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Why do we hunger for touch? The impact of daily gentle touch stimulation on maternal-infant physiological and behavioral regulation and resilience

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Abstract

We report the impact of a Gentle Touch Stimulation (GTS) program. Forty-three mothers provided daily 10-min GTS with C-tactile (CT) afferent optimal stroking touch, for 4 weeks to their 3–12 weeks old infants. CT-afferents are cutaneous unmyelinated, low-threshold mechanosensitive nerves hypothesized to underly the regulatory impact of affective touch. We compared physiological and behavioral responses during a no-touch-baseline (BL), static-touch-baseline (BL-T), intervention/control (GTS/CTRL), Still Face (SF) and Reunion (RU) condition for GTS-infants versus a control-group (CTRL) at the start (T1) and end of (T2) of the program. We collected mother-infant ECG, respiration, cortisol, video-recordings, and diary-reports. At T1, physiological arousal significantly increased during SF in both groups, that is, decreased respiratory sinus arrhythmia (RSA) and R-R interval (RRI). At T2, GTS-infants showed significantly increased RSA, RRI, decreased respiration during GTS, buffering SF-arousal and allowing complete recovery during RU; CTRL-infants showed higher SF-arousal and small recovery, under initial BL-levels. Maternal cardio-respiratory showed a metabolic investment during RU. Cortisol and behavioral analyses showed higher arousal in CTRL-infants than GTS-infants at T2. We suggest that the combination of phasic short-term and tonic long-term responses to CT-optimal stroking touch, delivered in a structured daily manner, contribute to the building of infant stress regulation and resilience.

KEYWORDS
cardiorespiratory, CT-afferents, gentle touch stimulation, infant development, infant resilience, mother-infant, respiration, RSA, stress-regulation

INTRODUCTION

The development and maintenance of social connectedness is one of the fundamental key factors of human survival (Eisenberger & Cole, 2012; Harlow, 1958; Uvnäs-Moberg et al., 2005) both from a phylogenetic and ontogenetic point of view (Dunbar & Shultz, 2007; Sutcliffe et al., 2012). Phylogenetically, a tight coevolutionary relationship between brain size and complexity of social groups has been hypothesized to be a crucial link in survival (Dunbar & Shultz, 2007). Ontogenetically, from birth onwards—if not neglected—a baby is to a greater or lesser extent engaged in an evolving learning process of social interaction (Feldman, 2007; Papoušek, 2007) to secure close contact and protection (Bowlby, 1969; Harlow, 1958). During repeated cycles of synchrony, a baby not only learns the basic rules of social communication such as the contingency of timing, turn-taking, facial and vocal expression etc. (e.g., Beebe et al., 1985; Feldman, 2007; Gratier et al., 2015; Papoušek, 2007; Van Puyvelde et al., 2013), but there is also an important layer of emotional regulation that is established. Every social interactive occasion entails physiological processes related to thermal, nutritional and sensorimotor regulation that create an alternating climate of stimulation and calming regulation for the infant (Feldman, 2007; Feldman et al., 2011; Van Puyvelde et al., 2014, 2015). Within this multimodal stream of information, touch is considered to play a key-role (Walker & McGlone, 2013).

A mounting number of studies has shown that affiliative touch between parents and infants modulates the typical physiological cascadic response to stress, mediated by the hypothalamic pituitary adrenal axis (HPA) and sympathetic nervous system (SNS) (e.g., Feldman et al., 2011; Feldman et al., 2014; Feldman et al., 2010; Meaney, 2001; Field, 2010; Moore & Calkins, 2004; Van Puyvelde et al., 2015; Vannorsdall et al., 2004; Van Puyvelde et al., 2019; Van Puyvelde et al., 2019; Walker, 2010; Winberg, 2005). This ability to self-regulate in moments of stress and the competence to adapt to changing external and internal conditions is the basis of allostasis, better known as resilience or the capacity to remain stable through change (McEwen, 1998). In rodent studies, several studies have shown that affective touch provided by the mother in the form of licking and grooming facilitated resilience in their pups (e.g., Champagne, 2008; Champagne & Meaney, 2007; Champagne et al., 2003; Hellstrom et al., 2012; Meaney, 2001). Even when the mother was absent and stroking was provided by a soft brush (Gonzalez et al., 2001; Van Oers et al., 1998) or the experimenter's hand (Walker et al., 2020), a beneficial impact of touch on stress resilience was observed.

The current main hypothesis to clarify this regulatory impact of affective touch on mammalian physiology refers to the existence of a population of mechanosensitive unmyelinated nerves called c-tactile (CT) afferents (Löken et al., 2009; Vallbo et al., 1999). Microneurography recordings showed that CT-afferents are found in hairy skin areas of the body (Ackerley, Wasling et al., 2014; Vallbo et al., 1999), responding optimally to low force skin temperature stroking touch, within a 1–10 cm/s velocity range (Ackerley, Saar et al., 2014, 2018; Croy et al., 2016; Löken et al., 2009; McGlone et al., 2014). It has clearly been shown that this window of velocity is related with the sensitivity to the social value of affective touch. People rate touch of 3 cm/s as more pleasant than touch delivered at lower or faster velocity rates (Essick et al., 2010). Moreover, recent studies reported that people with adverse childhood experiences showed a reduced sensitivity to both experienced (Devine et al., 2020) and perceived (Sailer & Ackerley, 2019; Spitoni et al., 2020) CT-targeted 3 cm/s touch. These studies not only underline the developmental importance of the establishment of CT-mechanisms but—taken into account the risk for mental health outcomes in a care-leaving population (e.g., Gypen et al., 2017)—also show that CT-targeted affective touch may be one mechanism that links early nurturing care with the establishment of psychophysiological regulation.

Indeed, it has been shown that the CT-afferent responsive system is part of the mutual cycles of intuitive parenting. Both mothers (Bytomski et al., 2020; Croy et al., 2016; Van, Gorissen Puyvelde et al., 2019) and fathers (Van, Collette Puyvelde et al., 2019) intuitively stroke their infants within the CT-afferent optimal stroking speed range and at CT-optimal body locations and a recent study showed a positive correlation between stroking velocity and baseline maternal heart rate before stroking (Bytomski et al., 2020). Moreover, stroking parental touch was shown to stimulate parasympathetic regulation characterized by an increased amplitude of Respiratory Sinus Arrythmia (RSA) during and after a brief stroking period in comparison with a pre-stroking baseline (Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019). RSA refers to the parasympathetic component of the natural heart rate variability (HRV) that occurs due to oscillations in the Autonomous Nervous System (ANS), impacting the cardio-respiration. It is mediated by the nervus vagus and is featured by a flexibility in the interconnection between cardiac and respiratory activity (Berntson et al., 1997), that is the alternation between increased heart rate (HR) during inhalation and decreased HR during exhalation (Berntson et al., 1997). The amount of this flexibility has been interpreted as an indicator for physiological self-regulation and resilience (Thayer & Lane, 2000) and it has been suggested in previous research that CT-afferents may play an important role within the building of this resilience (Morrison, 2016; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019).

