Affiliative Touch and Emotion Regulation

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1. Aims

In recent years a class of nerve fibre has been identified which respond optimally to gentle, slowly moving (approx. 3cm/second) touch, typical of a caress (Vallbo et al 1999). The 'Social Touch Hypothesis' posits that this C-tactile afferents (CT) system of nerves has evolved in mammals to signal the rewarding value of physical contact in nurturing and social interactions, providing a neurobiological basis for the formation and maintenance of social bonds and attachment relationships (Morrison et al 2010). The CT system has also been suggested as playing a significant role in the way in which physical contact acts to buffer against stress responses throughout the lifespan (Morrison 2016), however the majority of evidence cited in support of this theory currently comes from animal and not human research (McGlone Wessberg & Olausson 2014). The aim of this project was to test this hypothesis by exploring whether selective stimulation if this class of unmyelinated, mechanosensitive nerves, found only in hairy skin and responding optimally to gentle stroking touch, provide an innate sensory signal cueing the presence of social support, thereby aiding emotion regulation and buffering individuals from stress.

2. Experiment 1

Are trait differences in physiological arousal, as indexed by resting state heart rate variability (HRV), predictive of affective responses to CT optimal stroking touch? A preference for CT optimal touch is predicted for all participants, however those participants with relatively higher-HRV-HF (higher vagal tone), associated with enhanced sensitivity to social cues (Quintana et al 2012), are hypothesised to show greater preference for CT optimal over non-CT optimal stroking speeds, as well as a larger positive affective response, demonstrated by greater increases in m.zygomaticus activity and relaxation of m.corrugator.

2.1 Methods

2.1.1 Participants

45 participants (29 female / 16 male; mean age = 21.6 years, SD = 2.8 years) were recruited between November 2015 and January 2016.

2.1.2 Instruments & Measures

Heart Rate Variability (HRV): Inter-beat intervals from an Electrocardiogram (ECG) were analysed in the frequency domain to provide a measure of HRV. High frequency HRV (HRV-HF) activation indexes the influence of the Parasympathetic Nervous System (PSNS), or vagal nerve innervation of the heart, with greater vagal influence (vagal tone) resulting in increased HRV-HF. Vagal tone exerts an inhibitory effect on Sympathetic Nervous System (SNS) excitation of the heart.
Facial Electromyography (EMG): Emotional facial expressions result from the contraction of different combinations of facial striated muscle. Electrical activity resulting from muscle activity can be recorded from skin sites close to the muscles, providing a direct index of emotional experience. Stronger muscular contractions result in more extreme facial expressions and increased electrical amplitude. This technique is a validated correlate of implicit affective stimulus appraisal. Recordings from the cheek (m.zygomaticus major) and brow (m.corrugator supercilii) can differentiate between positive and negative stimuli, including facial expressions and valenced images.
Rotary Tactile Stimulator (RTS): A computer controlled robot designed to deliver a dynamic tactile stimulus with precise timing, velocity, and force was used to measure the effects of CT optimal versus CT non-optimal touch on psychophysiology and behaviour, in the absence of any confounding

factors of social context. Ratings demonstrating preference for CT optimal speeded touch delivered by the RTS have been reported in previous studies (eg Essick et al 2010).

Cognitive Tasks: Three cognitive tasks were used to test executive function. The first of these was a simple reaction time task. Participants watched for the appearance of a dot in the centre of the screen. Whenever a dot appeared, the participant was tasked with pressing a response key as quickly as possible. There were 50 trials in total. The second tasks was a choice reaction time task, where the participant watched the appearance of a stream of letters that appeared one by one, centrally on screen. The participant pressed a response key as fast as they could do whenever they saw the letter 'E', pressing nothing in response to other letters. There were 100 trials in total, of which 20 contained the letter 'E'. The final task was a serial memory reaction time task. Here the participant watched a stream of centrally presented numbers appearing one by one. The participant's task was to press a response key as fast as they could do, whenever they saw a number that was 1 smaller in value than the previous number had been. There were 100 trials in total, and the participant was required to respond on 20 of them. For each task the participant's reaction time was recorded if their response was a valid press to a target. Their accuracy was recorded, as misses on the simple reaction time task, and as a combination of misses and false alarms of the latter two tasks. These tasks were included to replicate the work of researchers such as Thayer et al (2009), whose theories relating to vagal tone were influential in the formation of the proposed research.

