The role of touch in regulating inter-partner physiological coupling during empathy for pain

Pavel Goldstein,

Abstract

The human ability to synchronize with other individuals is critical for the development of social behavior. Recent research has shown that physiological inter-personal synchronization may underlie behavioral synchrony. Nevertheless, the factors that modulate physiological coupling are still largely unknown. Here we suggest that social touch and empathy for pain may enhance interpersonal physiological coupling. Twenty-two romantic couples were assigned the roles of target (pain receiver) and observer (pain observer) under pain/no-pain and touch/no-touch conditions, and their ECG and respiration rates were recorded. The results indicate that the partner touch increased interpersonal respiration coupling under both pain and no-pain conditions and increased heart rate coupling under pain conditions. In addition, physiological coupling was diminished by pain in the absence of the partner's touch. Critically, we found that high partner's empathy and high levels of analgesia enhanced coupling during the partner's touch. Collectively, the evidence indicates that social touch increases interpersonal physiological coupling during pain. Furthermore, the effects of touch on cardio-respiratory inter-partner coupling may contribute to the analgesic effects of touch via the autonomic nervous system.

Introduction

The human capacity for generating events in synchrony[1] with other individuals has important evolutional significance. Behavioral synchrony is evident in the animal kingdom in various forms. Among them are synchronized periodic movements to create acoustic signals[2,3,4], synchronous flashing among fireflies[5], synchronized collective movements among predators while hunting[6] and synchronized reactions to stressful and dangerous situations[6,7,8]. Humans also tend to coordinate their actions and imitate the postures or actions of others whether they are aware of this or not[1, 9, 10]. This ability develops early in life[11, 12] and is crucial for social communication in general[13] and for the development of infant and mother bonding in particular[14]. Furthermore, synchronized coordinated behaviors have also been noted in other social behavioral contexts, such as speech understanding[15] or psychotherapy[16]. These studies indicate that social synchrony plays a major role in affiliative behaviors and in the development of social behavior.

Recently, an increasing number of studies have explored the physiological mechanisms that underlie social synchrony. These studies have shown that group synchrony is accompanied by cardiac rhythms that are synchronized between active participants and bystanders during collective rituals[17] and people collectively watching emotional movies[18]. In addition, cardiac and respiratory synchronization was found to underlie interpersonal action coordination during choir singing[19]. Similarly, dual synchrony between romantic dyads was associated with cardiac and respiratory coupling during gazing and imitation tasks[20] and even simply when the two members of the couple are together[20], suggesting that the mere presence of one's partner may trigger heart rate synchrony. Nonetheless, although synchrony has been reported in an

abundance of social contexts, the conditions that facilitate synchrony remain unclear.

One condition that may increase synchrony is empathy for pain, a concept that describes our tendency to experience distress automatically when confronted with someone else's pain[21]. Empathy for pain is associated with activity in pain neural networks[22, 23], along with physiological responses such as increased skin conductance[24] and increased heart rate[17, 25]. Since sharing the sufferer's pain constitutes empathy for pain, inflicting pain to a target may increase the coupling between sufferer (target) and observer. In line with this speculation, Levenson and Gottman (1983) showed that distress situations enhance physiological coupling in romantic dyads[26]. Therefore, we hypothesized that empathy for pain would increase synchrony between the physiological responses of the target and those of the observer.