Indeed, an increased parasympathetic facilitation—foundational in the building of resilience (Chrousos, 2009)—is clearly present in stroked infants in the short term (Fairhurst et al., 2014; Van Puyvelde et al., 2019; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019). However, it is not yet clear whether touch may play a role in building a stress buffer in the long run. And the latter is the essence of resilience, namely, the establishment of a psychophysiological buffer that provides adaptation capacity to face adversity (Cathomas et al., 2019). Walker et al. (2020) showed that, in rats, 10 min of daily dorsal stroking at a CT-optimal velocity, during 14-days, significantly reduced the elevations in corticosterone after a stress-inducing forced-swim test in comparison to rats that were stroked in a non-optimal velocity stroking window and non-stroked rats. Ten minutes of daily stroking, thus, offered a buffer against an acute stress test. A comparable acute stress test appliable in infants is the well-known "still-face paradigm" (SFP) (Tronick et al., 1978) that permits to observe the potential effects of maternal withdraw on infants' behavior and physiology (Feldman et al., 2010; Moore et al., 2001; Tronick et al., 1978; Tronick et al., 2005). The SFP contains three phases, that is, the initial interaction phase (2 min of free mother-infant interaction), the still-face phase (2 min of maternal refrain from interaction) and the reunion phase (2 min of free interaction) (Ham & Tronick, 2006). On a physiological level, it has been shown that the SF-phase induces increased cortisol and HR (Haley & Stansbury, 2003) and decreased parasympathetic tone (Moore & Calkins, 2004). On a behavioral level, the still face effect is characterized by a pallet of regulatory behaviors comparable with passive and active coping strategies in adults (Eisenberg et al., 1997; Weinberg & Tronick, 1996). Moreover, infants often attempt to restore the relationship and to retake agency by showing "social bidding behavior" (e.g., increased visual attention, smiling and vocalizing) (Bigelow & Power, 2016; Bigelow et al., 2015). The reunion phase reveals the infant's resilience capacity to recover (Weinberg & Tronick, 1996) physiologically (Haley & Stansbury, 2003; Ham & Tronick, 2006; Moore & Calkins, 2004) and behaviorally (Mesman et al., 2009). It has been shown how maternal touch can temper stress-reactivity and improve stress-recovery during an SFP (Feldman et al., 2010; Stack & Muir, 1992). Infants that were touched by their mother during the SFP, showed less negative arousal (Feldman et al., 2010; Stack & Muir, 1992), higher RSA-levels and lower cortisol during the SF-phase and better recovery during reunion (Feldman et al., 2010) than non-touched infants. Hence, the provided touch during the SFP appeared to offer a stress buffer and to induce resilience.

In the current study, we aimed at examining the impact of a structured program of a daily 10-min gentle touch stimulation (GTS), provided during 4 weeks to 3–12 weeks aged infants. Van Puyvelde et al. (2019b) suggested that recurrent affective touch may induce the combination of acute (short-term) or phasic reactivity and the installation of a more integrated, or tonic response of long-term regulation. Hence, we aimed at measuring whether such a tonic response of long-term regulation may be established. We measured the physiological (ECG, respiration and saliva) and behavioral (video-recordings) responses of GTS-infants versus a control-group (CTRL) that did not receive the GTS program and their mothers during the subsequent phases of the SFP compared to baseline. We measured once at the very start of the program (i.e., T1, after 2 days) and once at the end of the program (i.e., T2, after 4 weeks). We chose this design to capture all the physiological events during all the stages and to compare them in short-term (phasic reactivity) and long-term (tonic reactivity) in order to evaluate eventual changes over time. We analyzed cardio-respiratory stress reactivity in both mothers and infants and conducted behavioral micro-analyses of regulation and arousal in the infant. Further, we asked to complete a diary on general mother-infant aspects as well as the subjective evaluation of the GTS procedure. The data were collected at the mothers' home to optimize the ecological validity of the experiment (e.g., Van Puyvelde et al., 2014, 2015, 2019; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019). We hypothesized that at T1, both CTRL and GTS infants would show increased short-term regulation during the quiet interaction/GTS-intervention and a decreased regulation during the SF-phase and RU due to phasic reactivity responses. At T2, we expected that an association between GTS and parasympathetic regulation (i.e., a tonic response) would start to evolve in the GTS-infants due to the structured provision of GTS for 4 weeks, hence evoking a stronger effect of reinforcement. Moreover, we expected that, if a GTS-regulation association would establish after 4 weeks, a stronger regulation would provide a stress buffer during SF and a better recuperation during RU. We did not expect this stronger effect to occur in the CTRL infants since the free interaction would not evoke an association established through a recurrent structured stimulation.

1 | METHOD

1.1 | Participants

The study was approved by the Commission for Medical Ethics of UZ Brussels (B.U.N. 143201835659). Initially, 43 mothers and their infants enrolled and signed informed consent. They were alternately assigned to either the gentle touch stimulation (GTS) group or the control (CTRL) group (i.e., dyad 1 GTS, dyad 2, CTRL, dyad 3 GTS etc.). The mothers were recruited through midwives, word-of-mouth, and social media. The first three participating dyads served as pilot trials to finalize the experiment; they were excluded from the dataset. Two other dyads were excluded due to the state of the infant's health, mood or wakefulness at the time the first measurement was planned. Three mothers further withdrew from the study between signing the informed consent and the end of the study and two dyads were excluded due to procedural errors. The final sample therefore consists of 33 dyads (in the infants, 18 boys and 15 girls) with 20 dyads in the GTS group and 13 in the CTRL group. At T1 the average age was 30.55 years (SD = 3.76, range 24–41 years) for the mothers and 6.14 weeks (SD = 1.62, range 3.30-8.80 weeks) for the infants. The average infant birth length was 50.71 cm (SD = 2.00, range 46–55 cm). The average infant birth weight was 3.37 kg (SD = .37, range 2.55–3.96 kg). The infant inclusion criteria were age (2–8 weeks on the day of the first measurement), being healthy and full-term born with an APGAR score of at least 7 (Apgar, 1966) and no visual and/or auditory deficits. An infant exclusion criterium was previous or current experience with massage therapy. An exclusion criterium for the mothers was a diagnosis for postnatal depression.

1.2 | Missing values

Besides the withdrawals, there were quite some missing values that occurred in different data parameters and most of the time at different time measurements (either T1 or T2) which seriously restricted the final data samples that provided analyses over T1 and T2 (i.e., finally retained n = 24 for cardiorespiratory data; n = 19 for cortisol and video-analysis) (see Figure S1 in the supplementary section for an overview).

1.3 | Apparatus

The electrocardiogram (ECG) and respiration of mother and infant were synchronously registered using the Bio-Radio TM system (Great Lakes NeuroTechnologies, Inc., Cleveland, OH, USA). This is a mobile device consisting of a primary module, a wireless non-invasive system allowing participants to freely move during the measurements (see also Van Puyvelde et al., 2014, 2015; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019). The infant saliva samples were collected using the SalivaBio Infant's Swab and those from the mother using the SalivaBio Oral Swab (exclusively from Salimetrics, State College, PA, USA), which are non-invasive and validated tools to collect saliva. To monitor ECG, two standard single-channel ECG registrations (II derivation) were used, one for the mother and one for the infant; the positioning was on the upper right side and on the lower left side of the chest (Einthoven et al., 1913) with a grounding electrode on the back. The respiration was measured using a thoraco-abdominal respiratory effort belt for the mother, and a pediatric belt for the infant. These belts detect the breathing effort movements. The ECG signals were recorded using a sampling frequency of 960 Hz, with a lowpass Bessel filter order 4 and a lower cut-off of 100 Hz. For the respiratory signals, a lowpass Bessel filter order 2 with a lower cut-off at 1 Hz was used. The video recordings were made using a Sony Handycam type HDR-CX160 and HDRSR11E. The physiological analyses were conducted in VivoSense software version 3.1 (Vivonetics, San Diego, USA) and the statistical analyses were performed with the Statistical Package for Social Sciences Version 27.0 (SPSS). For the behavioral micro-analysis, the ELAN-software 5.4. was used (Lausberg & Sloetjes, 2009; Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands).