2.1.3 Procedure

Participants were fitted with an ECG as well as a breathing rate transducer and EMG sensors, placed over the zygomaticus and corrugator muscles. Each participant's resting ECG was taken while they watched a 5 minute, relaxing video of sea life. From this resting HRV was derived, providing an index of baseline levels of physiological arousal for each participant. Next, participants completed a touch rating task. The RTS delivered precisely speeded touch to the inner surface of the participant's forearm. The speeds of touch used included three speeds within the range known to activate CTs; 1cm/second, 3 cm/second, and 10 cm/second, and two speeds outside of that range; 0.3 cm/second and 30 cm/second. The participants provided subjective ratings of pleasantness to each speed of touch. At the same time their heart rate and emotional facial muscle responses were also measured via the ECG and EMG respectively. Finally the participants completed the set of reaction-timed tasks designed to measure their executive functioning and ability to sustain attention.

2.2 Results

The touch ratings data revealed the predicted quadratic relationship between speed of touch and perceived pleasantness (Loken et al 2009; Olausson et al 2010). In this 'inverted U' shaped function, speeds of touch activating CTs are preferred to those faster and slower speeds that do not activate CTs (see Figure 1A).

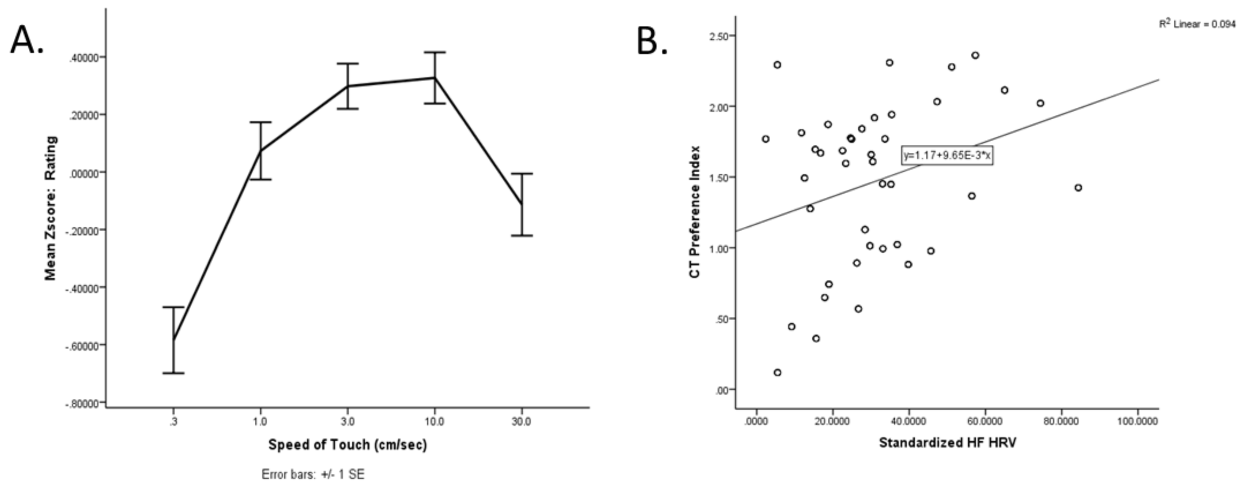

Figure 1. ***A.*** *Standardised pleasantness ratings for robotically delivered touch, delivered at 5 speeds: CT activating speeds of 1 cm /second, 3 cm/second and 10 cm/second. Non CT-activating speeds of 0.3 cm/second and 30 cm/second. The pattern of ratings shows the predicted 'inverted U' shaped function.* ***B.*** *Scatter plot depicting the relationship between standardized levels of high-frequency heart rate variability (HF-HRV) and CT preference index, which is a measure of preference for touch that optimally activate CTs over touch that does not. As HF-HRV increases, indicating lower levels of baseline arousal, preference for CT touch also increases, suggesting its affective qualities are more accessible to those participants with lower levels of stress.*

