori, I., Cohen-Zimerman, S., & Grafman, J. (2019). *Executive functions. Handbook of clinical neurology*, 163, 197–219. https://doi.org/10.1016/B978-0-12-804281-6.00011-2;

Crucianelli, L., Krahé, C., Jenkinson, P. M., & Fotopoulou, A. K. (2018). Interoceptive ingredients of body ownership: Affective touch and cardiac awareness in the rubber hand illusion. *Cortex*, 104, 180–192. https://doi.org/10.1016/j.cortex.2017.04.018;

Crucianelli, L., Wheatley, L., Filippetti, M. L., Jenkinson, P. M., Kirk, E., & Fotopoulou, A. K. (2019). The mindedness of maternal touch: An investigation of maternal mind-mindedness and mother-infant touch interactions. *Developmental cognitive neuroscience*, 35, 47–56. https://doi.org/10.1016/j.dcn.2018.01.010;

Culver, N. C., Stoyanova, M., & Craske, M. G. (2012). Emotional variability and sustained arousal during exposure. *Journal of behavior therapy and experimental psychiatry*, 43(2), 787–793. https://doi.org/10.1016/j.jbtep.2011.10.009;

Dawson, M. E., Schell, A. M., & Filion, D. L. (2007). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 159–181). Cambridge University Press;

Della Longa, L., Dragovic, D., & Farroni, T. (2021). In Touch with the Heartbeat: Newborns' Cardiac Sensitivity to Affective and Non-Affective Touch. *International journal of environmental research and public health*, 18(5), 2212. https://doi.org/10.3390/ijerph18052212;

Della Longa, L., Carnevali, L., & Farroni, T. (2023). The role of affective touch in modulating emotion processing among preschool children. *Journal of experimental child psychology*, 235, 105726. https://doi.org/10.1016/j.jecp.2023.105726;

Dickman S. J. (2002). Dimensions of arousal: wakefulness and vigor. *Human factors*, 44(3), 429–442. https://doi.org/10.1518/0018720024497673;

Dydenkova, E., McGlone, F., Mayorova L, & Nikolaeva, E. (2024) The impact of early life experiences on inhibitory control and working memory. *Frontiers in Psychology,* 15:1484424. https://doi: 10.3389/fpsyg.2024.1484424;

Draine, S. (1999). Inquisit 6 [Millisecond software]. Retrieved from https://www.millisecond.com;

Duhn L. (2010). The importance of touch in the development of attachment. *Advances in neonatal* *care*, 10(6), 294–300. https://doi.org/10.1097/ANC.0b013e3181fd2263;

Ellingsen, D. M., Leknes, S., Løseth, G., Wessberg, J., & Olausson, H. (2016). The Neurobiology Shaping Affective Touch: Expectation, Motivation, and Meaning in the Multisensory Context. *Frontiers in psychology*, 6, 1986. https://doi.org/10.3389/fpsyg.2015.01986;

Essick, G. K., James, A., & McGlone, F. P. (1999). Psychophysical assessment of the affective components of non-painful touch. *Neuroreport*, 10(10), 2083–2087. https://doi.org/10.1097/00001756-199907130-00017;

Etzi, R., Spence, C., & Gallace, A. (2014). Textures that we like to touch: An experimental study of aesthetic preferences for tactile stimuli. *Consciousness and Cognition*, 29, 178-188. https://doi.org/10.1016/j.concog.2014.08.006;

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods*, 39(2), 175–191. https://doi.org/10.3758/bf03193146;

Forte, G., Favieri, F., & Casagrande, M. (2019). Heart Rate Variability and Cognitive Function: A Systematic Review. *Frontiers in neuroscience*, 13, 710. https://doi.org/10.3389/fnins.2019.00710;

Forte, G., & Casagrande, M. (2025). The intricate brain-heart connection: The relationship between heart rate variability and cognitive functioning. *Neuroscience*, 565, 369–376. https://doi.org/10.1016/j.neuroscience.2024.12.004;

Fotopoulou, A., & Tsakiris, M. (2017). Mentalizing homeostasis: The social origins of interoceptive inference. *Neuropsychoanalysis*, 19(1), 3–28. https://doi.org/10.1080/15294145.2017.1294031;