1.4 | Diary

The mothers kept a diary to evaluate the subjective experience of maternal and infant wellbeing, interaction quality and GTS quality related aspects (i.e., comfort and interaction before, during and after the GTS) by means of scores on a 10-point Likert scale. Both GTS and CTRL mothers completed a general diary which inquired about maternal and infant wellbeing and interaction quality, that is, mother/baby mood, mother/baby sleep quality and the interaction quality during that day. “Mood mother”, “mood baby”, “sleep mother” and “sleep baby” were used as indicators of infant and maternal wellbeing. “Interaction” was used as an indicator of interaction quality. GTS mothers completed an additional GTS diary which gathered information about the GTS intervention, that is, the experienced comfort and interaction by the mother and baby before, during and after the GTS. GTS mothers were also instructed to note the time of the GTS intervention in the GTS diary.

1.5 | Procedure

Figure 1 displays an overview of the interventional period. On the first day (T0), an instruction session took place at the mothers' home to inform them about the entire procedure, the experiment, and the questionnaires. The experimenter practiced with the mother the structured

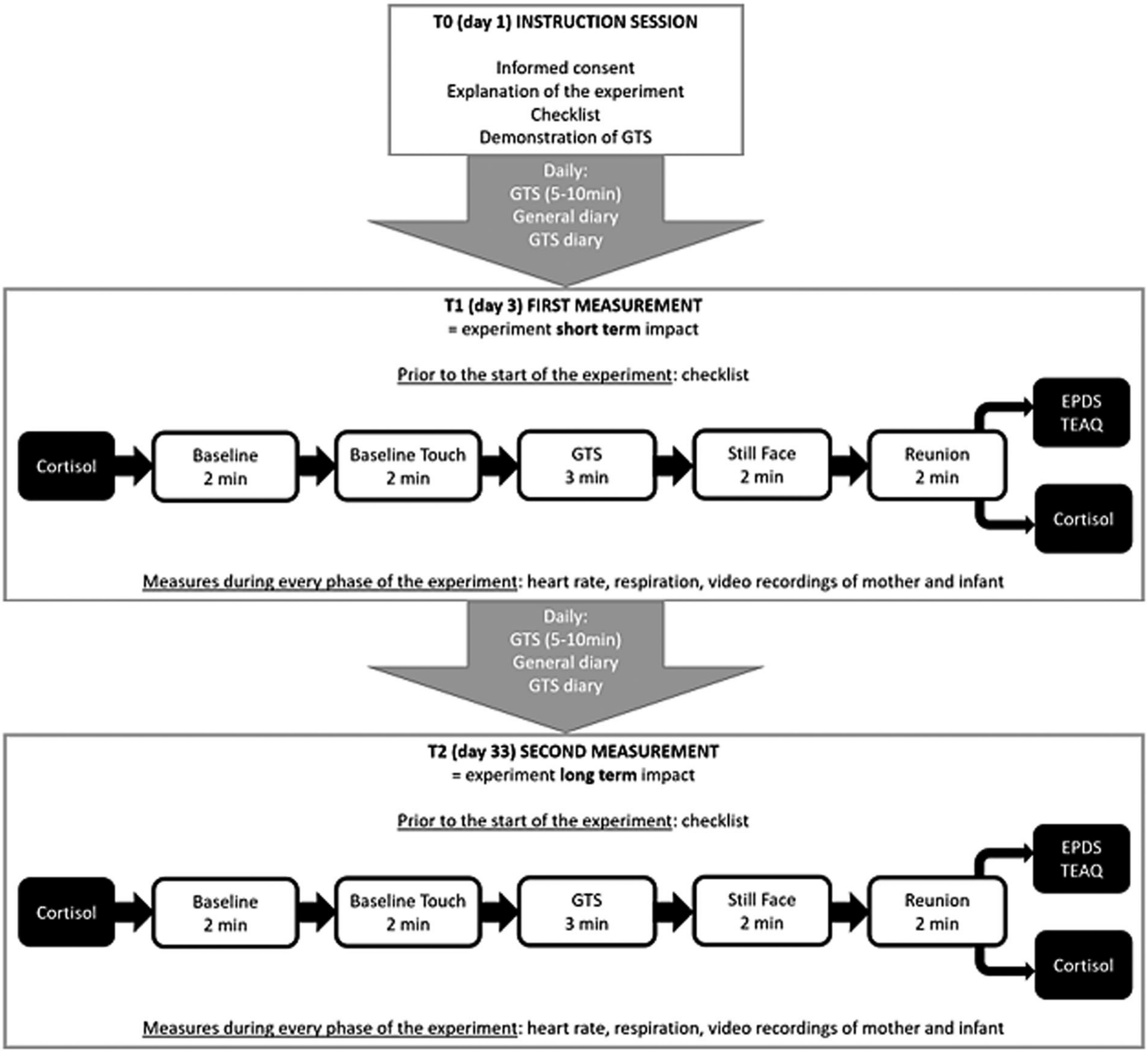

FIGURE 1 Overview of the 4-weeks design of the gentle Touch Stimulation (GTS) program

GTS-intervention and provided a video that showed the GTS on a doll, showing the CT-afferent optimal zones and how to apply gentle stroking rather than a pressure massage.

After this first information session, the same day mothers started the GTS program. They were instructed to apply GTS 10 min per day, preferably at the same time and to complete the GTS diary after each GTS session, and the general diary at the end of the day. The first measurement took place on day 3 (T1) and the second on day 33 (T2). The 3-day period before T1 was foreseen to minimize the first novelty effects. Between T1 and T2, the mothers daily provided GTS to their infant and completed the diaries.

The data were collected during home visits to maximize the ecological validity of the experiment. The mothers were asked to control the room temperature at 22–24°Celsius in accordance with the recommendations for the best practices for healthy neonate skin care (Blume-Peytavi et al., 2016). The mothers were instructed to neither bath the infant, nor use body-lotions on the day of the experiment to avoid confounding effects on the GTS impact (e.g., Argawal et al., 2000). To avoid interference with the cortisol saliva sampling, the mothers were not allowed to eat or drink 1 h prior to the experiment, apart from water, and the infants 10 min prior to the experiment (Salimetrics, LLC). T1 and T2 were planned about similar clock times as cortisol levels vary according to the circadian cycle (Krieger et al., 1971).

