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Face your heart: resting vagally mediated Heart Rate Variability Shapes Social Attributions from facial appearance

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Abstract

Phylogenetic theories suggest resting vagally mediated heart rate variability (vmHRV) as a biomarker for adaptive behavior in social encounters. Until now, no study has examined whether vmHRV can predict individual differences in inferring personality traits and intentions from facial appearance. To test this hypothesis, resting vmHRV was recorded in 83 healthy individuals before they rated a series of faces based on their first impression of trustworthiness, dominance, typicality, familiarity, caring, and attractiveness. We found an association between individual differences in vmHRV and social attributions from facial appearance. Specifically, higher levels of vmHRV predicted higher scores on ratings of caring and trustworthiness, suggesting that strangers' faces are more likely to be perceived as safer. The present results suggest that higher levels of vmHRV (compared with lower levels of vmHRV) are associated with the tendency to minimize social evaluative threat and maximize affiliative social cues at a first glance of others' faces.

Keywords Caring · Facial appearance · First impression · Heart rate variability · Trustworthiness

Introduction

Humans are social animals by nature. They are born to form social relationships and interact with others. In fact, humans have a predisposition to prosocial behavior because connecting with and understanding others is important in order to navigate the social environment (Adolphs, 2003). Phylogenetic theories suggest that determined biological factors may predispose humans to be social (e.g., Porges, 2007). One such factor is resting vagally mediated heart rate variability (vmHRV), which derives from the synergistic actions of the sympathetic and parasympathetic autonomic nervous systems (ANS) that enable the cardiovascular system to adapt to the changing demands of the environment by regulating appropriate behavioral responses and modulating physiological states to support social behavior (Berntson et al., 1997; Smith et al., 2020). Findings suggest that vmHRV provides a non-invasive proximal measure of cardiac vagal modulation (e.g., Laborde et al., 2017), and its role in social engagement becomes evident when we consider that the vagus nerve (i.e., the 10th cranial nerve) richly innervates the entire body, including the face and the vocal apparatus.

Individuals with higher levels of vmHRV tend to exhibit higher social skills (reviewed in Colonnello et al., 2017) such as the ability to seize opportunities to reinforce positive emotions and social connections (Kok & Fredrickson, 2010), higher openness to experience (Costa & McCrae, 1985, 1992), and the tendency to affiliate with new groups (Sahdra et al., 2015). Moreover, vmHRV positively correlates with a greater ability to regulate emotional responses towards others (Eisenberg et al., 1996; Geisler et al., 2010, 2013; Lischke et al., 2019; Williams et al., 2015), with increased pro-sociality, altruistic behavior (Bornemann et al., 2016; Kogan et al., 2014; Kok & Fredrickson, 2010; Stellar & Keltner, 2017), compassion (Di Bello et al., 2020 for a meta-analysis), and a more accurate understanding of others' mental states (Lischke et al., 2017). On the contrary, individuals with lower vmHRV appear to be characterized by inflexibility and a reduced ability to respond to situational demands (Thayer & Lane, 2000), poorer self-regulatory capacity (Thayer & Lane, 2009), a higher defensiveness

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personality trait (Lane et al., 1990; Weinberger, 1990) and diminished inhibition of the physiological stress responses to safe or ambiguous stimuli (e.g., Brosschot et al., 2017).