Fotopoulou, A., von Mohr, M., & Krahé, C. (2022). Affective regulation through touch: homeostatic and allostatic mechanisms. *Current opinion in behavioral sciences*, 43, 80–87. https://doi.org/10.1016/j.cobeha.2021.08.008;

Gallese, V., & Ebisch, S. J. H. (2013). Embodied simulation and touch: The sense of touch in social cognition. *Phenomenology and Mind*, 4(4), 269-291. https://doi.org/10.13128/Phe_Mi-19602;

Gliga, T., Farroni, T., & Cascio, C. J. (2019). Social touch: A new vista for developmental cognitive neuroscience?. *Developmental cognitive neuroscience*, 35, 1–4. https://doi.org/10.1016/j.dcn.2018.05.006;

Goldstein, P., Weissman-Fogel, I., & Shamay-Tsoory, S. G. (2017). The role of touch in regulating inter-partner physiological coupling during empathy for pain. *Scientific Reports*, 12;7(1):3252. https://doi: 10.1038/s41598-017-03627-7;

Gordan, R., Gwathmey, J. K., & Xie, L. H. (2015). Autonomic and endocrine control of cardiovascular function. *World journal of cardiology*, 7(4), 204–214. https://doi.org/10.4330/wjc.v7.i4.204;

Gordon, I., Voos, A. C., Bennett, R. H., Bolling, D. Z., Pelphrey, K. A., & Kaiser, M. D. (2013). Brain mechanisms for processing affective touch. *Human brain mapping*, 34(4), 914–922. https://doi.org/10.1002/hbm.21480;

Grafman, J. (2002). The structured event complex and the human prefrontal cortex. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 292–310). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195134971.003.0019;

Grol, M., & De Raedt, R. (2020). The link between resting heart rate variability and affective flexibility. *Cognitive, affective & behavioral neuroscience*, 20(4), 746–756. https://doi.org/10.3758/s13415-020-00800-w;

Gursul, D., Goksan, S., Hartley, C., Mellado, G. S., Moultrie, F., Hoskin, A., Adams, E., Hathway, G., Walker, S., McGlone, F., & Slater, R. (2018). Stroking modulates noxious-evoked brain activity in human infants. *Current biology*, 28(24), R1380–R1381. https://doi.org/10.1016/j.cub.2018.11.014;

Hartmann, R., Schmidt, F. M., Sander, C., & Hegerl, U. (2019). Heart Rate Variability as Indicator of Clinical State in Depression. *Frontiers in psychiatry*, 9, 735. https://doi.org/10.3389/fpsyt.2018.00735;

Hoshikawa, Y., & Yamamoto, Y. (1997). Effects of Stroop color-word conflict test on the autonomic nervous system responses. *The American journal of physiology*, 272(3 Pt 2), H1113–H1121. https://doi.org/10.1152/ajpheart.1997.272.3.H1113;

Hovland, A., Pallesen, S., Hammar, Å., Hansen, A. L., Thayer, J. F., Tarvainen, M. P., & Nordhus, I. H. (2012). The relationships among heart rate variability, executive functions, and clinical variables in patients with panic disorder. *International journal of psychophysiology*, 86(3), 269–275. https://doi.org/10.1016/j.ijpsycho.2012.10.004;

Huang, W. L., Liao, S. C., & Gau, S. S. (2021). Association between Stroop tasks and heart rate variability features in patients with somatic symptom disorder. *Journal of psychiatric research*, 136, 246–255. https://doi.org/10.1016/j.jpsychires.2021.02.002;

Huzard, D., Martin, M., Maingret, F., Chemin, J., Jeanneteau, F., Mery, P. F., Fossat, P., Bourinet, E., & François, A. (2022). The impact of C-tactile low-threshold mechanoreceptors on affective touch and social interactions in mice. *Science advances*, 8(26), eabo7566. https://doi.org/10.1126/sciadv.abo7566;

Jablonski N. G. (2021). Social and affective touch in primates and its role in the evolution of social cohesion. Neuroscience, 464, 117–125. https://doi.org/10.1016/j.neuroscience.2020.11.0;