During T1 and T2, mother-infant ECG and respiration were monitored during all the experimental conditions, that is, a no-touch-baseline (BL), static-touch-baseline (BL-T), intervention/control (GTS/CTRL), Still Face (SF) and Reunion (RU) condition at the start (T1) and end of (T2) of the program to analyze cardiorespiratory parameters. Cortisol saliva sampling was done in both mothers and infants before the experiment and 20 min after the experiment to measure stress reactivity. Besides, video recordings were made for behavioral micro-analyses of regulation and arousal in the infant (see Figure 1). More detailed, after setting up the mobile testing lab, the mother-infant saliva samples were collected for cortisol assay and the mother was asked to undress the infant except from the diaper. Subsequently, the electrodes and respiratory belts were attached, and the mother was asked to place the infant laying down on its back in front of her. During BL, mothers were asked to sit quietly with their infant while making eye contact for 2 min. When the infant asked attention, they could calmly respond to it (to avoid a still-face situation), but they could not initiate any interaction by singing, talking, and so on (Van Puyvelde et al., 2014, 2015, Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019). The BL-T condition was similar to the BL, except that the mothers touched their infant in a static non-stroking manner. During the GTS condition, mothers applied the GTS as they were used to do during the last 2 days (T1) or last 4 weeks (T2). After 3 min, the experimenter instructed the mother to start the SF. She was asked to gaze at her infant with a neutral facial expression for 2 min and to not respond to eventual attempts of the infant to elicit interaction. Finally, after 2 min, the mother was asked to retain contact and to interact during the RU and to sooth her infant when necessary. The researcher, who remained at the background, timed each phase, and gently instructed the mother to transfer to the next condition. Apart from that, there was no contact between the mother and experimenter. When the experiment finished, the second saliva sample was collected from mother and infant 20 min after the SF condition (e.g., Engert et al., 2011; Feldman et al., 2010). Dyads in the CTRL condition did not conduct the GTS intervention, but had a quiet interaction with their infant.

1.6 | Physiological signal analysis

The ECG and respiration signals were visually examined for artefacts and (in)correct detections. Ectopic heartbeats or erroneous detections were manually corrected by removal or making a cubic spline interpolation (corrections < 1%). Other undesired signals in the physiological data, such as talking, sneezing, crying, and so on, were removed in accordance with the inspection of the video recordings. For each testing phase, the RR-interval (RRI), respiration frequency (*f*R) and RSA of mother and infant were calculated. RRI was generated based on the timing of the detected R-waves. Respiration rate was used to calculate *f*R in each condition, and RSA was determined using the peak-valley method (Grossman et al., 1990). This implies a calculation of the mean difference between the longest heart period, associated with expiration, and the shortest heart period, associated with inspiration, for each respiratory cycle. The VivoSense software possesses algorithms corresponding to the advised standards of Grossman et al. (1990) and Grossman et al. (1991). For the calculations with the infant, ECG RR-lockout period for R-wave picking was adjusted to .1 and minimum tidal volume to 10–30 ml. In agreement with Grossman et al. (1990), inspiratory and expiratory windows were moved forward to 750 ms to accommodate to phase shifts occurring between heart period and respiration rate (e.g., Eckberg, 2003). The VivoSense R-wave detection and the RSA calculation account for violations of the Nyquist criterion (i.e., the requirement for the sampling rate to be twice as high as the frequency of interest) (see Van Puyvelde et al., 2015).

1.7 | Cortisol analysis

Within 24 h after saliva collection, the swabs were stored at −80°Celsius (Salimetrics, LLC). The saliva swabs were transported to the RIA-laboratory of UZ Brussel, to assay the amount of cortisol, displayed in μg/L. When thawed, the salivettes were centrifuged for 15 min at 4°C x 1000 g. The levels of cortisol were tested with a commercial ELISA kit (Assay Design, MI, USA) and measurements were done according to the instructions on the kit. The calculations of cortisol levels were done using MatLab-7 in conformity with the relevant standard curves.

1.8 | Video analysis

1.8.1 | Coding system for multimodal regulation and arousal responses during still-face

The coding system of the current study was an integration of former observation schemes of Manini et al. (2013) to code arousal, Weinberg and Tronick (1994) to code regulatory infant behaviors and Bigelow (Bigelow & Power, 2012; Bigelow & Power, 2016) to code social bid behavior (see Table 1 for an overview of the nine observation categories with a brief behavioral description).

1.8.2 | Coding and inter-rater reliability

We processed inter-rater reliability of two coders on a random 20% of the recordings after a training process with regular cross-checking. These training videos were not included for data-analysis. The two coders did allow a 1 s deviation on the agreement of the start or ending of a coded

TABLE 1 Coding system for multimodal regulation and arousal responses during still-face

Category	Code	Type of regulation	Behavioral description
No regulation No arousal	0	No	Neutral or positive (smiling) facial expressions slow non-goal-directed movements of limbs
Regulation	1R	Internal	Neutral or positive (smiling) facial expressions with one of the following behaviors: • turning away from mother, reaching for another insignificant object or itself, gazing to another insignificant object, staring into space • covering or touching face with arms or another object • hugging the body • putting fingers in mouth or lower lip is rolled in • yawning
Social bid	1SB	External	Neutral or positive (smiling) facial expressions while gazing at the mother + reaching towards mother/ positive or neutral vocalization/ laughing
Regulation and social bid	1RSB	Internal + External	Minimum one behavior of 1R and 1SB simultaneously or back-to-back
Arousal with regulation	2R	Internal	Negative facial expressions (anger, sadness, disgust, distress, cry or grimace faces) or tearful (pre-crying) with one of the following behaviors: • withdrawing from mother and/or situation, reaching for another insignificant object or itself, gazing to another insignificant object • covering or touching face with the arms or an object • hugging the body • putting fingers in mouth or lower lip is rolled in • yawning
Arousal with social bid	2SB	External	Negative facial expressions or tearful (pre-crying) while looking at the mother + reaching towards mother/ negative vocalization
Arousal with both regulation and social bid	2RSB	Internal + External	Minimum one behavior of 2R and 2SB simultaneously or alternating
Arousal without regulation	3	No	Randomly pronounced movements; Back arching; Moment before crying
Distress	4	No	Crying

Note: descripted behaviors partially based on Bigelow and Power (2012) and Bigelow and Power (2016), Manini et al. (2013), Weinberg and Tronick (1994).

period. A high averaged kappa inter-rater reliability of .83 (Cohen's κ) was reached.

1.9 | Statistical analysis

For all the conditions (i.e., BL, BL-T, GTS/CTRL, SF, RU), we calculated the proportional changes (PC) from the baseline (100%) and this for every RSA, RRI and *f*R values as a reactivity score through the conditions. For cortisol, the PC from pre-experiment to post-experiment were calculated. In a proportional change, any number larger than 1 is considered as a positive change with regard to the reference value (BL) and a deviation smaller than 1 as a negative change with regard to the reference value. All data were inspected for outliers based on z-standardizations (z = +/- 2.56). The assumption of normality, homogeneity and sphericity using the Mauchly's test were controlled. When the assumption of sphericity was violated, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity (ε). An alpha level of .05 was used for tests of significance.