Preliminary analysis of the relationship between resting HRV and preference for CT touch revealed a significant positive relationship between the two measures, with those participants with higher levels of high-frequency HRV (HF-HRV) showing a more pronounced preference for CT activating touch over non-CT activating touch (see Figure 1B). This analysis was based upon an index of preference created by calculating the difference between individual participant's mean ratings for CT optimal touch (1-10cm/sec) and non CT optimal touch (.3 and 30 cm/second).

To examine more sensitively the relationship between HRV and ratings of CT and control touch, the sample were divided using a median split into those participants with relatively higher, and lower ratios of high-frequency to low-frequency HRV. Those participants in the 'high ratio' group, are those who demonstrate a greater vagal tone, in comparison to those in the 'low ratio' group. The ratings plots for each group can be seen in Figure 2. Each group's ratings distribution was analysed to see whether it demonstrated the quadratic fit, predicted by previous research (e.g. Loken et al 2009). As suggested by the preliminary analysis, in those participants in the high ratio group (those with greater vagal tone), only the quadratic function significantly fitted the ratings data. However, both a quadratic and linear function significantly fitted the data from those participants in the low ratio group – suggesting a weaker sensitivity to CT touch amongst those participants with lower vagal tone.

A final analysis sought to probe whether the differences between those participants with stronger and weaker vagal tone reflected a CT specific effect, or a more general difference in touch ratings. This analysis compared the two groups in terms of their ratings of CT optimal speeds of touch, their ratings of non CT optimal speeds of touch, and their preference for CT touch over non CT touch. The analysis revealed that whilst there was no difference between the groups in terms of their ratings of non CT optimal touch, there was both a significant difference in their ratings of CT optimal touch, and in their preference for CT over non CT touch. This strengthens the argument that lower vagal tone has a specific impact on the perception of touch conducted by CT fibres, rather than a general effect on the perceived pleasantness of any touch.

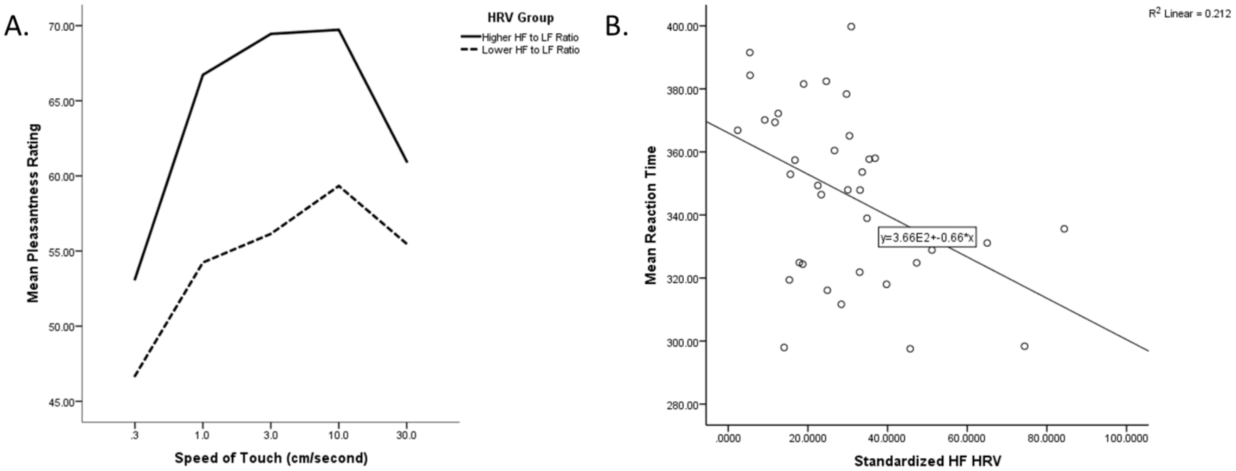

Figure 2. ***A.*** *Pleasantness ratings from participants in Experiment 1, in response to touch at CT optimal (1, 3 and 10 cm/second) and non CT optimal (.3 and 30 cm/second) touch, delivered robotically. Only a quadratic function*