Jenkinson, P. M., Papadaki, C., Besharati, S., Moro, V., Gobbetto, V., Crucianelli, L., Kirsch, L. P., Avesani, R., Ward, N. S., & Fotopoulou, A. (2020). Welcoming back my arm: affective touch increases body ownership following right-hemisphere stroke. *Brain communications*, 2(1), fcaa034. https://doi.org/10.1093/braincomms/fcaa034;

Kemp, A. H., & Quintana, D. S. (2013). The relationship between mental and physical health: insights from the study of heart rate variability. *International journal of psychophysiology*, 89(3), 288–

296. https://doi.org/10.1016/j.ijpsycho.2013.06.018;

Kemp, A. H., Brunoni, A. R., Santos, I. S., Nunes, M. A., Dantas, E. M., Carvalho de Figueiredo, R., Pereira, A. C., Ribeiro, A. L., Mill, J. G., Andreão, R. V., Thayer, J. F., Benseñor, I. M., & Lotufo, P. A. (2014). Effects of depression, anxiety, comorbidity, and antidepressants on resting-state heart rate and its variability: an ELSA-Brasil cohort baseline study. *The American journal of psychiatry*, 171(12), 1328–1334. https://doi.org/10.1176/appi.ajp.2014.13121605;

Kidd, T., Devine, S. L., & Walker, S. C. (2023). Affective touch and regulation of stress responses. *Health psychology review*, 17(1), 60–77. https://doi.org/10.1080/17437199.2022.2143854;

Kim, D. J., Kim, H., Kim, K., Kim, M. J., & Jeon, H. J. (2023). Association between anxiety and skin conductance according to the intensity of shaking of virtual reality images. *Frontiers in psychiatry*, 14, 1196767. https://doi.org/10.3389/fpsyt.2023.1196767;

Knight, E. L., Giuliano, R. J., Shank, S. W., Clarke, M. M., & Almeida, D. M. (2020). Parasympathetic and sympathetic nervous systems interactively predict change in cognitive functioning in midlife adults. *Psychophysiology*, 57(10), e13622. https://doi.org/10.1111/psyp.13622;

Kop, W. J., Synowski, S. J., Newell, M. E., Schmidt, L. A., Waldstein, S. R., & Fox, N. A. (2011). Autonomic nervous system reactivity to positive and negative mood induction: the role of acute psychological responses and frontal electrocortical activity. *Biological psychology*, 86(3), 230–238. https://doi.org/10.1016/j.biopsycho.2010.12.003;

Knutson, B., & Greer, S. M. (2008). Anticipatory affect: neural correlates and consequences for choice. *Biological sciences*, 363(1511), 3771–3786. https://doi.org/10.1098/rstb.2008.0155;

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research - Recommendations for Experiment Planning, Data Analysis, and Data Reporting. *Frontiers in psychology*, 8, 213. https://doi.org/10.3389/fpsyg.2017.00213;

Lazaridi, M., Panagiotaropoulou, G., Covanis, P., Karantinos, T., Aggelopoulos, E., Klein, C., &

Smyrnis, N. (2022). Brain-Heart Link in Schizophrenia: Cognitive Inhibitory Control Deficit in Patients Is Specifically Related to Parasympathetic Dysregulation. *Schizophrenia bulletin*, 48(5), 1155–1163. https://doi.org/10.1093/schbul/sbac033;

Lee, H. J., Macbeth, A. H., Pagani, J. H., & Young, W. S., 3rd (2009). Oxytocin: the great facilitator of life. *Progress in neurobiology*, 88(2), 127–151. https://doi.org/10.1016/j.pneurobio.2009.04.001;

Lee, Y., Goyal, N., & Aruin, A. S. (2018a). Effect of a cognitive task and light finger touch on standing balance in healthy adults. *Experimental brain research*, 236(2), 399–407. https://doi.org/10.1007/s00221-017-5135-9;

Lee, Y. S., Sehlstedt, I., Olausson, H., Jung, W. M., Wallraven, C., & Chae, Y. (2018b). Visual and physical affective touch delivered by a rotary tactile stimulation device: A human psychophysical study. *Physiology & behavior*, 185, 55–60. https://doi.org/10.1016/j.physbeh.2017.12.022;