For the cardio-respiration, in both mother and infant, three 5 × 2 (condition [BL, BL-T, GTS/CTRL, SF, RU] x group [GTS, CTRL]) mixed ANOVAs were calculated at T1 and T2, with condition as within and group as between subjects factors, and PC-RSA, PC-RRI and PC-*f*R as dependent variables. For cortisol, a 2 × 2 (time [T1, T2] x group [GTS, CTRL]) mixed ANOVA was calculated to compare the PC-pre/post of T1 with T2 in both groups. The effect size in the mixed ANOVA analyses was defined by the partial eta squared (η_p^2). The usual cut-offs to interpret η_p^2 are .01, .06 and .14 for, respectively, small, mediocre and large effect sizes (Cohen, 1988). Extra evaluations of the mixed ANOVA analyses using pairwise comparisons with the critical *p*-value for significance adjusted with the Bonferroni correction.

For the diaries, we first calculated a mean week score per mother per response category. Since the largest part of the diary variables were not normally distributed, we could not use mixed ANOVAs. We conducted therefore per group (GTS/CTRL) a repeated measure Friedman test with week (W1, W2, W3, W4) as repeated measure and the reported scores as dependent variables for the non-normally distributed data and the repeated measures ANOVA equivalent for the normally distributed data.

2 | RESULTS

2.1 | Cardio-respiratory data

Raw data

An overview of the raw physiological data of the mother and the infant groups in T1 and T2 can be found in the supplementary data section (Table S1).

PC-RSA reactivity

In the infants, at T1, there was a significant main effect of condition on PC-RSA, $F(4, 88) = 4.62$, $p = .002$, $\eta_p^2 = .17$. PC-RSA significantly decreased from BL-T ($M = 1.09$, $SD = .06$) to SF ($M = .84$, $SD = .07$), $p = .012$, Bonferroni corrected. There was no interaction effect, $F(4, 88) = 1.71$, $p = .155$, $\eta_p^2 = .07$. At T2, there was a significant interaction effect between condition and group in PC-RSA, $F(4, 88) = 2.61$, $p = .041$, $\eta_p^2 = .11$. There were significant differences between both groups in their responses from BL to GTS/CTRL, $p = .027$, from BL to SF, $p = .035$ and from SF to RU, $p = .007$. The PC-RSA increases during RU were larger in the GTS group than in the CTRL group. During the RU, GTS infants showed a recovery with PC values > 1.0 (see Figure 2).

In the mothers, at T1, there was a significant main effect of condition on PC-RSA, $F(2.35, 37.64) = 3.77$, $p = .026$, $\eta_p^2 = .19$, with a significant contrast between the BL ($M = 1$, $SD = 0$) and SF conditions ($M = 1.45$, $SD = .78$), $p = .030$, that was, however, not confirmed by Bonferroni post-hoc corrections. There was no interaction effect, $F(2.35, 37.64) = .80$, $p = .476$, $\eta_p^2 = .05$. At T2, there was no main effect of condition on PC-RSA, $F(2.17, 28.16) = 2.32$, $p = .113$, $\eta_p^2 = .15$, and no interaction effect, $F(2.17, 28.16) = .29$, $p = .769$, $\eta_p^2 = .02$ (see Figure 2).

PC-RRI reactivity

In the infants, at T1, there was a main effect of condition on PC-RRI, $F(2.93, 70.36) = 4.56$, $p = .006$, $\eta p2 = .16$. PC-RRI significantly decreased from BL ($M = 1$, $SD = 0$) to RU ($M = .95$, $SD = .07$), $p = .024$, Bonferroni corrected. There was no interaction effect, $F(2.93, 70.36) = .35$, p = .788, $\eta p2 = .01$. At T2, there was a main effect of condition on PC-RRI, $F(2.20, 48.38) = 4.83$, $p = .010$, $\eta_p^2 = .18$. PC-RRI significantly decreased from BL ($M = 1$, $SD = 0$) to SF ($M = .96$, $SD = .01$), $p = .030$, Bonferroni corrected and from BL-T ($M = 1.02$, $SD = .01$) to SF, $p = .023$, Bonferroni corrected. The difference between both groups during SF visible on Figure 2, was marginally significant, $p = .051$. There was, however, no interaction effect, $F(2.20, 48.38) = 1.18$, $p = .321$, $\eta_p^2 = .05$ (see Figure 2).

In the mothers, at T1, a significant main effect of condition on PC-RRI was found, $F(2.37, 59.27) = 4.51$, $p = .011$, $\eta_p^2 = .03$, with a significant contrast between the BL ($M = 1$, $SD = 0$) and GTS/CTRL condition ($M = .93$, $SD = .08$), $p = .001$, confirmed by the post hoc Bonferroni corrections, $p = .005$ and between the GTS/CTRL ($M = .93$, $SD = .02$) and SF ($M = .99$, $SD = .02$) conditions, $p = .018$. There was no interaction effect, $F(2.37, 59.27) = .79$, $p = .476$, $\eta_p^2 = .03$ (see Figure 2).

PC-fR reactivity

In the infants, at T1, we found no main effect of condition on PC-fR, $F(4, 88) = .86$, $p = .494$, $\eta p2 = .04$, p = .318 and no interaction effect, $F(4, 88) = .68$, $p = .606$, $\eta p2 = .03$. At T2, there was a significant interaction effect between group and condition, $F(2.21, 48.64) = 7.33$, $p = .001$, $\eta_p^2 = .25$. There were significant differences between both groups in their responses from BL to BL-T, $p = .003$, to GTS/CTRL, $p < .001$, and to RU, $p = .001$, with the GTS group reacting with lower PC-fR values than the CTRL group. The lower values in the GTS-infants were confirmed by a significant between-subjects effect, $F(1, 22) = 13.361$, $p = .002$, $\eta_p^2 = .36$ (see Figure 2).

In the mothers, at T1, there was a main effect of condition, $F(4, 88) = 4.00$, $p = .006$, $\eta_p^2 = .21$, that was, however, not confirmed by Bonferroni post-hoc testing. At T2, the mother group showed a main effect of condition on PC-fR, $F(4, 88) = 3.89$, $p = .007$, $\eta_p^2 = .22$. Bonferroni post hoc tests indicated that there was a significant difference between the SF ($M = .91$, $SD = .08$) and RU ($M = 1.12$, $SD = .07$) conditions, $p = .021$, with lower respiratory frequencies during SF versus BL (see Figure 12). There was no significant interaction effect between condition and group, $F(4, 88) = 1.73$, $p = .155$, $\eta_p^2 = .11$ (see Figure 2).