fitted the ratings from the participants in the Higher HF to LF Ratio group (those participants with higher apparent vagal tone), as predicted by previous research. However in those participants in the Lower HF and LF ratio group, both a quadratic and linear function fitted the data. ***B.*** *Scatter plot depicting the relationship between standardised levels of high-frequency heart rate variability (HF-HRV) and mean reaction time on the sustained attention task. The relationship indicates that as HF-HRV increases, indicating decrease baseline arousal levels, participants are better at sustaining attention.*

Finally some evidence for the previously reported negative relationship between HF-HRV levels and reaction times on the executive functioning tasks was found (see Figure 2B), specifically relating to the sustained attention component of these tasks. This significant relationship was predicted by previous research linking decreased HF-HRV with decreased ability to utilise frontal cortical regions (Thayer et al 2009), and therefore in performing tasks that require executive functions. This additional cognitive component was added to Experiment 1 as a means testing the effective distribution of HF-HRV in our sample, given that it is very hard to determine normative values for HRV measures. Our analysis of this data replicates the finding of papers such as Hansen, Johnsen and Thayer (2003), providing us with confidence that we have captured a diverse enough sample of HF-HRV to reflect a range of vagal tone amongst our participants.

No significant effects were found in the EMG data. This is possibly down to the limited window for EMG capture afforded by the design of the task, which was targeted at collecting the clearest self-report measures. Our concern was that by leaving a longer window between the end of the touch period, and the participant's rating of the pleasantness of the touch, we might lose sensitivity in the self-report as participant risked wrongly recalling or over thinking their response. Our aim appears justified by the effects found in the self-report data. However, we are carrying out a more sensitive analysis of the EMG data from the short time window afforded by the task, using timing data from the robot to more accurately time lock the EMG responses to the onset of the touch stimulus. As we have recently published work showing differential EMG responses to CT and non-CT touch (over longer windows of time), we are hopeful that this closer scrutiny of the data may shed light on whether the apparent effects of stress on perceptions of CT touch extend to objective as well as subjective responses.

2.3 Discussion

As hypothesised, our data suggest that those more aroused participants are less capable of discerning the specific rewarding value of CT activating touch. This is in line with previous research reporting higher sensitivity to social cues amongst people with relatively higher-HRV-HF (higher vagal tone) (Quintana et al 2012). The specificity for the High-HF group's preference for CT versus Non CT optimal touch provides support for the Social Touch Hypothesis that activation of CTs is an innate social signal.

3. Experiment 2

Does CT optimal touch attenuate startle responses in the same manner as previously shown in the visual domain by positively valenced environmental stimuli? Startle reflexes represent automatic defensive and appetitive reactions to surprising events. These reflexes have been found to be modulated by current emotional context. Therefore we hypothesise that CT optimal touch, as a social signal carrying a positive affective value, will act to attenuate startle responses.

3.1 Methods

3.1.1 Participants

Forty-nine participants (32 female, 17 male; mean age = 22.78 years, SD = 3.74 years) took part in Experiment 2, piloted in February 2016 and run between April 2016 and June 2016.

3.1.2 Instrument/measures

Facial Electromyography (EMG): Startle eye-blinks (SEBs) are measured using EMG over the orbicularis oculi, in response to unexpected loud noises. There is reduction in SEB magnitude when the startling event is presented in the context of a positive stimulus, such as an emotional image (or friendly face. Another measure of appetitive reflex, the postauricular reflex (PAR), is robustly modulated by positive context. The PAR, a muscular response that pulls the ear back during startle, measured using EMG of the PAR muscle, is reliably potentiated by the presentation of positive stimuli, including images of food and smiling or familiar faces. It has been suggested that these responses can index the emotional value of human social signals.