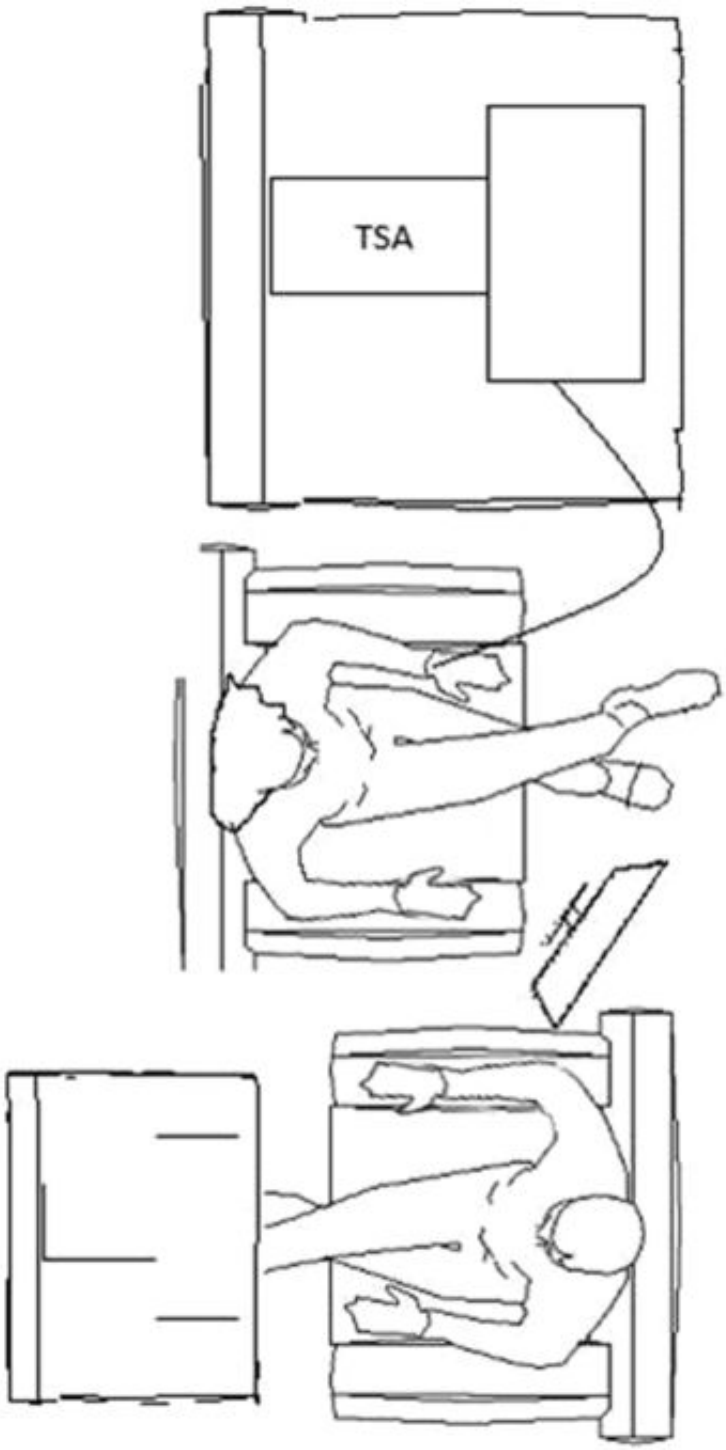
Another condition that may promote synchrony is touch. Interpersonal touch has important social and affective values[27,28,29]. Specifically, skin-to-skin touch contributes to the development of premature infants[30], regulates their stress responses[31], provides comfort and emotional well-being[32,33,34] and has an analgesic effect[34]. Physiologically, interpersonal touch increases the coupling of electrodermal activity and pulse rate variability[35] and modulates blood pressure reactivity to stress[36] as well as reactivity to distress[37]. Therefore, our second hypothesis was that interpersonal touch would increase interactional physiological coupling.

Furthermore, it has been shown that touch moderates (1) the relationship between the observer's trait empathy and the target's analgesia; (2) inter-partner synchrony of pain rating; and (3) touch-related analgesia[38]. Moreover, it has been found that empathic

accuracy, i.e., the extent to which the supporting partner accurately estimates the pain of the suffering person, is related to the sufferer's pain perception[39]. Accordingly, we predicted that inter-dyad variability in level of physiological coupling while experiencing pain would be moderated by levels of trait empathy and empathic accuracy and by the analgesic effect of touch.

To examine these predictions, we designed an experiment consisting of six conditions in which romantic partners were instructed to hold hands or sit with no physical contact or in separated rooms during the pain vs. no pain conditions (Fig. 1). Throughout the experiment the electrocardiogram and respiration of both partners were simultaneously recorded.

Figure 1



No touch-pain condition.

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Results

The sample mean and standard deviations of the pain ratings of both partners appear in Table 1 (women rated their own pain and the men

evaluated their partner's pain). As was reported in the initial report of this data (Goldstein *et al.*, 2016), the pain ratings in the *partner-touch* condition were lower than in the *partner-no touch* condition ($M_{diff} = -0.36$, $p = 0.029$) and the *pain-alone* condition ($M_{diff} = -0.66$, $p < 0.001$), confirming that touch had an analgesic effect. In addition, during the *pain-alone* condition, the women's pain ratings were marginally higher than in the *partner-no touch* condition ($M_{diff} = 0.29$, $p = 0.093$).

Table 1: Average (standard deviation) pain ratings in each condition.