An important mechanism that affects various aspects of interpersonal interactions and social decisions is the tendency to make inferences about personality and intentions from facial appearance (Todorov et al., 2015). Based on the first impression of a face, these inferences can be made very quickly and long-lasting (Willis & Todorov, 2006). Regardless of an attribution's accuracy, certain facial features are more likely to be linked to positive personality traits, more friendly behavior, and more favorable consequences in political elections, court cases, healthcare, and hiring (e.g., Bagnis et al., 2021; Bagnis et al., 2020; Schäfer et al., 2016; Todorov, 2005; Wilson & Rule, 2015; for a review, see Todorov et al., 2015). Face evaluation based on social traits involves an overgeneralization of adaptive mechanisms for inferring harmful or helpful intentions. This evaluation of faces is impacted by levels of trust, which best approximate the valence evaluation of faces (Oosterhof & Todorov, 2008, Todorov et al. 2008; Todorov et al., 2015) which affects approach/avoidance behavior (Todorov et al., 2015). Similarly, several studies have identified a relationship between vagal tone, social engagement, and approach/avoidance tendencies (Davidson, 1998; Porges et al., 1994; Porges, 1995; Shahrestani et al., 2014) - suggesting avenues to hypothesize about a relationship between vmHRV and the processing of social stimuli, such as faces. Recently, two independent studies demonstrated that vmHRV modulates facial memory, with individuals with higher levels of vmHRV gaining enhanced memory for faces from (i) the associated affectively relevant behavioral information (Mattarozzi et al., 2019) and (ii) facial appearance (Wendt et al., 2019). Given the existing evidence, it seems reasonable to assume that vmHRV may modulate not only memory formation of socially relevant stimuli but also face perception in terms of the automatic process of social attributions from facial appearance (Todorov & Oh, 2021). To our knowledge, the present study is the first to investigate the link between biologically based individual differences, such as vmHRV, and face evaluation based on social traits. Specifically, we first measured resting vmHRV in individuals and then asked them to rate faces based on their first impressions of various social traits, i.e., trustworthiness, dominance, typicality, familiarity, caring, and attractiveness. We chose these attributes due to their relevance in different social contexts. In particular, trustworthiness and dominance are the two most important trait dimensions that determine the social evaluation of faces, signaling whether a person should be approached or avoided and as an indication of people's physical strength and weakness, respectively (Oosterhof & Todorov, 2008). Typicality and familiarity are important for social perception and cognition since people tend to prefer typical and familiar facial configurations, and judge familiar faces to be safer than unfamiliar ones (Bartlett et al., 1984; Zebrowitz et al., 2007). Notably, appearances perceived as more caring and attractive are associated with evolutionary advantages, as these traits respectively represent signals of safety (Mattarozzi et al., 2020) and health (Shackelford & Larsen, 1999). This study therefore tested the hypothesis that vmHRV could be associated to inferences based on facial appearance, such that higher levels of resting vmHRV would predict higher ratings of traits that favor approaching behaviors.

Method

Participants

We performed an a priori power analysis to determine the number of participants needed. G*Power indicated that we had to recruit 74 participants to have sufficient power (1 - $\beta = 0.95$, $\alpha = 0.05$) to detect medium-sized effects. A total of 83 healthy participants volunteered for the study. We excluded data from four participants due to extreme outliers in vmHRV values (z-scores $> \pm 3$ SD), yielding 79 participants (44 women, age 20.56 ± 1.41 years).

All participants were university students, receiving partial course credit for their participation. They gave written informed consent before participating in the study and were fully debriefed after they completed the study. The study was approved by the Ethics Committee of the University of Bologna and conducted in accordance with the 1964 Declaration of Helsinki and its later addenda.

Procedure

Participants were instructed not to engage in strenuous exercise on the day of the study and to abstain from alcohol, caffeine, and nicotine within twenty-four hours prior to their participation. Participants were asked to sit in a comfortable chair upon arrival at the laboratory. After the electrocardiography (ECG) electrodes were placed on their chest, participants were instructed to sit still, breathe spontaneously, and leaf through a neutral-valenced garden magazine during the HR recording (i.e., "vanilla baseline," Jennings et al., 1992). Immediately after receiving instructions, HR was recorded for a total duration of 8 min. Participants then completed the first impression rating task. At home, participants answered a series of lifestyle questions (e.g., nicotine, physical activity) via the online survey platform Qualtrics. After completing the questionnaire, they received a brief written description of the aims of the study.