Liang, W. C., Yuan, J., Sun, D. C., & Lin, M. H. (2009). Changes in Physiological Parameters Induced by Indoor Simulated Driving: Effect of Lower Body Exercise at Mid-Term Break. *Sensors*, 9(9), 6913-6933. https://doi.org/10.3390/s90906913;

Löken, L. S., Wessberg, J., Morrison, I., McGlone, F., & Olausson, H. (2009). Coding of pleasant touch by unmyelinated afferents in humans. *Nature neuroscience*, 12(5), 547–548. https://doi.org/10.1038/nn.2312;

Lovibond, S. H., & Lovibond, P. F. (1995). *Depression Anxiety Stress Scales (DASS--21, DASS--42)*. APA PsycTests.https://doi.org/10.1037/t01004-000;

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience*, 10(6), 434–445. https://doi.org/10.1038/nrn2639;

Mammarella, N., Fairfield, B., & Di Domenico, A. (2012). When touch matters: an affective tactile intervention for older adults. *Geriatrics & gerontology international*, 12(4), 722–724. https://doi.org/10.1111/j.1447-0594.2012.00836.x;

Manzotti, A., Cerritelli, F., Monzani, E., Savioli, L., Esteves, J. E., Lista, G., Lombardi, E., Rocca, S., Biasi, P., Galli, M., Chiera, M., & McGlone, F. P. (2023). Dynamic touch induces autonomic changes in preterm infants as measured by changes in heart rate variability. *Brain research*, 1799, 148169. https://doi.org/10.1016/j.brainres.2022.148169;

Mather, M., & Thayer, J. (2018). How heart rate variability affects emotion regulation brain networks. *Current opinion in behavioral sciences*, 19, 98–104. https://doi.org/10.1016/j.cobeha.2017.12.017;

Mathewson, K. J., Jetha, M. K., Drmic, I. E., Bryson, S. E., Goldberg, J. O., Hall, G. B., Santesso, D. L., Segalowitz, S. J., & Schmidt, L. A. (2010). Autonomic predictors of Stroop performance in young and middle-aged adults. *International journal of psychophysiology*, 76(3), 123–129. https://doi.org/10.1016/j.ijpsycho.2010.02.007;

Matsushita, H., Latt, H. M., Koga, Y., Nishiki, T., & Matsui, H. (2019). Oxytocin and Stress: Neural Mechanisms, Stress-Related Disorders, and Therapeutic Approaches. *Neuroscience*, 417, 1–10. https://doi.org/10.1016/j.neuroscience.2019.07.046;

Mazza, A., Cariola, M., Capiotto, F., Diano, M., Schintu, S., Pia, L., & Dal Monte, O. (2023). Hedonic and autonomic responses in promoting affective touch. *Scientific reports*, 13(1), 11201. https://doi.org/10.1038/s41598-023-37471-9;

McCabe, C., Rolls, E. T., Bilderbeck, A., & McGlone, F. (2008). Cognitive influences on the affective representation of touch and the sight of touch in the human brain. *Social cognitive and affective neuroscience*, 3(2), 97–108. https://doi.org/10.1093/scan/nsn005;

McRae, K., Misra, S., Prasad, A. K., Pereira, S. C., & Gross, J. J. (2012). Bottom-up and top-down emotion generation: implications for emotion regulation. *Social cognitive and affective neuroscience*, 7(3), 253–262. https://doi.org/10.1093/scan/nsq103;

McCraty, R., Atkinson, M., Tomasino, D., & Stuppy, W. P. (2001). Analysis of twenty-four hour heart rate variability in patients with panic disorder. *Biological Psychology*, 56(2-3), 131–150. https://doi.org/10.1016/S0301-0511(01)00074-6;

McEwen B. S. (2007). Physiology and neurobiology of stress and adaptation: central role of the brain. *Physiological reviews*, 87(3), 873–904. https://doi.org/10.1152/physrev.00041.2006;

McGlone, F., Olausson, H., Boyle, J. A., Jones-Gotman, M., Dancer, C., Guest, S., & Essick, G. (2012). Touching and feeling: differences in pleasant touch processing between glabrous and hairy skin in humans. *The European journal of neuroscience*, 35(11), 1782–1788. https://doi.org/10.1111/j.1460-9568.2012.08092.x;