Full size table

Respiration analysis

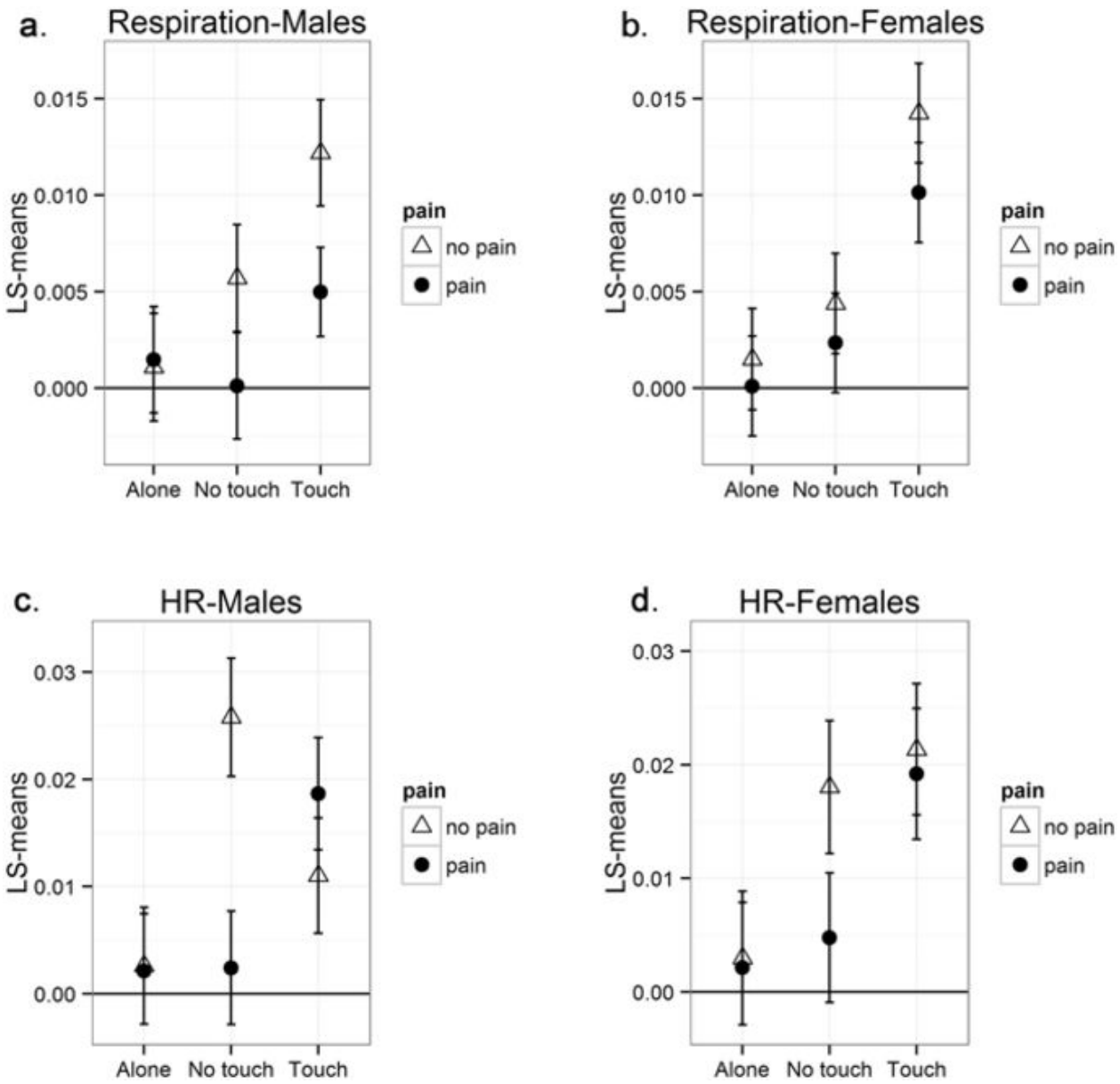
We analyzed the data using the coupled linear oscillator (CLO) model (see Methods section), estimating the inter-partner relationship between one partner's inhalation (predictor) and the other partner's exchange between inhalation and exhalation (outcome) in six combinations of pain (no pain/pain) and touch (alone/no-touch/touch) factors. The CLO analysis indicated that touch and pain moderated the partners' velocity effect both in men and in women ($F_{(4,55000)} = 14.44$, $p < 0.0001$, $\Delta BIC = -47.8$, $\Delta R^2 = 0.18$), indicating that the partner's velocity effect differed across experimental conditions. We further carried out separate post-hoc analyses for men and women to examine differential effects in targets (women) and observers (men).