2.2 | Cortisol reactivity

The raw cortisol data can be found in the supplementary section (see Table S2). In the infants, there was a significant interaction effect between time and group on the cortisol PC-values, $F(1,17) = 5.861$, $p = .027$, $\eta p^2 = .26$. Whereas CTRL infants at T1 did not show a difference between pre and post experimental measurement, they showed in

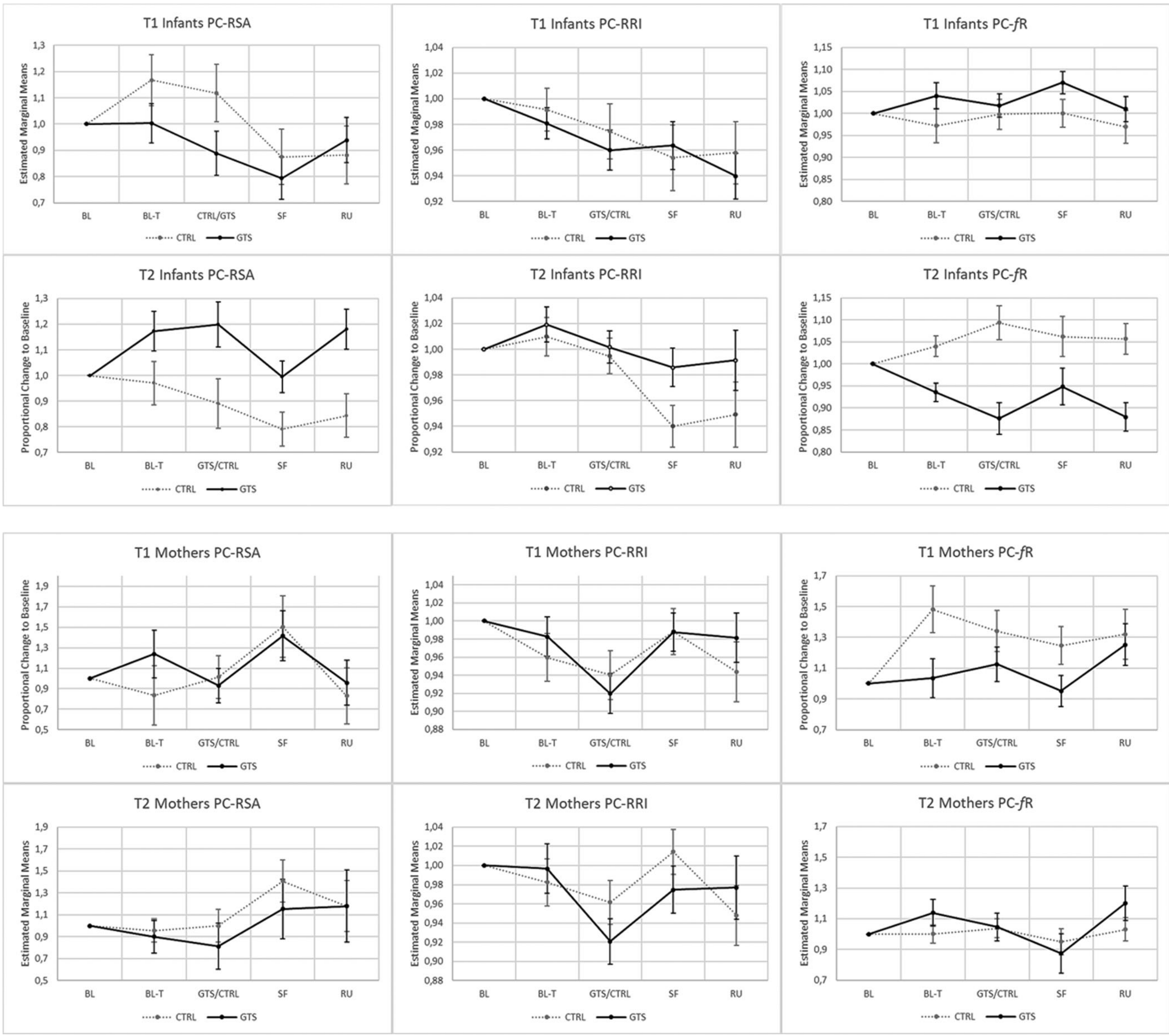

FIGURE 2 Overview of RSA, RRI and *f*R during the five within-subject conditions, that is, BL, BL-T, GTS/CTRL, SF, and RU of the GTS-infants/GTS-mothers and CTRL-infants/CTRL-mothers. In the infants, there were no significant interaction effects between group and condition at T1. At T2, significant interaction effects showed an increased respiration-driven parasympathetic regulation that buffered against SFP-related stress in GTS-infants compared to CTRL-infants. Moreover, GTS-infants recovered with a reset to the levels measure during GTS, whereas CTRL-infants did not show this recovery, their physiological levels remained under initial BL-levels. In the mothers, only the lower *f*R values during SF were confirmed by Bonferroni post-hoc tests

T2 an increased cortisol after the experiment in comparison with the pre-measurement. The GTS infants, at the contrary, showed a large increase of cortisol from pre to post measurement at T1, but a decrease in cortisol from pre to post experiment in T2 (see Figure 3). There was no between subjects effect, $F(1,17) = .240$, $p = .630$, $\eta p^2 = .01$. The mothers showed no significant main effect of time, $F(1,21) = 1.74$, $p = .201$, $\eta p^2 = .08$, no between-subjects effect, $F(1,21) = 1.74$, $p = .202$, $\eta p^2 = .08$, and no interaction effect, $F(1,21) = 2.59$, $p = .123$, $\eta p^2 = .11$ (see Figure 3).

2.3 | Infant video micro analyses of the SF-phase

For the video-analyses non-parametric tests were used due to non-normal distribution. Wilcoxon signed-rank tests showed that there were significant differences from T1 to T2 for 1SB%, $T = 49$, $p = .028$, $r = .37$ (T1: *Mdn* = 0; *IQR* = 1.82; T2: *Mdn* = 3.69; IQR = 7.77); for 2RSB% $T = 28$, $p = .018$, $r = .41$ (T1: *Mdn* = .00; *SD* = .00; T2: *Mdn* = 1.19; *IQR* = 1.97) and for 2RSB mean duration, $T = 28$ $p = .018$,

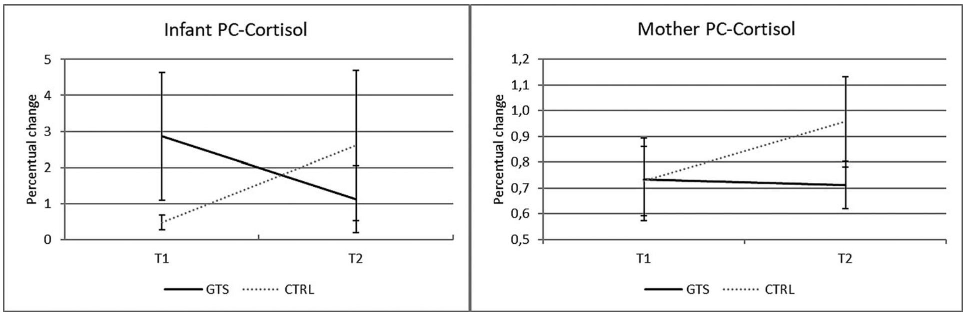

FIGURE 3 Overview of the PC-values during T1 and T2 in the mothers and the infants, showing a non-significant tendency to mirror the infant stress

r = .41 (T1: Mdn = .00; SD = .00; T2: Mdn = .78; SD = 1.02). The Mann-Whitney's U statistics indicated that this change between T1 and T2 was due to an increase within the CTRL group. There was a significant difference between CTRL and GTS at T2 for 2RSB number of moments, U = 33, z = −2.399, p = .031, r = -.49; for 2 RSB %, U = 30, z = −2.533, p = .019, r = -.51 and for 2RSB mean duration, U = 31, z = −2.489, p = .022, r = -.51. There was no significant difference between CTRL and GTS at T2 for 1SB%, U = 49, z = −1.263, p = .235.