HRV assessment

Heart rate was recorded as beat-to-beat interval in ms using BodyGuard 2 (FirstBeat Technologies Ltd., Jyväskylä, Finland; Parak & Korhonen, 2015). VmHRV was assessed by calculating the root mean square value of successive beat-to-beat interval differences (rMSSD), which reflects the vagal regulation of HR and is less susceptible to respiratory influences (Laborde et al., 2017; Task Force, 1996). Throughout the remainder of this manuscript, we will use the term vmHRV to specifically refer to rMSSD. VmHRV analyses were performed using Kubios HRV software (Tarvainen et al., 2014). This software uses an advanced detrending method based on the formulation of smoothing priorities, where the filtering effect is attenuated at the beginning and the end of the data, avoiding the distortion of the data end-points. Furthermore, the frequency response of the method is fitted with a single smoothing parameter chosen so that the spectral components of interest are not significantly affected by detrending (Tarvainen et al., 2002). Kubios HRV includes two methods for correcting for artefacts and ectopic beats: (1) a threshold-based correction, where these are simply corrected by comparing each RR interval value to a local average interval, and (2) an automatic correction, where artefacts are detected from a time series consisting of the differences between successive RR intervals.

First impression rating task

16 faces from the Chicago Face Database (Ma et al., 2015) were selected based on a standardized average (z-score) of their trustworthiness ratings, as in Oosterhof and Todorov (2008). Since it would have been impossible to select faces according to every trait examined in the study, we chose to select them according to trustworthiness. In fact, although people make a variety of inferences from faces, studies suggest that judgments about trustworthiness approximate the intrinsic valence of faces that underlies the other social judgments (Oosterhof & Todorov, 2008; Todorov et al., 2008). Specifically, we selected four male and four female faces that were rated as trustworthy (i.e., with a positive intrinsic valence, z = > 0.50) and four male and four female faces that were rated as untrustworthy (i.e., with a negative intrinsic valence, z = > − 0.50).

Each participant was instructed to report their first "gut impression" and was asked to rate the faces in terms of trustworthiness, dominance, typicality, familiarity, caring, and attractiveness. Participants rated the targets for all traits at once. Ratings were collected on a Likert-type scale ranging from 1 (not at all) to 9 (extremely). Using Qualtrics software, faces were presented individually and randomly in the center of a computer screen (18 cm high x 21 cm wide) at the 80 cm viewing distance from the center of a 19-in computer monitor, subtending a visual angle of approximately 12.83° − 14.95°. Each photo presentation was preceded by a central fixation cross (500 ms). There was no time limit or feedback during the task.

Statistical analysis

Data were first analyzed for skewness and kurtosis to inspect for non-normality. Data did not differ from normality beyond acceptable limits (Hair et al., 2010) and, therefore, parametric tests were used in all analyses. Preliminary analyses were conducted to examine the characteristics of the participants. For this purpose, correlations were calculated between the vmHRV and habits related to smoking, coffee consumption, alcohol consumption and physical activity. Bivariate correlations were performed to determine the relationship between vmHRV and traits ratings from facial appearance, while a multivariate simple linear regression analysis was computed with vmHRV as an independent variable and ratings of trustworthiness, dominance, typicality, familiarity, caring, and attractiveness as dependent variables to investigate whether inter-individual differences in vmHRV could predict trait ratings. Sex was used as a between-factor variable, while age and BMI were used as covariates.

All statistical analyses were conducted using SPSS® 28.0 software (SPSS, Chicago, IL, USA). The significance level was set at $p < .05$.

Results

Table 1 presents descriptive statistics and *t*-test results for sex differences in the main variables of the study. Habits in terms of smoking ($r = -.10$, $p = .40$), coffee consumption ($r = -.04$, $p = .71$), alcohol consumption ($r = -.06$, $p = .59$) and physical activity ($r = .12$, $p = .29$) were not significantly correlated with vmHRV. Positive correlations were found between vmHRV and ratings of trustworthiness ($r = .26$, $p < .05$), dominance ($r = .23$, $p < .05$) and caring ($r = .39$, $p < .001$).