Model for male participants: How changes in respiration in females predict shifts in changes of males

The post-hoc analysis revealed a significant effect of cross-partner velocity for male participants during the *touch-no pain* ($\eta_{t(np)} = -0.012$, $p < 0.001$, 95% CI [−0.06, −0.18]), *no touch-no pain* ($\zeta_{nt(np)} =$

−0.006, p = 0.012, 95% CI [−0.001, −0.010]) and *touch-pain* ($\zeta_{t(p)}$ = −0.005, p = 0.017, 95% CI [−0.001, −0.010]) conditions (Fig. 2a). This pattern of effects describes a consistent pattern of inhalation among women while men shift from inhalation to exhalation. However, the woman's cross-partner velocity during the *no touch-pain* condition ($\zeta_{nt(p)} < 0.001$, p = 0.96) was not related to the man's acceleration. No significant cross-partner effects were detected for the *pain alone* ($\zeta_{a(p)} = -0.001$, p = 0.78) and the *no pain alone* ($\zeta_{a(np)} = 0.001$, p = 0.86) conditions. In line with our hypotheses, the coupling during the *touch* conditions was higher than in the *no touch* conditions, whether without pain ($\Delta\zeta_{t/nt(np)} = 0.006$, p < 0.001, 95% CI [0.003, 0.008]) or with pain ($\Delta\zeta_{t/nt(p)} = 0.012$, p < 0.001, 95% CI [0.007, 0.016]). However, the pain vs. no pain comparison was associated with decreased respiration synchronization in both the *touch* ($\Delta\zeta_{t(p/np)} = -0.007$, p < 0.001, 95% CI [−0.004, 0.010]) and the *no touch* ($\Delta\zeta_{nt(p/np)} = -0.006$, p < 0.001, 95% CI [−0.004, 0.008]) conditions. Figure 3 depicts these findings.

Figure 2



Results of the Coupled Linear Oscillator (CLO) Model for heart rate and respiration. For the sake of simplicity, results are presented as absolute values. The Y-axis presents models based on the least squares (LS) means of each experimental condition, expressing the level of physiological coupling in different experimental conditions. Zero represents a case without interpersonal coupling, while scores that differ from zero indicate interpersonal coupling.

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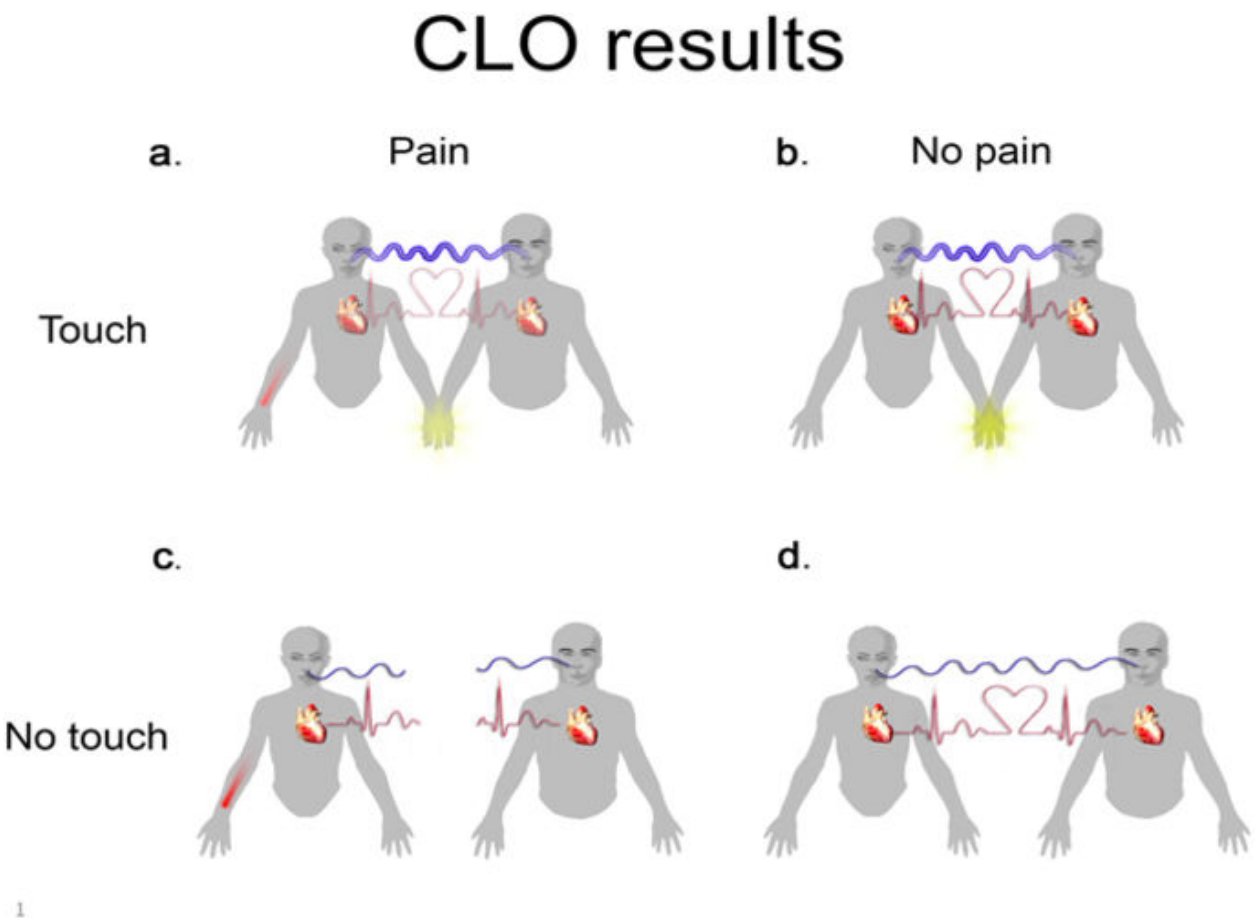
Figure 3