Positive Images: Prior to coming into the lab participants provided digital photographs of three 'loved ones' who could be parents, siblings, long term partners, or best friends. Faces of the friends and family of the experimenters were used as control stimuli, they were matched to the Loved Ones in terms of gender and approximate age. The photographs were digitally cropped to a portrait format, before being inserted into the participant's version of the experiment.

RTS: see experiment 1

3.1.3 Procedure

When the participants arrived at the lab they were fitted with EMG electrodes. These were placed in two locations on the left side of the face, the orbicularis muscle below the eye and the PAR behind the ear. Participants were also fitted with an ECG and breathing belt. The participants wore over-ear headphones.

Initially participants relaxed and watched a video of sea life, during which baseline recordings of heart rate were taken. After this they viewed all the faces they would see during the experiment, one by one, and rated each in terms of how pleasant they found the face to look at, and how intense they found the feelings evoked by looking at the face. The faces included the three Loved Ones that the participant had submitted, & seven Strangers. After rating each face, the participants received touch from the robot at CT optimal (3 and 5 cm/second), and non CT optimal (30 and 35 cm/second) speeds. They rated each touch in terms of how pleasant it felt to them and how intense the feeling was.

Next the participants completed a task divided into four blocks. During two of the blocks participants viewed images of their Loved Ones, and three Strangers. The faces appeared on screen in a counterbalanced order. During two thirds of presentations of each type of face a loud burst of white noise was played down the participant's headphones, concurrently with the presentation of the face, with the onset of the noise occurring a jittered interval after the onset of the face. Eye blink and heart rate responses to the white noise startles were recorded. A selection of trials for each type of face were followed by a request to rate the pleasantness of the face. The participants were not aware of when they would be asked to provide a rating, and the aim of the ratings was to ensure the participants maintained focus on the faces.

The other two blocks of the task were identical to those in which the participants viewed faces, except that in these blocks the faces appearing of screen were always those of a second set of four Strangers, and during the presentation of each face the participant also received touch delivered by the robot. The CT and non CT touch stimuli were counterbalanced across trials in the same way as Loved Ones and Strangers faces had been, and formed the experimental stimulus. Whilst the faces were simply to give the participants extra stimulation to maintain their concentration. In these blocks participants were occasionally asked to rate the pleasantness of the touch they had just received, meaning that their attention was primarily on the touch stimulus. Again, white noise startle probes were played during the experimental stimulus (touch), on two thirds of trials. The participants received the four blocks (two of face stimuli, two of touch stimuli), in an ABAB or BABA order, and each block lasted approximately six minutes. Between blocks, participants relaxed by watching two minutes of the sea life documentary.

3.2 Results

The participant's ratings indicated tha,t as predicted, the faces of Loved Ones were rated as both more pleasant and intense than the faces of the strangers used as control stimuli. Despite careful counterbalancing, the faces that were to be paired with CT touch during the main task were found to be more pleasant to look at than those faces later paired with non-CT touch, although there was no difference in intensity ratings. Importantly though, pleasantness ratings of the two speeds of CT touch (3 and 5 cm/second) did not differ from one another, nor did the two speeds of non CT touch (30 and 35 cm/second). The CT speeds were found significantly more pleasant than the non CT speeds. The intensity of feeling evoked by the different speeds of touch did not significantly differ. The analysis of the eye-blink, PAR, and heart rate responses however revealed no significant differences. The eye blink data in Figure 5, demonstrate the similar patterns of responding seen between both the Loved Ones and Strangers conditions, and the CT and non CT touch conditions. Whilst the data from the PAR muscle demonstrated the same pattern of responses as that of the orbicularis (eye-blink), there was a trend in the heart rate responses towards a differential response to startle probes presented during CT and non CT touch. Here, there appeared to be a greater initial deceleration, indicative of orienting to a stimulus, in the non CT condition. This difference did not reach significance, but the pattern trended in the direction predicted by the hypothesis that CT touch would act to reduce the impact of the startle probes and therefore the level of orienting.