McGlone, F., Wessberg, J., & Olausson, H. (2014). Discriminative and affective touch: sensing and feeling. *Neuron*, 82(4), 737–755. https://doi.org/10.1016/j.neuron.2014.05.001;

McGlone, F., Uvnäs Moberg, K., Norholt, H., Eggart, M., & Müller-Oerlinghausen, B. (2024). Touch medicine: bridging the gap between recent insights from touch research and clinical medicine and its special significance for the treatment of affective disorders. *Frontiers in psychiatry*, 15, 1390673. https://doi.org/10.3389/fpsyt.2024.1390673;

Morrison, I., Löken, L.S. & Olausson, H. (2010). The skin as a social organ. *Experimental Brain Research*, 305–314. https://doi.org/10.1007/s00221-009-2007-y;

Morrison, I. (2016). Keep Calm and Cuddle on: Social Touch as a Stress Buffer. *Adaptive Human Behavior and Physiology*, 2, 344–362. https://doi.org/10.1007/s40750-016-0052-x;

Morrison, I., & Croy, I. (2021). The Science of Social and Affective Touch. *Neuroscience*, 464, 1–2. https://doi.org/10.1016/j.neuroscience.2021.03.013;

Munoz, M. L., van Roon, A., Riese, H., Thio, C., Oostenbroek, E., Westrik, I., de Geus, E. J., Gansevoort, R., Lefrandt, J., Nolte, I. M., & Snieder, H. (2015). Validity of (ultra-)short recordings for heart rate variability measurements. *PLoS ONE*, 10:e0138921. https://doi: 10.1371/journal.pone.0138921;

Nahshoni, E., Aravot, D., Aizenberg, D., Sigler, M., Zalsman, G., Strasberg, B., Imbar, S., Adler, E., & Weizman, A. (2004). Heart rate variability in patients with major depression. *Psychosomatics*, 45(2), 129–134. https://doi.org/10.1176/appi.psy.45.2.129;

Nicolini, P., Malfatto, G., & Lucchi, T. (2024). Heart Rate Variability and Cognition: A Narrative Systematic Review of Longitudinal Studies. *Journal of clinical medicine*, 13(1), 280. https://doi.org/10.3390/jcm13010280;

Olausson, H., Wessberg, J., Morrison, I., McGlone, F., & Vallbo, A. (2010). The neurophysiology of unmyelinated tactile afferents. *Neuroscience and biobehavioral reviews*, 34(2), 185–191. https://doi.org/10.1016/j.neubiorev.2008.09.011;

Oya, R., & Tanaka, A. (2023). Touch and voice have different advantages in perceiving positive and negative emotions. *i-Perception*, 14(2), 20416695231160420. https://doi.org/10.1177/20416695231160420;

Pallak, M. S., Pittman, T. S., Heller, J. F., & Munson, P. (1975). The effect of arousal on Stroop color-word task performance. *Bulletin of the Psychonomic Society*, 6(3), 248–250. https://doi.org/10.3758/BF03336652;

Park, G., & Thayer, J. F. (2014). From the heart to the mind: cardiac vagal tone modulates top-down and bottom-up visual perception and attention to emotional stimuli. *Frontiers in psychology*, 5, 278. https://doi.org/10.3389/fpsyg.2014.00278;

Parkin, B. L., Warriner, K., & Walsh, V. (2017). Gunslingers, poker players, and chickens 1: Decision making under physical performance pressure in elite athletes. In *Progress in Brain Research* (Vol. 234, pp. 291-316). https://doi.org/10.1016/bs.pbr.2017.08.001;

Pawling, R., McGlone, F., & Walker, S. C. (2024). High frequency heart rate variability is associated with sensitivity to affective touch. *Physiology & behavior*, 283, 114600. https://doi.org/10.1016/j.physbeh.2024.114600;

Pendleton, D. M., Sakalik, M. L., Moore, M. L., & Tomporowski, P. D. (2016). Mental engagement during cognitive and psychomotor tasks: Effects of task type, processing demands, and practice. *International Journal of Psychophysiology*, 109, 124–131. https://doi.org/10.1016/j.ijpsycho.2016.08.012;