Multivariate simple linear regression showed a statistical significance in trait ratings scores based on vmHRV, F (6, 65) = 2.40, $p < .05$, Wilk's $\Lambda = 0.81$, partial $\eta^2 = 0.18$, while sex, age, and BMI were found not to be statistically significant. Univariate analyses revealed that vmHRV was able to significantly predict caring (F (1, 70) = 12.67; $p < .001$; partial $\eta^2 = 0.15$, R^2 adj = 0.18; $B = 0.01$, $p < .001$) and trustworthiness (F (1, 70) = 5.36; $p < .05$; partial $\eta^2 = 0.07$, R^2 adj = 0.07; $B = 0.01$, $p < .05$) rating scores. Figure 1 shows positive correlation between vmHRV and the significant

Table 1 *Descriptive statistics for female and male participants*

	Females		Males		Total			
	M	*SD*	*M*	*SD*	*M*	*SD*	*t* (77)	*p*
Age (years)	20.62	1.67	20.49	1.01	20.56	1.41	0.40	0.69
BMI (Kg/m^2)	21.76	3.09	23.48	3.36	22.54	3.31	2.31	<0.05
vmHRV (ms)	34.07	21.16	39.21	24.81	36.34	22.84	0.99	0.32
Social traits								
Trustworthiness	4.75	0.95	4.86	0.81	4.80	0.89	0.55	0.58
Dominance	4.83	0.84	5.05	0.86	4.91	0.85	1.06	0.29
Typicality	5.28	1.16	4.94	1.13	5.13	1.15	1.31	0.19
Familiarity	3.83	0.92	3.83	1.03	3.83	0.96	0.03	0.98
Caring	4.46	0.90	4.59	0.87	4.52	0.88	0.64	0.52
Attractiveness	4.09	0.94	3.95	0.81	4.03	0.88	0.72	0.48

Note. N = 79 (44 females, 35 males). BMI = Body Mass Index; vmHRV = vagally-mediated Heart Rate Variability

dependent variables in the regression model (i.e., caring and trustworthiness rating scores).

Discussion

Autonomic responses modulate the individual's affective experience, influencing engagement in the social environment (Berntson et al., 1997). We hypothesized that resting vmHRV would predict social attributions from facial appearance. Results showed that higher levels of vmHRV were associated with higher scores on caring and trustworthiness ratings, suggesting that strangers' faces were more likely to be perceived as safer and less threatening by these individuals. This is consistent with phylogenetic theories linking vagal modulation to social bonding, social engagement, and prosocial behavior (Porges, 2007; Thayer & Lane, 2009). Higher vmHRV has been associated with better adaptability and flexibility in coping with various situational demands, as well as with prosocial motives and emotions that help alleviate and prevent psychological distress (Petrocchi & Cheli, 2019). On the other hand, lower vmHRV has been associated with the release of the default physiological defensive response in a safe environment (e.g., Brosschot et al., 2017). Current data suggest that resting vmHRV contributes to shape social attributions about strangers such that individuals with higher vmHRV tend to perceive others as more caring and trustworthy, and therefore being more willing to approach and bond with others.

Caring and bonding motivations are ingrained in human nature and rooted in evolutionarily developed brain systems that we share with other mammals (Panksepp, 2004). From birth, survival depends on others, especially on caretakers. Humans learn to recognize them as important, to see them as social buffers, and to perceive the environment as safer in their presence (Bowlby, 1958). Perceiving strangers as more caring may contribute to fostering social behaviors that have an evolutionary advantage. As such, we found that higher levels of vmHRV were associated with higher ratings on caring, i.e., with a greater tendency to maximize the perception of facial cues that suggest more caring behavior and a feeling of safety. Consistently, higher vmHRV has predicted a higher feeling of safeness during stressful circumstances (Makovac et al., 2022), while a reduction in vmHRV has been associated with social inhibition, avoidance, and anxiety (Alvares et al., 2013).

Facial appearance-based ratings of trustworthiness have been associated with the functional role of inferring behavioral intention and preparing the decision to approach or avoid a stranger during social interactions (Todorov, 2008). Perceiving strangers as more trustworthy (i.e., as less threatening) may increase the chance of cooperation