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Graphical representation of Coupled Linear Oscillator (CLO) model findings for heart rate and respiration (Fig. 2). Blue lines represent respiration inter-partner coupling and red lines represent coupling in heart-rate. The line's thickness represents the strength of the coupling, with broken lines denoting a total lack of the coupling. (**a**) Coupling of respiration and heart rate during *touch-pain* condition. (**b**) Coupling of respiration and heart rate during *touch-no pain* condition. (**c**) No coupling of respiration and heart rate during *no touch-pain* condition. (**d**) Coupling of respiration and heart rate during *no touch-no pain* condition.

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Model for female participants: How changes in respiration in males predict shifts in changes of females

In line with the male model, a significant effect of cross-partner velocity was found for women during the *touch-no pain* ($\zeta_{t(np)}$ = 0.014, $p < 0.001$, 95% CI [0.009, 0.019]) and the *touch-pain* ($\zeta_{t(p)}$ = 0.010, $p < 0.001$, 95% CI [0.006, 0.014]) conditions, while a marginal effect was found in the *no touch-no pain* condition ($\zeta_{nt(np)}$ = 0.004, p

= 0.092, 95% CI [−0.001, 0.008]) (Fig. 2b). These effects indicated that women tend to shift from exhalation to inhalation when men inhale. However, women's cross-partner velocity during the *no touch-pain condition* was not significant ($\zeta_{nt(p)} = 0.002$, $p = 0.54$). No significant cross-partner effects were detected for the *pain alone* ($\zeta_{a(p)} = -0.001$, $p = 0.64$) or the *no pain alone* ($\zeta_{a(np)} < 0.001$, $p = 0.92$) conditions.

In line with our hypotheses, the coupling during *touch* increased compared to during *no touch* in both the *no pain* ($\Delta\zeta_{t/nt(np)} = 0.010$, $p < 0.001$, 95% CI [0.006, 0.014]) and the *pain* ($\Delta\zeta_{t/nt(p)} = 0.008$, $p < 0.001$, 95% CI [0.003, 0.012]) conditions. However, there was no difference between *pain* and *no pain* during both *touch* ($\Delta\zeta_{t(p/np)} = 0.004$, $p = 0.115$) and *no touch* ($\Delta\zeta_{nt(p/np)} = 0.002$, $p = 0.637$) conditions.

Heart rate analysis

For heart rate we carried out a similar analysis based on the CLO model (see Methods section), estimating the inter-partner relationship between an increase in heart rate of one partner and the exchange between increase and decrease of heart rate in the second partner as a function of pain and touch factors. As in the case of respiratory rate, touch and pain moderated the partners' velocity effect both in women and in men ($F_{(4,25000)} = 19.40$, $p < 0.0001$, $-\Delta BIC = 7.7$, $\Delta R^2 = 0.12$), indicating that the partner velocity effect differed across experiment conditions. We further carried out separate post-hoc analyses for male and female participants.