Poehlmann, J., Schwichtenberg, A. J., Bolt, D. M., Hane, A., Burnson, C., & Winters, J. (2011). Infant physiological regulation and maternal risks as predictors of dyadic interaction trajectories in families with a preterm infant. *Developmental psychology*, 47(1), 91–105. https://doi.org/10.1037/a0020719;

Porter, C. L. (2003). Coregulation in mother-infant dyads: Links to infants' cardiac vagal tone. *Psychological Reports*, 92(1), 307–319. https://doi.org/10.2466/PR0.92.1.307-319;

Portnova, G. V., Proskurnina, E. V., Sokolova, S. V., Skorokhodov, I. V., & Varlamov, A. A. (2020). Perceived pleasantness of gentle touch in healthy individuals is related to salivary oxytocin response and EEG markers of arousal. *Experimental brain research*, 238(10), 2257–2268. https://doi.org/10.1007/s00221-020-05891-y;

Püschel, I., Reichert, J., Friedrich, Y., Bergander, J., Weidner, K., & Croy, I. (2022). Gentle as a mother's touch: C-tactile touch promotes autonomic regulation in preterm infants. *Physiology & behavior*, 257, 113991. https://doi.org/10.1016/j.physbeh.2022.113991;

Ree, A., Mayo, L. M., Leknes, S., & Sailer, U. (2019). Touch targeting C-tactile afferent fibers has a unique physiological pattern: A combined electrodermal and facial electromyography study. *Biological Psychology*, 140, 55–63. https://doi.org/10.1016/j.biopsycho.2018.11.006;

Renaud, P., & Blondin, J. P. (1997). The stress of Stroop performance: physiological and emotional responses to color-word interference, task pacing, and pacing speed. *International journal of* *psychophysiology*, 27(2), 87–97. https://doi.org/10.1016/s0167-8760(97)00049-4;

Rogers, A. J., & Weiss, S. (2009). Epidemiologic and population genetic studies. Clinical and Translational Science;

Rónai, L., Hann, F., Kéri, S., Ettinger, U., & Polner, B. (2024). Emotions under control? Better cognitive control is associated with reduced negative emotionality but increased negative emotional reactivity within individuals. *Behaviour research and therapy*, 173, 104462. https://doi.org/10.1016/j.brat.2023.104462;

Sacchetti, S., McGlone, F., Cazzato, V., & Mirams, L. (2021). The off-line effect of affective touch on multisensory integration and tactile perceptual accuracy during the somatic signal detection task. *PloS one*, 16(12), e0261060. https://doi.org/10.1371/journal.pone.0261060;

Sailer, U., Friedrich, Y., Asgari, F., Hassenzahl, M., & Croy, I. (2024). Determinants for positive and negative experiences of interpersonal touch: context matters. *Cognition & emotion*, 38(4), 565–586. https://doi.org/10.1080/02699931.2024.2311800;

Saunders, B., Riesel, A., Klawohn, J., & Inzlicht, M. (2018). Interpersonal touch enhances cognitive control: A neurophysiological investigation. *Journal of experimental psychology*, 147(7), 1066–1077. https://doi.org/10.1037/xge0000412;

Schirmer, A., & McGlone, F. (2022). Editorial overview: Affective touch: Neurobiology and function. *Current Opinion in Behavioral Sciences*, 45, 101129. https://doi.org/10.1016/j.cobeha.2022.101129;

Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. *Frontiers in psychology*, 5, 1040. https://doi.org/10.3389/fpsyg.2014.01040;

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in public health*, 5, 258. https://doi.org/10.3389/fpubh.2017.00258;

Silvestri, V., Giraud, M., Macchi Cassia, V., & Nava, E. (2024). Touch me or touch me not: Emotion regulation by affective touch in human adults. *Emotion*, 24(4), 913–922. https://doi.org/10.1037/emo0001320;

Siraji, M. A., Spitschan, M., Kalavally, V., & Haque, S. (2023). Light exposure behaviors predict mood, memory and sleep quality. *Scientific reports*, 13(1), 12425. https://doi.org/10.1038/s41598-023-39636-y;

Sloan, R. P., Schwarz, E., McKinley, P. S., Weinstein, M., Love, G., Ryff, C., Mroczek, D., Choo, T. H., Lee, S., & Seeman, T. (2017). Vagally-mediated heart rate variability and indices of well-being: Results of a nationally representative study. *Health psychology*, 36(1), 73–81. https://doi.org/10.1037/hea0000397;