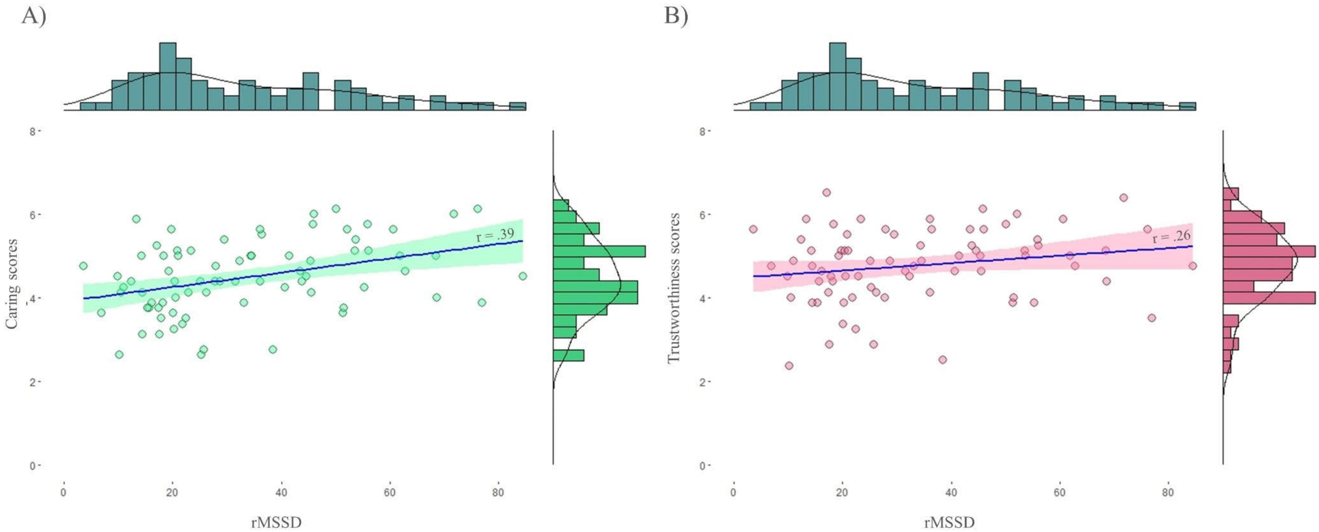

Fig. 1 *Scatter plots illustrating the positive correlations between vmHRV and rating scores*
Note. Scatter plots with marginal histograms and density lines showing relationship between vmHRV (rMSSD) and rating scores. Panel A shows the correlation between vmHRV and caring scores, while panel B shows the correlation between vmHRV and trustworthiness scores. The small circles represent the plotted values obtained for each of the variables while the blue lines represent the fitted regression lines. The bands around the regression lines represent the 95% confidence interval. rMSSD = root mean square value of successive beat-to-beat interval differences

and affiliation and serve to facilitate social interactions. Not surprisingly, we found that higher levels of vmHRV are associated with higher ratings on trustworthiness, maybe because individuals with higher vmHRV are more prone to detect potential relevant positive cues in the absence of other information. This is consistent with studies showing that higher vmHRV is associated with lower negativity bias, i.e., the tendency to favor negative information over positive (Shook et al., 2007). In general, it seems that individuals with higher vmHRV are adaptively engaged in the social world. For example, compared to individuals with lower vmHRV, they are more inclined to perceive neutral stimuli as potential cooperators and to remember negative stimuli to avoid potential danger (Lischke et al., 2018; Mattarozzi et al., 2019; Wendt et al., 2019).

In this study, we found no evidence that vmHRV may be a predictor of judgments of typicality, familiarity, and attractiveness. One possible reason for this is that these social traits differ from trustworthiness and caring in their ability to predict the behavior or decision of others in an unknown situation. As Todorov and Ho's (2021) model suggests, judgments of trustworthiness and caring are related to perceived valence and represent an overgeneralization of adaptive mechanisms to infer behavioral intentions and signal whether or not to approach a person. Instead, judgments of typicality, familiarity and attractiveness are more rooted in individual experience and are associated with less stable dispositions (Verosky & Todorov, 2013). People who interact with someone whose facial features are typical or familiar tend to generalize their evaluation and transfer the characteristics of familiar people to strangers. However, because our experiences with familiar people are mixed and heterogeneous (i.e., both positive and negative), predicting the intentions of strangers with typical or familiar facial features in terms of valence would be more difficult and less accurate than predicting the intentions of strangers perceived as more trustworthy or caring. Similarly, people cannot infer the intentions of others from perceived attractiveness, as research suggests that cues of attractive facial features alone do not signal a potentially effective interaction but require more powerful cues (e.g., a smile) (Okubo et al., 2015).