Model for male participants: How changes in respiration in females predict shifts in changes of males

The post-hoc analysis revealed a significant effect of cross-partner

velocity for men during the *no touch-no pain* ($\zeta_{nt(np)} = 0.026$, $p < 0.001$, 95% CI [0.016, 0.036]), *touch-pain* ($\zeta_{t(p)} = 0.019$, $p < 0.001$, 95% CI [0.010, 0.027]) and *touch-no pain* ($\zeta_{t(np)} = 0.011$, $p < 0.001$, 95% CI [0.005, 0.016]) conditions (Fig. 2c). Thus, an increase in the woman's heart rate was related to a shift from a decrease to an increase in the man's heart rate under the above-mentioned conditions. However, cross-partner female velocity during the *no touch-pain* condition ($\zeta_{nt(p)} = 0.002$, $p = 0.57$) was not related to acceleration in the men's heart rate. No significant cross-partner effects were detected for the *pain alone* ($\zeta_{a(p)} = -0.002$, $p = 0.62$) and *no pain alone* ($\zeta_{a(np)} = 0.002$, $p = 0.56$) conditions. In line with our hypotheses, the synchronization during *touch-pain* was higher than in the *no touch-pain* ($\Delta\zeta_{t/nt(p)} = 0.017$, $p < 0.001$, 95% CI [0.009, 0.024]) and the *touch-no pain* ($\Delta\zeta_{t(p/np)} = 0.007$, $p < 0.001$, 95% CI [0.003, 0.010]) conditions. However, during the *no touch-no pain* condition, there was increased synchronization compared to the *touch-no pain* ($\Delta\zeta_{t/nt(np)} = 0.015$, $p < 0.001$, 95% CI [0.008, 0.021]) and *no touch-pain* ($\Delta\zeta n_{t(p/np)} = 0.024$, $p < 0.001$, 95% CI [0.014, 0.034]) conditions.

Model for female participants: How changes in respiration in males predict shifts in changes of females

In line with the results of the model for male participants, a significant effect of cross-partner velocity was found for female participants during the *touch-no pain* ($\zeta_{t(np)} = 0.021$, $p < 0.001$, 95% CI [0.012, 0.029]), *touch-pain* ($\zeta_{t(p)} = 0.019$, $p < 0.001$, 95% CI [0.011, 0.027]) and *no touch-no pain* ($\zeta_{nt(np)} = 0.018$, $p < 0.001$, 95% CI [0.010, 0.026]) conditions (Fig. 2d). These effects indicate that the increase in the men's heart rate was associated with the change in the women's heart rate from decreasing to increasing. In addition, the women's cross-partner velocity was not related to the men's

acceleration in heart rate ($\zeta_{nt(p)} = -0.005$, $p = 0.32$) in the *no touch-pain* ($\zeta_{nt(p)} = 0.004$, $p = 0.183$), *pain alone* ($\zeta_{a(p)} = 0.002$, $p = 0.59$) or the *no pain alone* ($\zeta_{a(np)} = 0.002$, $p = 0.71$) conditions. The increased synchronization during the *touch-pain* condition compared to the *no touch-pain* ($\Delta\zeta_{t/nt(p)} = 0.014$, $p < 0.001$, 95% CI [0.007, 0.021]) and *touch-no pain* ($\Delta\zeta_{t(p/np)} = 0.007$, $p < 0.001$, 95% CI [0.003, 0.010]) conditions is in line with our hypothesis. However, the heart rate synchronization during the *touch-no pain* condition did not differ from the *touch-pain* ($\Delta\zeta_{t\ (np/p)} = 0.002$, $p = 0.368$) or the *no touch-no pain* ($\Delta\zeta n_{t/nt(np)} = 0.003$, $p = 0.274$) conditions.