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. *Dialogues in clinical neuroscience*, 8(4), 383–395. https://doi.org/10.31887/DCNS.2006.8.4/ssmith

Solhjoo, S., Haigney, M.C., McBee, E. et al. Heart Rate and Heart Rate Variability Correlate with Clinical Reasoning Performance and Self-Reported Measures of Cognitive Load. *Scientific Reports*, 9, 14668 (2019). https://doi.org/10.1038/s41598-019-50280-3;

Stevens, P.E., Bruck, J.N. (2019). Sensitization. In: Vonk, J., Shackelford, T. (eds) Encyclopedia of Animal Cognition and Behavior. Springer, Cham. https://doi.org/10.1007/978-3-319-47829-6_1503-1;

Storbeck, J., & Clore, G. L. (2008). Affective Arousal as Information: How Affective Arousal Influences Judgments, Learning, and Memory. *Social and personality psychology compass*, 2(5), 1824–1843. https://doi.org/10.1111/j.1751-9004.2008.00138.x;

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643–662. https://doi.org/10.1037/h0054651;

Suga, A., Uraguchi, M., Tange, A., Ishikawa, H., & Ohira, H. (2019). Cardiac interaction between mother and infant: enhancement of heart rate variability. *Scientific reports*, 9(1), 20019. https://doi.org/10.1038/s41598-019-56204-5;

Suvilehto, J.T., Cekaite, A. & Morrison, I. (2023). The why, who and how of social touch. *Nature reviews Psychology*, 2, 606–621 (2023). https://doi.org/10.1038/s44159-023-00217-5;

Taneja, P., Olausson, H., Trulsson, M., Svensson, P., & Baad-Hansen, L. (2021). Defining pleasant touch stimuli: a systematic review and meta-analysis. *Psychological research*, 85(1), 20–35. https://doi.org/10.1007/s00426-019-01253-8;

Tarvainen, M. P., Niskanen, J. P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV--heart rate variability analysis software. *Computer methods and programs in biomedicine*, 113(1), 210–220. https://doi.org/10.1016/j.cmpb.2013.07.024;

Terrile, S., Miguelañez, J., & Barrientos, A. (2021). A Soft Haptic Glove Actuated with Shape Memory Alloy and Flexible Stretch Sensors. *Sensors*, 21(16), 5278. https://doi.org/10.3390/s21165278;

Thayer, J. F., Friedman, B. H., & Borkovec, T. D. (1996). Autonomic characteristics of generalized anxiety disorder and worry. *Biological psychiatry*, 39(4), 255–266. https://doi.org/10.1016/0006-3223(95)00136-0;

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of affective disorders*, 61(3), 201–216. https://doi.org/10.1016/s0165-0327(00)00338-4;

Thayer, J. F., & Friedman, B. H. (2002). Stop that! Inhibition, sensitization, and their neurovisceral concomitants. *Scandinavian journal of psychology*, 43(2), 123–130. https://doi.org/10.1111/1467-9450.00277;

Thayer J. F. (2006). On the importance of inhibition: central and peripheral manifestations of nonlinear inhibitory processes in neural systems. *Dose-response*, 4(1), 2–21.

https://doi.org/10.2203/dose-response.004.01.002.Thayer;

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009a). Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of behavioral medicine*, 37(2), 141–153. https://doi.org/10.1007/s12160-009-9101-z;

Thayer, J. F., & Lane, R. D. (2009b). Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. *Neuroscience and biobehavioral reviews*, 33(2), 81–88. https://doi.org/10.1016/j.neubiorev.2008.08.004;

Thayer, J. F., Ahs, F., Fredrikson, M., Sollers, J. J., 3rd, & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. *Neuroscience and biobehavioral reviews*, 36(2), 747–756. https://doi.org/10.1016/j.neubiorev.2011.11.009;

Triscoli, C., Ackerley, R., & Sailer, U. (2014). Touch satiety: differential effects of stroking velocity on liking and wanting touch over repetitions. *PloS one*, 9(11), e113425. https://doi.org/10.1371/journal.pone.0113425;