Finally, it is worth noting that, although vmHRV does not appear to be a specific predictor of dominance judgements, we found a positive correlation between the level of vmHRV and dominance judgements. This result is consistent with the findings on the traits of trustworthiness and caring, as dominance (i.e., social cues that signal power, strength, and potential threat) represents the other component of Todorov and Ho's (2021) model that leads to inferences about intent and ability to harm. Overall our significant and non-significant results suggest that differences in vmHRV are more likely to be associated with differences in the evaluation of social traits (i.e., trustworthiness, caring, and dominance) that signal the behavioral intentions of others.

There are limitations to the interpretation of the present results. Firstly, although the relationship between vmHRV and social attributions and behavior is well recognized and supported by existing meta-analytic studies on the topic (e.g., Di Bello et al., 2020; Shahrestani et al., 2014; Zammuto et al., 2021), effect sizes are rather small. This is not surprising if we consider that the current study focused on granular constructs (e.g., trustworthiness) and attempted for the first time to disentangle fine effects (e.g., trustworthiness versus familiarity or attractiveness). In contrast, previous investigations mostly assessed the association of vmHRV with broader social constructs, such as empathic behavior (e.g., Sassenrath et al., 2021), with effects of larger size. Secondly, findings suggest that both vmHRV (Schmalenberger et al., 2020) and face perception (Macrae et al., 2002) are influenced by menstrual cycle and this potential confounder was not taken into account in the current investigation. Similarly, the emotional state of participants at baseline was not assessed and this confounding variable may have potentially biased the results; however, Vanilla baseline has been used as a way to minimize individual differences in worrisome thoughts and anticipatory state anxiety. Moreover, vmHRV measures are known to decrease with age (Agelink et al., 2001), and the sample of the present study consisted of healthy students; it is mandatory that the current findings are replicated in different age groups from the general population.

Conclusion

Overall, these data suggest that tonic vmHRV may be an important individual difference that biases trait inferences from faces. Specifically, we have shown that higher levels of vmHRV are associated with a greater tendency to perceive a stranger's face as less negative (i.e., more trustworthy, and more caring), thereby minimizing social evaluative threat and maximizing affiliative social cues. As a result, individuals with higher resting vmHRV might be more likely to form positive relationships, which could help them cooperate and better manage stressful experiences in social situations where they are surrounded by strangers. On the other hand, individuals with lower vmHRV (compared with individuals with higher vmHRV) might be inclined to judge others more negatively (i.e., to "err on the side of caution") and thus, to carry out avoidance behaviors, which can hamper adaptive social strategies, such as cooperation, with less evolutionary advantages.

The current study supports phylogenetic theories underpinning the view that vmHRV may function as a biomarker of approach-related behavior and social engagement (Porges, 2007), and extend previous findings further pointing that tonic vagal modulation of the heart may contribute to the rapid and unconscious processing streams underlying facial appearance-based judgments (e.g., Frisanco et al., 2021). This is not unexpected, since that high resting vmHRV is considered a proxy for functional ventromedial prefrontal cortex inhibitory control (Thayer et al., 2012 for a meta-analysis), and the latter is required for predicting others' intentions (Leopold et al., 2012).

Given that the tendency to adopt a "better-safe-than-sorry" processing strategy has been proposed as a risk factor for mental and somatic health (Van den Bergh et al., 2021), the present results are also of clinical relevance. Several strategies (e.g., physical exercise, slow breathing, psychotherapeutic interventions) have been identified that are capable of increasing resting vmHRV (Vanderhasselt & Ottaviani, 2022), and Bornemann and colleagues (2016) have already reported that the ability to voluntarily upregulate vmHRV by the use of biofeedback predicts individual differences in altruistic prosocial behavior. In conclusion, future studies are warranted to assess whether the experimental manipulation of vmHRV has the potential to change individuals' first impressions of strangers and its consequences.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

References

Adolphs, R. (2003). Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience*, *4*(3), 165–178. https://doi.org/10.1038/nrn1056