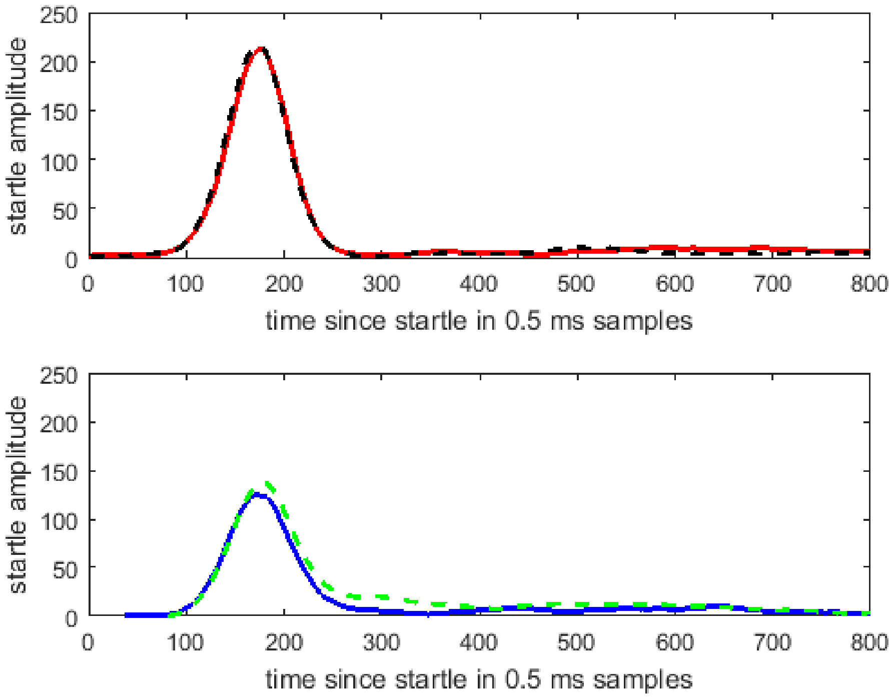

Figure 3: Eye blink responses from the orbicularis oculi muscle, in response to white noise startle probes presented during Experiment 2. The top row shows the startle responses during trials where participants were viewing Loved Faces (red line), and Stranger Faces (black dashed line). The bottom row shows the startle responses during trials when participants were receiving CT touch (blue line) and non CT touch (green dashed line).

3.3 Discussion

Whilst participants responded subjectively to the touch and face stimuli in the manner predicted, the results to the main task did not support the hypothesis that in comparison to touch that did not activate CTs, CT touch would cause a reduction in startle stress reflex responses. Nor did we replicate the results of Guerra et al (2012) who showed that viewing loved ones reduced the amplitude of startle eye blinks. Given the findings from study 1, that those participants with higher levels of HRV were more sensitive to the specific rewarding value of CT activating touch, further analysis of this data is underway including the participant's baseline levels of HRV as a covariate when modelling the effects of touch and face type on the three measures of startle reflex.

4. Experiment 3

Does CT optimal touch facilitate emotional regulation by increasing PSNS activity in a stressfully arousing context? Stressful events cause increased activity of the SNS and down-regulation of the PSNS, resulting in decreased vagal tone (Thayer & Lane 2000). If social touch acts to promote autonomic regulation, it is predicted that CT optimal touch should reduce the SNS effects of a stressful experience, through an increase in vagal tone.

4.1 Methods

4.1.1 Participants

Thirty-nine participants (20 female / 19 male; mean age = 21.6 years, SD = 2.5 years) were successfully recruited to take part in Experiment 3 between June and August 2016.