2.4 | Maternal subjective reports

An overview of the mothers' general diary reports and the GTS diary reports with the week-means and standard deviations and repeated measures ANOVA or Friedman repeated measures for normally and non-normally distributed data, respectively, can be found in the supplementary data section (see Tables S3 and S4). The results showed that reported infant comfort after GTS, F(1,36) = 4.746, p = .007, η_p^2 = .28 and interaction after GTS, $\chi^2(3)$ = 8.5, p = .037 significantly increased from week 2 to week 3 (p = .046), Bonferroni corrected.

3 | DISCUSSION

In the current study we aimed to study the impact of a daily 10-min GTS during 4 weeks on 3–12 weeks aged infants. We compared the physiological and behavioral responses during a BL, BL-T, GTS/CTRL, SFP and RU condition of the GTS infants with a control group that did not receive the GTS program. We measured once in the very start of the program (T1) to have a baseline and once at the end of the program after 4 weeks (T2). We analyzed cardio-respiratory parameters and cortisol of both the mother and the infant, conducted a video micro-analysis of the infants' behavioral regulation and arousal responses and overviewed maternal subjective reports collected by diaries. We expected a short-term phasic response at T1 in both groups that would not buffer against stress induced by the SFP. At T2, after 4 weeks of GTS in the experimental group, we expected that an association between GTS and regulation would be established in the GTS group resulting in a stress buffer during the SFP. We did not expect a similar effect of stress buffering in the CTRL group.

At T1, there was no difference in cardio-respiratory reactivity between GTS and CTRL infants in response to the experimental conditions. In both groups, the infants showed a clear arousal to the SFP, with significant decreases in RSA during the SF-phase in comparison with BL-T and significant increases in HR that continued during the RU-phase. Respiration remained stable during the experiment, pointing to a pure parasympathetic withdrawal in reaction to the SFP. Contrary to our hypothesis and previous studies that demonstrated an immediate parasympathetic regulatory response of infants to gentle stroking touch studies (Fairhurst et al., 2014; Van Puyvelde et al., 2015; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019), we did not observe increased parasympathetic regulation during the GTS/interaction condition. However, there was a difference between the manner of stroking in the current study compared to the previous studies. For instance, in Van, Gorissen Puyvelde et al. (2019), Van, Collette Puyvelde et al. (2019) the mothers were instructed to stroke their infant intuitively as they would normally do on one body location in a manner that felt natural to them. The current GTS-method comprised a full-body structured (i.e., the mothers followed a body-scheme) "massage-like" stroking touch that impacted the entire body. This experience was new both for the mothers and the infants and it has already been reported before that infants need to familiarize to and may feel uncomfortable in the beginning of a massage training program (Glover et al., 2002). This need for habituation was also reported by the mothers in the diaries; the comfort during and after the GTS-application appeared to be well established only at week 3 of the program. The results at T1 are interesting from a methodological point of view because they show

how fast the infant's physiological state can destabilize when situational circumstances deviate. This may explain certain unexpected results in infant experiments that were conducted in a laboratory context in place of the ecological infant environment as reported previously by Pirazzoli, Lloyd-Fox, Braukmann, Johnson and Gliga (2018).

At T2, our hypothesis was confirmed. After 4 weeks GTS, the responses between both groups were significantly different. The infants in the GTS group reacted with an increased parasympathetic regulation from the BL to the GTS condition, which we ascribe to an established association between GTS and regulation that has been built through the 4 weeks of GTS. We suggest that, once the association is established, CT-optimal touch evokes stronger responses and thus more regulation than when this association has not been established. The CTRL-infants did show a parasympathetic withdrawal at that point. Consequently, the GTS-infants entered the SF-phase with a small lead or advantage in regulation on their CTRL-opponents. The SF-induced vagal withdrawal that occurred then in both infant groups, resulted in a reset to the initial BL-levels for the GTS-infants, whereas the CTRL infants showed a steeper withdrawal under the initial BL-levels. This is a clear illustration of autonomic flexibility (Friedman, 2007), needed to shape resilience or allostasis (McEwen, 1998). That is, a higher initial parasympathetic response creates a reservoir for more autonomic flexibility and inhibition subsequently. Consequently, during RU the GTS-infants showed a fast recovery with RSA-levels that reached again the RSA-levels of the GTS-condition (hence above initial BL-levels) whereas the CTRL-infants were not able to make up their arrears, not reaching even their initial BL-levels anymore.

We suggest that two processes may be at work, reinforcing one another. At the one hand the establishment of the association between GTS and parasympathetic regulation due to the structured recurrent provision of GTS over 4 weeks that may reflect a tonic regulatory long-term response and at the other hand a short-term phasic response acutely evoked by the GTS provided at the time of measurement. We propose that the short-term response may activate previous established associations—as if the body "memorizes" previous experiences—and that vice versa an established association may reinforce the strength of a short-term acute response to a similar stimulus. The current design, however, did not allow to disentangle both processes. To examine whether a long-term association may be established independent from a phasic short-term response, a replication study should test the impact of an SFP on both GTS and CTRL infants without a preceding interaction or GTS intervention at the experimental test moment.

Several physiological events were indicative of both processes to be present. Firstly, in favor of a long-term tonic responses, the GTS infants showed increased raw values from T1 to T2 whereas this was not the case in the CTRL group. Secondly, there was also a significant difference in *f*R between both groups at T2 that was not present at T1, possibly pointing to a faster maturation of respiratory reactivity in GTS infants than in CTRL infants. During the first weeks of life, a dramatic maturation in the respiratory correlates of an infant occurs. Infants not only have to learn to regulate the breathing (Finley & Nugent, 1983; Giddens & Kitney, 1985) but also to integrate it as a well-functioning part of the neurovisceral system (Ritz et al., 2012; Van Puyvelde et al., 2015). Hence, the combined *f*R-decrease and RSA-increase may reflect this maturation in the GTS group. However, the fact that down-regulation of arousal in the GTS infants was strongly respiration driven is also in favor of a short-term phasic response since previous studies suggested a role for respiration in phasic adjustments to the environment, both in infants (Van, Collette Puyvelde et al., 2019) and adults (Pattyn et al., 2010). The GTS-infants showed an immediate regulatory effect in their respiration during BL-T and GTS. The SF-phase elicited an increase in *f*R again, pointing to the arousing situation, that was, however, still significantly lower than in the CTRL-group and that recovered—just as it was the case with the RSA/RRI-values—again to the GTS-values. Both the short-term and long-term effect have been showed in previous research as well. In favor of a short-term mechanism, some studies (Feldman et al., 2010; Stack & Muir, 1992) showed a better recovery after an SFP during which touch was allowed. In favor of a long-term effect, Walker et al. (2020) reported an increased resilience to a stress test in rodents that received for 2 weeks daily 10 min of stroking touch. Further, Sharp et al. (2012) found that the amount of maternal stroking as reported by the mothers throughout the first weeks of life predicted infants' physiological stress reactivity to a stressor at 29 weeks of age.