Agelink, M. W., Malessa, R., Baumann, B., Majewski, T., Akila, F., Zeit, T., & Ziegler, D. (2001). Standardized tests of heart rate variability: normal ranges obtained from 309 healthy humans, and effects of age, gender, and heart rate. *Clinical Autonomic Research*, *11*(2), 99–108. https://doi.org/10.1007/BF02322053

Alvares, G. A., Quintana, D. S., Kemp, A. H., Van Zwieten, A., Balleine, B. W., Hickie, I. B., & Guastella, A. J. (2013). Reduced heart rate variability in social anxiety disorder: Associations with gender and Symptom Severity. *Plos One*, *8*(7), e70468. https://doi.org/10.1371/journal.pone.0070468

Bagnis, A., Caffo, E., Cipolli, C., De Palma, A., Farina, G., & Mattarozzi, K. (2020). Judging health care priority in emergency situations: patient facial appearance matters. *Social Science and Medicine*, *260*(May), https://doi.org/10.1016/j.socscimed.2020.113180

Bagnis, A., Cremonini, V., Pasi, E., Pasquinelli, G., Rubbi, I., Russo, P. M., & Mattarozzi, K. (2021). Facing up to bias in healthcare: the influence of familiarity appearance on hiring decisions. *Applied Cognitive Psychology*, 1–7. https://doi.org/10.1002/acp.3873

Bartlett, J. C., Hurry, S., & Thorley, W. (1984). Typicality and familiarity of faces. *Memory & Cognition*, *12*(3), 219–228. https://doi.org/10.3758/BF03197669

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

Bornemann, B., Kok, B. E., Böckler, A., & Singer, T. (2016). Helping from the heart: Voluntary upregulation of heart rate variability predicts altruistic behavior. *Biological Psychology*, *119*, 54–63. https://doi.org/10.1016/j.biopsycho.2016.07.004

Bowlby, J. (1958). The nature of the child's tie to his mother. *International Journal of Psycho-Analysis*, *39*, 350–373. https://doi.org/10.4324/9780429475931-15

Brosschot, J. F., Verkuil, B., & Thayer, J. F. (2017). Exposed to events that never happen: generalized unsafety, the default stress response, and prolonged autonomic activity. *Neuroscience and Biobehavioral Reviews*, *74*, 287–296. https://doi.org/10.1016/j.neubiorev.2016.07.019

Colonnello, V., Petrocchi, N., Farinelli, M., & Ottaviani, C. (2017). Positive social interactions in a Lifespan Perspective with a focus on Opioidergic and Oxytocinergic Systems: implications for Neuroprotection. *Current Neuropharmacology*, *15*(4), 543–561. https://doi.org/10.2174/1570159x14666160816120209

Costa, P. T., & McCrae, R. R. (1985). *The NEO personality Inventory Manual Psychological Assessment Resources*. Odessa, FL.

Costa, P. T. Jr., & McCrae, R. R. (1992). Four ways five factors are basic. *Personality and individual differences*, *13*(6), 653–665.

Davidson, R. J. (1998). Affective style and affective disorders: perspectives from affective neuroscience. *Cognition & Emotion*, *12*, 307–330.

Di Bello, M., Carnevali, L., Petrocchi, N., Thayer, J. F., Gilbert, P., & Ottaviani, C. (2020). The compassionate vagus: a meta-analysis on the connection between compassion and heart rate variability. *Neuroscience & Biobehavioral Reviews*, *116*, 21–30. https://doi.org/10.1016/J.NEUBIOREV.2020.06.016

Eisenberg, N., Fabes, R. A., Murphy, B., Karbon, M., Smith, M., & Maszk, P. (1996). The relations of children's dispositional empathy-related responding to their emotionality, regulation, and social functioning. *Developmental Psychology*, *32*, 195–209. https://doi.org/10.1037/0012-1649.32.2.195

Frisanco, A., Biella, M., Brambilla, M., & Kret, M. E. (2021). All that meets the eye: The contribution of reward processing and pupil mimicry on pupillary reactions to facial trustworthiness. *Current Psychology*, 1–8.