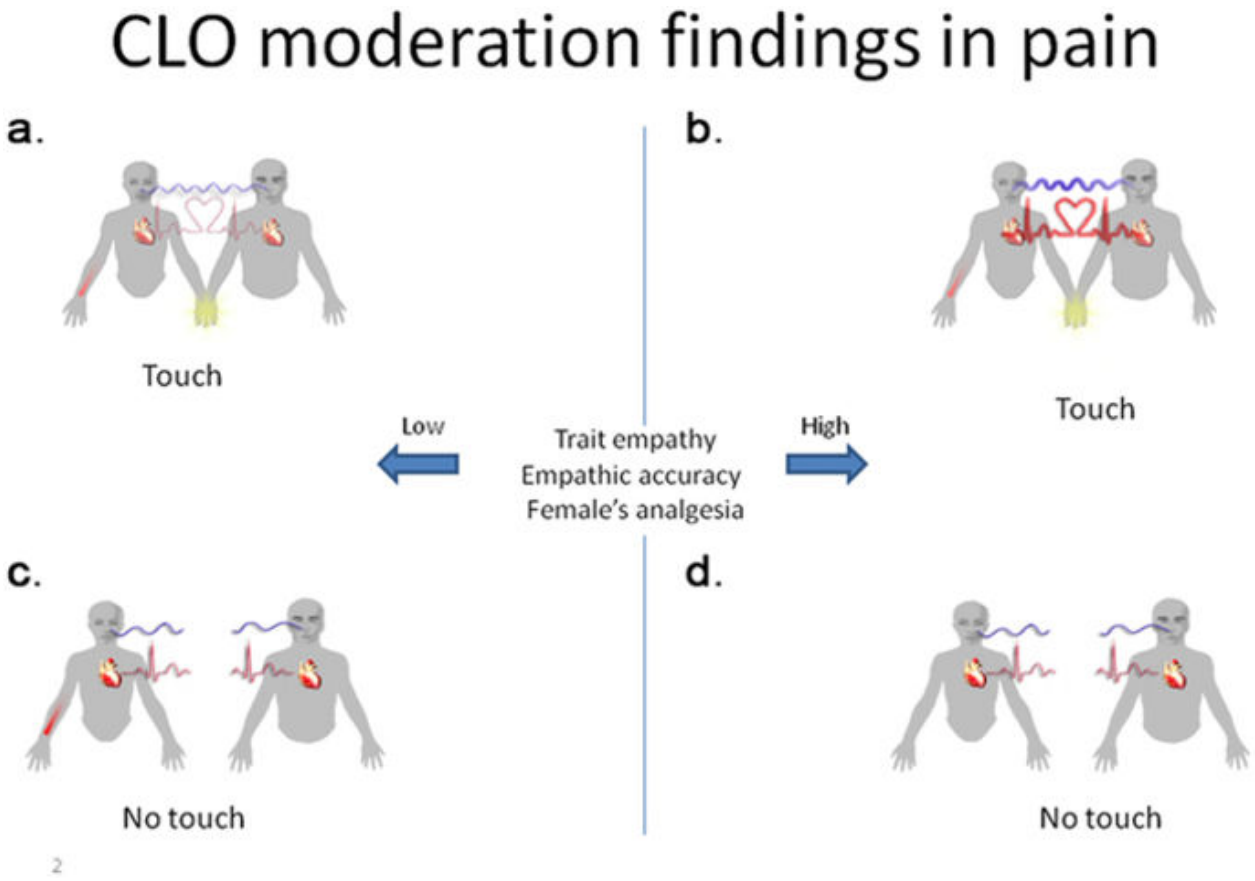
In summary, all four analyses (men/women X respiration/heart rate) followed a common pattern—touch increased synchronization during pain.

Moderation analysis

We applied Confirmatory Factor Analysis (CFA) to test the structure of the Interpersonal Reactivity Index (IRI) questionnaire, assuming the same unique latent empathy content for both partners. The analysis revealed a good fit between the measurement model and the data ($\chi 2/df = 1.69$, CFI = 0.94, RMSEA = 0.071). Thus, in the following analysis we treated trait empathy as a single factor. For the empathy trait measure we used the average of all questions from the IRI questionnaire. Empathic accuracy and trait empathy measurements demonstrated high correlation ($r = 0.62$, $p < 0.001$). We tested the moderation effect of empathic accuracy, trait empathy and women's analgesia on across-partner coupling of heart rate and respiration fluctuations in the *touch-pain* and *no touch pain* conditions. This analysis tested the hypothesis that the observer's level of empathy, his empathic accuracy and the levels of pain analgesia moderate touch-related physiological coupling.

In line with our hypothesis, the male partner's empathic accuracy significantly moderated the effect of touch on synchronization for respiration fluctuations ($F_{(4,28000)} = 27.87$, $p < 0.0001$, $\Delta BIC = 419439.8$, $\Delta R^2 = 0.23$). More specifically, a high level of empathic accuracy (one standard deviation above the mean) compared to a low level (one standard deviation below the mean) was associated with increased coupling between female velocity and male acceleration in respiration during the touch condition ($\Delta\zeta_{t(p)} = 0.028$, $p < 0.001$, 95% CI [0.016, 0.040]). Correspondently, high levels of empathic accuracy between partners compared to low levels indicated increased coupling between male velocity and female acceleration in the touch condition ($\Delta\zeta_{t(p)} = 0.029$, $p < 0.001$, 95% CI [0.016, 0.041]) (Fig. 4a,b). The corresponding contrasts were not significant in the condition without partner touch ($\Delta\zeta_{nt(p)} = 0.002$, $p = 0.56$, men), ($\Delta\zeta_{nt(p)} = 0.001$, $p < 0.73$, women) (Fig. 4c,d).