4.1.2 Instrument & measures

Heart Rate Variability (HRV): As per experiment 1

Skin Conductance (SC): Unstimulated changes in skin conductance reflect changes in perspiration levels resulting from SNS activity. In the current experiments we used fixed current SC to index the activity of the SNS during resting *state, stress, and modulation of stress responses by CT touch.*

RTS: As per experiment 1

Stress Induction Procedure: The challenge started with a subtraction task based upon a similar task used in the classic Trier Stress Test (Kirschbaum, Pirke & Hellhammer, 1993). Participants were given a high number (1992) from which they had to subtract the number 7 in a serial manner. In our computerised version the participants saw two possible answers, one of which was correct. The other answer was generated by the computer to be between plus or minus 1 and 3 from the correct answer, or the correct answer minus 10. The side of the screen on which the correct and incorrect answers were presented was randomised. Selecting the correct answer with the computer mouse brought up the possible answers for that value, minus seven, and so forth. Selecting the incorrect answer at any stage resulted in a loud error tone and a return to the starting number.

Cognitive Task: The cognitive task used was the serial memory reaction time task used in Experiment 1. All parameters were the same for this task as in Experiment 1, however in this version of the task the key press was replaced with a mouse click, a more straight forward response for participants to make whilst seated in the reclining chair.

4.1.3 Procedure

Participants were fitted with an ECG, breathing belt, and electrodes on the index and middle fingers of their left hand to measure SC.

Initially participants relaxed in a reclining chair, and completed a very simple task where they counted the numbers of red squares appearing in an array of squares of different colours. This task acted as a baseline during which levels of skin conductance, heart rate and HRV were measured. The baseline was recorded for five minutes.

Next, the participants completed the first block of a cognitive challenge, designed to induce a stress response. Following this task, participants completed the hardest of the executive function tasks used in Experiment 1 (the serial memory reaction time task). In total the block took five minutes, during which the participant's ECG and SC recordings continued.

During a second five minute block of the cognitive challenge, the participants received concurrent touch, delivered by the RTS. Half the participants received a CT optimal touch at 3cm/second, while the other half received non CT optimal touch at 30 cm/second. The touch was applied in five periods lasting approximately thirty seconds, interspersed during the five minutes of the cognitive challenge, and balanced so that the duration of the touch periods, and the intervals between them were matched across the two conditions of touch. Again, the ECG and SC were recorded. Finally, the participants again relaxed and completed the colour counting task. During this five minute recovery period the ECG and SC were recorded, meaning that for each participant, SC, heart rate, and HRV were measured throughout a period of baseline rest, cognitive stress, cognitive stress with touch (CT or non CT), and recovery.

4.2 Results

An initial analysis was conducted on the behavioural data. Our prediction was that performance of the CT touch group might improve in comparison to the non CT touch group, once touch was applied in the second cognitive challenge block. However, as can be seen in Figure 6 A and B, whilst both demonstrated an improvement over time, presumably due to practise effects, there was no significant interaction between touch group and period.

The second analysis focussed on the psychophysiological indicators of stress. Both groups demonstrated the predicted significant increases in sympathetic activity, demonstrated across both cardiac and skin conductance measures, from pre-challenge baseline, to the challenge blocks where the participants were engaged in the stressful cognitive tasks. Both groups showed a return towards baseline levels of sympathetic activity during the five minute recovery period at the end of the task.

We predicted a significant interaction between touch group (CT v non CT) and time – in that it was expected that whilst the groups would not differ in terms of their increase in sympathetic arousal from baseline to the first block of the challenge, where no touch was applied, the CT touch group would show either a significantly greater decrease in sympathetic activity once touch was applied in the second block of the cognitive challenge, or at least a significantly reduced increase. We also predicted that the CT touch group would show a significantly greater recovery towards baseline levels of sympathetic activity during the recovery period. Figure 6C illustrates the trend towards this effect, with the CT group demonstrating a greater reduction in sympathetic induced cardiac activity from the pre-touch cognitive challenge to the cognitive challenge with concurrent touch, and from the cognitive challenge with concurrent touch, to the recovery period. There were no significant effects in the SC data.