Triscoli, C., Croy, I., Steudte-Schmiedgen, S., Olausson, H., & Sailer, U. (2017). Heart rate variability is enhanced by long-lasting pleasant touch at CT-optimized velocity. *Biological psychology*, 128, 71–81. https://doi.org/10.1016/j.biopsycho.2017.07.007;

Vallbo, A. B., Olausson, H., & Wessberg, J. (1999). Unmyelinated afferents constitute a second system coding tactile stimuli of the human hairy skin. *Journal of neurophysiology*, 81(6), 2753–2763. https://doi.org/10.1152/jn.1999.81.6.2753;

Van Puyvelde, M., Gorissen, A. S., Pattyn, N., & McGlone, F. (2019). Does touch matter? The impact of stroking versus non-stroking maternal touch on cardio-respiratory processes in mothers and infants. *Physiology & behavior*, 207, 55–63. https://doi.org/10.1016/j.physbeh.2019.04.024;

Vazan, R., Filcikova, D., & Mravec, B. (2017). Effect of the Stroop test performed in supine position on the heart rate variability in both genders. *Autonomic neuroscience*, 208, 156–160. https://doi.org/10.1016/j.autneu.2017.10.009;

von Mohr, M., Kirsch, L. P., & Fotopoulou, A. (2017). The soothing function of touch: affective touch reduces feelings of social exclusion. *Scientific reports*, 7(1), 13516. https://doi.org/10.1038/s41598-017-13355-7;

von Mohr, M., Krahé, C., Beck, B., & Fotopoulou, A. (2018). The social buffering of pain by affective touch: a laser-evoked potential study in romantic couples. *Social cognitive and affective neuroscience*, 13(11), 1121–1130. https://doi.org/10.1093/scan/nsy085;

Walker, S. C., Trotter, P. D., Swaney, W. T., Marshall, A., & Mcglone, F. P. (2017). C-tactile afferents: Cutaneous mediators of oxytocin release during affiliative tactile interactions?. *Neuropeptides*, 64, 27–38. https://doi.org/10.1016/j.npep.2017.01.001;

Walker, S. C., Cavieres, A., Peñaloza-Sancho, V., El-Deredy, W., McGlone, F. P., & Dagnino-Subiabre, A. (2022). C-low threshold mechanoafferent targeted dynamic touch modulates stress resilience in rats exposed to chronic mild stress. *The European journal of neuroscience*, 55(9-10), 2925–2938. https://doi.org/10.1111/ejn.14951;

Watkins, R. H., Dione, M., Ackerley, R., Backlund Wasling, H., Wessberg, J., & Löken, L. S. (2021). Evidence for sparse C-tactile afferent innervation of glabrous human hand skin. *Journal of neurophysiology*, 125(1), 232–237. https://doi.org/10.1152/jn.00587.2020;

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, 54(6), 1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063;

Waxenbaum, J. A., Reddy, V., & Varacallo, M. (2023). *Anatomy, Autonomic Nervous System*. In StatPearls. StatPearls Publishing;

Weiss, S. M., Meltzoff, A. N., & Marshall, P. J. (2018). Neural measures of anticipatory bodily attention in children: Relations with executive function. *Developmental cognitive neuroscience*, 34, 148–158. https://doi.org/10.1016/j.dcn.2018.08.002;

Wijaya, M., Lau, D., Horrocks, S., McGlone, F., Ling, H., & Schirmer, A. (2020). The human "feel" of touch contributes to its perceived pleasantness. *Journal of experimental psychology*, 46(2), 155–171. https://doi.org/10.1037/xhp0000705;

Wilson, A. D., & Golonka, S. (2013). Embodied Cognition is Not What you Think it is. *Frontiers in psychology,* 4, 58. https://doi.org/10.3389/fpsyg.2013.00058;

Yachi, C. T., Hitomi, T., & Yamaguchi, H. (2018). Two Experiments on the Psychological and Physiological Effects of Touching-Effect of Touching on the HPA Axis-Related Parts of the Body on Both Healthy and Traumatized Experiment Participants. *Behavioral sciences*, 8(10), 95. https://doi.org/10.3390/bs8100095;

Yerkes R, Dodson J. (1908). The relation of strength of stimulus to rapidity of habit-information. *Journal of Comparative Neurology of Psychology*. 18:459–482.