The infant cortisol analyses supported the cardio-respiratory findings with opposite reactivity patterns in the GTS versus CTRL group. Whereas infants in the GTS group showed an initial bigger stress reactivity at T1 and recovery at T2, the CTRL infants showed the inverse. In the mothers, the cortisol should be interpreted in relation to the cardio-respiration. Although non-significant, their reactivity showed a tendency to mirror the infant cortisol, certainly in the CTRL-group. Hence, the mothers may have empathized with the sympathetic infant arousal, which may have stimulated their eagerness to invest in the recovery of their infant consuming cardiorespiratory metabolic energy. Nevertheless, the cortisol results should be interpreted with caution due to the small sample. As it has been reported in previous studies (e.g., Bettendorf et al., 1998; Herrington et al., 2004), saliva collection from young infants less than 3 months old often results in insufficient specimen volume which might be due to the infant parotid's glands having low fluid production rates (Granger et al., 2007). Moreover, the timing of saliva sampling in a multi-condition design as in the current study is delicate. We applied the second sampling 20 min after the SFP procedure as advised in the literature (Engert et al., 2011) and previous infant studies (e.g., Feldman et al., 2010).

We hypothesize that stimulation of the mechanosensitive CT-afferents underpinned the observed physiological responses in the present study. It has already been suggested that CT-afferents may be the missing link between affective touch and the development of physiological and emotional self-regulation (Van, Gorissen Puyvelde et al., 2019). Besides the demonstrated impact on parasympathetic regulation (Fairhurst et al., 2014; Van, Gorissen Puyvelde et al., 2019; Van, Gorissen Puyvelde et al., 2019), CT-optimal gentle stroking touch has been shown to activate regions in the posterior insular cortex and the mid-anterior orbitofrontal cortex (e.g., Gordon et al., 2013; Jönsson et al., 2018; Olausson et al., 2002; Tuulari et al., 2017) but also to stimulate myelinization processes in the prefrontal cortex which is important in the building of resilience at the long-term (Cathomas et al., 2019). Moreover, stroking touch was linked with oxytocin release in both adults (e.g., Light et al., 2005; Turner et al., 1999) and infants (e.g., Matthiesen et al., 2001) and oxytocin has been shown to down-regulate cortisol release after a stress event (Ditzen et al., 2009). Also specific within a parent-infant context, parent-infant synchrony and affective touch at 6 months of age was predicted by parental oxytocin sampled 4 months earlier and was related with lower cortisol levels in the mother (Gordon et al., 2010). Hence, all of these studies do support the current findings and are highly suggestive of CT-afferents—as the neurobiological basis of affective touch—to be a moderator within the development of physiological and emotional self-regulation as a precursor for resilience.

The mothers' cardio-respiration showed a reversed pattern to that of their infants, both at T1 and T2, showing increased RSA, RRI and decreased *f*R during the SF-phase and decreased RSA, RRI and increased *f*R during RU. These results correspond with previous findings (Ham & Tronick, 2006; Hill-Soderlund et al., 2008; Moore, 2009). Moore (2009) argued that a physiological dysregulation can be functional for the dyadic goal. They found that after an SF-phase larger decreases in mothers' RSA corresponded with higher behavioral synchrony. Indeed, when mothers are investing with great effort in the recovery of their infant, this implies a great metabolic demand which influences the cardio-respiration (Bazhenova et al., 2001; Ritz et al., 2012; Van Puyvelde et al., 2014, 2015). The decrease in RSA is thus an expression of investment in the relationship underpinned by metabolic changes. Reversed regulation patterns can thus be adaptive (Ham & Tronick, 2006; Moore, 2009; Moore & Calkins, 2004) and associations between physiological synchrony and behavioral synchrony are situational-dependent (Van Puyvelde et al., 2014).

The video micro-analyses of multimodal infant regulation and arousal responses during the SF-phase revealed one small mechanism, that is, the mixed category of combined internal regulation and social bid responses, 2RSB. Although its occurrence was very short and seldom, it was significantly more present in the CTRL group. This ambiguous behavioral expression of withdrawal and approach is comparable with the disorganized behavior described by Tronick et al. (1978) during an SFP but on micro-level. Tronick et al. (1978) explained ambiguous infant behavior during the still-face as a stress-full mirroring of the contradictory behavior at the mother's side; what he called "communicating Hello and Good-bye simultaneously" (Tronick et al., 1978, p.11). We believe that the reason we did not observe this behavior at T1 is age-related. At T2, the infants were already more habituated to the contingency patterns with their mother, and thus potentially more disturbed by the interruption of it but also more capable to respond to it.

This study had several shortcomings and strengths. The most important minor point was the small sample size due to dropouts and missing values. Hence, the study needs replication in a larger sample. Moreover, an extra condition with an isolated SF-test should be included to disentangle short-term and long-term effects. Secondly, saliva sampling in infants remains difficult to complete. We lost infant samples due to a lack of saliva and the timing within a multiple conditions design may be questionable. Thirdly, research in infants' regulatory capacities has reported temperament as a possible influencing factor for differences in sensitivity to arousal and coping style (Compas, 1987). Hence, in future studies, temperament could be controlled, for instance by using the Infant Behavior Questionnaire (Rothbart, 1981). An advantage of the current study was its multidisciplinary in-depth approach to increase insight in the different layers of the development of infant resilience; however, this type of research is very time-consuming both in the data-collection and analysis. Further, we chose to conduct the experiments T1 and T2 at the mothers' home to preserve the infant's ecological context (Van Puyvelde et al., 2015; Van, Gorissen Puyvelde et al., 2019; Van, Collette Puyvelde et al., 2019), being an important part of the targeted developmental sensitization processes to CT-optimal touch. Finally, for cardio-respiration, we registered both the ECG and respiration which offered us insight in the respiratory drive that evolved over the 4 weeks in the GTS-infants.

Increased respiratory control is an important expression of the autonomous maturation of the infant and should thus be considered in infant developmental research.

The findings of the present study are serendipitously germane at this current time in human history. The Covid-19 pandemic has been depriving a large part of the world-population from social touch (Durkin et al., 2020) and risks to turn our future society into a touch-poor and masked copy of the prior one. It is therefore of extreme importance that we do not forget the crucial impact of touching and being touched. The current results may also be of importance for maternal postnatal depression and treatment programs on a dyadic level. Several studies linked the SFP to maternal depression and its impact on infants (e.g., Tronick & Reck, 2009). In mothers suffering from maternal depression, the maternal-infant communication risks to be non-contingent, comparable with a still-face situation (Papoušek, 2007; Tronick & Reck, 2009) and touch deprivation has been reported (Field, 2010). Former touch-stimulating interventions have already shown to facilitate mother-infant bonding (e.g., Glover et al., 2002) and relationships between maternal stroking, maternal depression and the emotional and physiological development of the infant have been demonstrated as well (Pickles et al., 2017; Sharp et al., 2012). The current study added an additional puzzle piece of evidence that daily stroking GTS impacts the different layers of the development of infant resilience.

In summary, we observed a beneficial impact of a 4-weeks daily infant GTS on infants' physiological and behavioral self-regulation and resilience to stress during an SFP. Compared to CTRL-infants, GTS-infants showed an increased respiration-driven parasympathetic regulation that buffered against SFP-related stress. We suggest that within this observed regulation, both short-term and long-term response processes are at work. Cortisol measures supported a better recovery in GTS-infants and a behavioral micro-analysis showed ambivalent stress responses during the SF-phase in the CTRL infants that were not observed in the GTS-infants. We believe that these results provide empirical evidence to answer the question "why we hunger for touch?".

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