Figure 4



Graphical representation of moderation analysis of trait empathy, empathic accuracy and women's analgesia on across-partner synchronization in HR and RR fluctuations. Empathic accuracy = man's accuracy in estimating woman's pain, trait empathy = IRI questionnaire, woman's analgesia = reduction in woman's pain as a result of man's presence or touch. Blue and red lines mark respiration and heart rate inter-partner coupling, respectively. The line's thickness represents the strength of the synchronization, and a broken line indicates a total lack of the coupling. (**a**) Coupling of respiration and heart rate during *touch-pain* condition for dyads with low (−1 SD) trait empathy, low empathic accuracy and low women's analgesia. (**b**) Coupling of respiration and heart rate during *touch-pain* condition for dyads with high (+1 SD) trait empathy, high empathic accuracy and high women's analgesia. (**c**) No coupling of respiration and heart rate during *no touch-pain* condition for dyads with low (−1 SD) trait empathy, low empathic accuracy and low women's analgesia. (**d**) No coupling of respiration and heart rate during *no touch-pain* condition for dyads with high (+1 SD) trait empathy, high empathic accuracy and high women's analgesia.

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We found significant moderation of the effect of women's analgesia and touch on the cross-partner synchronization in velocity of respiration fluctuations ($F_{(4,28000)} = 26.59$, $p < 0.0001$, $\Delta BIC = -418367.9$, $\Delta R^2 = 0.19$). Higher levels of women's analgesia predicted increased coupling between female velocity and male acceleration ($\Delta\zeta_{t(p)} = 0.027$, $p < 0.001$, 95% CI [0.015, 0.039]) and increased associations between male velocity and female acceleration ($\Delta\zeta_{t(p)} = 0.068$, $p < 0.001$, 95% CI [0.042, 0.093]) in the touch condition. However, the corresponding contrasts were not significant in the absence of partner touch ($\Delta\zeta_{nt(p)} = 0.005$, $p = 0.32$, men; $\Delta\zeta_{nt(p)} < 0.001$, $p = 0.87$, women). It is important to note that trait empathy showed a pattern of moderation similar to that of empathic accuracy. However, the effect of trait empathy was redundant in the model that included empathic accuracy and women's analgesia as moderators (most likely because of the high correlation between them).

The same pattern of moderation effects emerged in the heart rate analysis. Empathic accuracy and touch moderated the effect of synchronization in heart rate ($F_{(4,13000)} = 20.73$, $p < 0.0001$, $\Delta BIC =$

−265162.9, $\Delta R^2 = 0.24$). High as opposed to low levels of empathic accuracy predicted greater coupling between female velocity and male acceleration ($\Delta\zeta_{t(p)} = 0.046$, $p < 0.001$, 95% CI [0.026, 0.066]) and larger associations between male velocity and female acceleration ($\Delta\zeta_{t(p)} = 0.049$, $p < 0.001$, 95% CI [0.028, 0.070]) in the touch condition. The corresponding contrasts were not significant in the condition without partner touch ($\Delta\zeta_{nt(p)} = 0.008$, $p = 0.28$, males), ($\Delta\zeta_{nt(p)} = 0.008$, $p = 0.34$, females). As in the case of respiration fluctuations, women's analgesia and touch significantly moderated the effect of cross-partner velocity for heart rate ($F_{(4,13000)} = 5.03$, $p < 0.0001$, $\Delta BIC = -267895.6$, $\Delta R^2 = 0.25$). Specifically, high women's analgesia as opposed to low analgesia was related to increased coupling between female velocity and male acceleration ($\Delta\zeta_{t(p)} = 0.015$, $p < 0.001$, 95% CI [0.008, 0.022]) and greater association between male velocity and female acceleration ($\Delta\zeta_{t(p)} = 0.019$, $p < 0.001$, 95% CI [0.010, 0.028]) in the touch condition. However, these contrasts were not significant in the no-touch conditions ($\Delta\zeta_{nt(p)} = 0.003$, $p = 0.67$, males), ($\Delta\zeta_{nt(p)} = 0.022$, $p = 0.17$, females). Similar to respiration fluctuations, trait empathy showed a pattern of moderation similar to that of empathic accuracy. However, the moderation effect of trait empathy did not contribute beyond empathic accuracy and women's analgesia. In addition, the females' feeling of comfort during the touch did not moderate coupling in respiration fluctuations ($F_{(4,28000)} = 1.37$, $p = 0.24$) nor heart rate ($F_{(4,13000)} = 1.47$, $p = 0.21$).