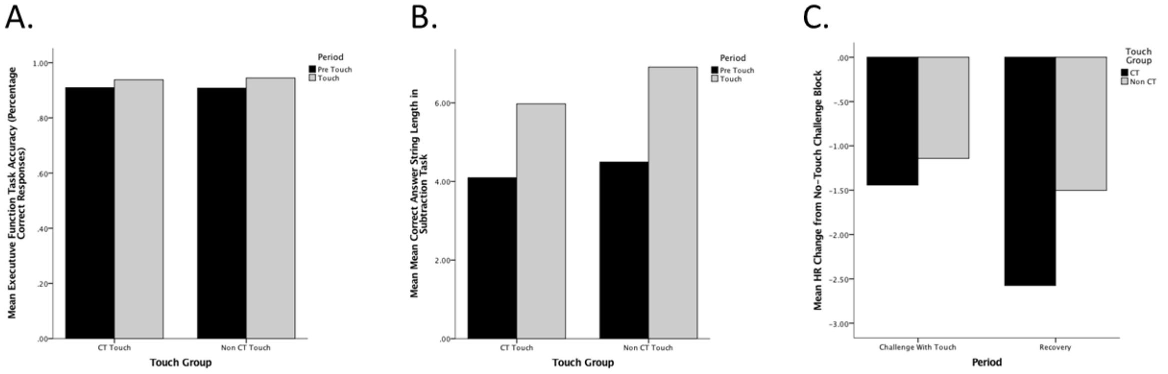

*Figure 6: **A**. Performance on the Executive Function section of the cognitive challenge. During the second performance of the task (grey bars), participants were receiving either CT or non CT touch, and both touch groups showed an improvement in performance. **B.** Shows the data for the Subtraction Task section of the cognitive challenge, where again both the CT and non CT touch groups demonstrated improvement during the second performance of the task where touch was concurrently applied. **C**. Change in heart rate from cognitive challenge without touch to cognitive challenge with concurrent touch (left hand bars), and from cognitive challenge with touch to recovery period (right hand bars). The means indicate that those participants receiving CT touch demonstrated a more rapid reduction in arousal after the application of touch.*

4.3 Discussion

No evidence was found to support the notion that by buffering against stress, CT touch might aid cognitive performance. However, the cardiac measures taken during the cognitive challenge and post challenge recovery did indicate that CT touch acted to buffer against the stressful consequences of the cognitive challenge, and lead to a more rapid return towards baseline levels of arousal. This is consistent with a previous report that physical touch, but not verbal social support from a loved one, buffers against psychological stressors (Ditzen et al 2007). As the cognitive performance of the two groups did not significantly differ overall, we are conducting a further analysis on the skin conductance data to examine whether the SRs elicited after errors, which are believed to be a stronger indicator of sympathetic arousal than tonic skin conductance alone, might demonstrate the predicted group differences.

5.Conclusions and Recommendations

Our results from Experiment 1 suggest that those individuals demonstrating higher levels of stress have a reduced sensitivity to the hedonic value of a CT stimulus, versus touch that does not optimally activate CTs. The results of Experiments 2 and 3 also went some way towards supporting our initial hypotheses, in that the data revealed trends towards a reduced level of orienting to startle probes when receiving CT touch, and a greater reduction in sympathetic activity, as indicated by cardiac measures, when CT touch was applied during a cognitive challenge. However, further analysis is required taking into account the findings from experiment 1 which indicate that those with high baseline levels of HRV will be more sensitive to the stress buffering effects of CT targeted touch than others. Pawling took up a new permanent academic position immediately after the completion of the project, and now aims to complete these additional analyses in the coming months, with the aim being produce a publication from the Experiment 1 and Experiment 3 data by the end of 2017. To fully leverage the potential impact of this work, it may be necessary to increase the sample sizes across both experiments over the summer.

The finding that individual differences in sensitivity to the rewarding value of CT touch exist, in the same way they do to other social cues, provides strong support for the Social Touch Hypothesis. The project has broken new ground in being the first to empirically examine the stress buffering hypothesis of CT touch in humans and paves the way for future work in the area.

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