Geisler, F. C. M., Vennewald, N., Kubiak, T., & Weber, H. (2010). The impact of heart rate variability on subjective well-being is mediated by emotion regulation.*Pers. Individ. Dif. 49*,723–728. https://doi.org/10.1016/j.paid.2010.06.015

Geisler, F. C. M., Kubiak, T., Siewert, K., & Weber, H. (2013). Cardiac vagal tone is associated with social engagement and self-regulation. *Biological Psychology*, *93*(2), 279–286. https://doi.org/10.1016/j.biopsycho.2013.02.013

Hair, J., Black, W. C., Babin, B., & Anderson, R. E. (2010). *Multivariate Data Analysis: Global Edition, 7th Edition*. Pearson. https://www.pearson.com/uk/educators/higher-education-educators/program/Hair-Multivariate-Data-Analysis-Global-Edition-7th-Edition/PGM916641.html

Jennings, J. R., Kamarck, T., Stewart, C., Eddy, M., & Johnson, P. (1992). Alternate Cardiovascular Baseline Assessment techniques: Vanilla or resting baseline. *Psychophysiology*, *29*(6), 742–750. https://doi.org/10.1111/j.1469-8986.1992.tb02052.x

Kogan, A., Oveis, C., Carr, E., Gruber, W., Mauss, J., Shallcross, I. B., A., et al. (2014). Vagal activity is quadratically related to prosocial traits, prosocial emotions, and observer perceptions of prosociality. *J Pers Soc Psychol*, *107*, 1051–11063. https://doi.org/10.1037/a0037509

Kok, B. E., & Fredrickson, B. L. (2010). Upward spirals of the heart: autonomic flexibility, as indexed by vagal tone, reciprocally and prospectively predicts positive emotions and social connectedness. *Biological Psychology*, *85*(3), 432–436. https://doi.org/10.1016/j.biopsycho.2010.09.005

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research - recommendations for experiment planning, data analysis, and data reporting. *Frontiers in Psychology*, *8*(FEB), 213. https://doi.org/10.3389/fpsyg.2017.00213

Lane, R. D., Merikangas, K. R., Schwartz, G. E., Huang, S. S., et al. (1990). Inverse relationship between defensiveness and lifetime prevalence of psychiatric disorder. *American Journal of Psychiatry*, *147*, 573–578.

Leopold, A., Krueger, F., Dal monte, O., Pardini, M., Pulaski, S. J., Solomon, J., & Grafman, J. (2012). Damage to the left ventromedial prefrontal cortex impacts affective theory of mind. *Social Cognitive and Affective Neuroscience*, *7*(8), 871–880. https://doi.org/10.1093/scan/nsr071

Lischke, A., Lemke, D., Neubert, J., Hamm, A. O., & Lotze, M. (2017). Inter-individual differences in heart rate variability are associated with inter-individual differences in mind-reading. *Scientific Reports*, *7*(1), 1–6. https://doi.org/10.1038/s41598-017-11290-1

Lischke, A., Mau-Moeller, A., Jacksteit, R., Pahnke, R., Hamm, A. O., & Weippert, M. (2018). Heart rate variability is associated with social value orientation in males but not females. *Scientific Reports*, *8*(1), 1–9. https://doi.org/10.1038/s41598-018-25739-4

Lischke, A., Weippert, M., Mau-Moeller, A., Päschke, S., Jacksteit, R., et al. (2019). Sexspecific associations between inter-individual differences in heart rate variability and inter-individual differences in emotion regulation. *Front Neurosci*, *12*, 1040. https://doi.org/10.3389/fnins.2018.01040

Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: a free stimulus set of faces and norming data. *Behavior Research Methods*, *47*(4), 1122–1135. https://doi.org/10.3758/s13428-014-0532-5

Macrae, C. N., Alnwick, K. A., Milne, A. B., & Schloerscheidt, A. M. (2002). Person perception across the menstrual cycle: hormonal

influences on social-cognitive functioning. *Psychological Science*, *13*(6), 532–536. https://doi.org/10.1111/1467-9280.00493
Makovac, E., Carnevali, L., Medina, S., Sgoifo, A., Petrocchi, N., & Ottaviani, C. (2022). Safe in my heart: resting heart rate variability longitudinally predicts emotion regulation, worry, and sense of safeness during COVID-19 lockdown. *Stress (Amsterdam, Netherlands)*, *25*(1), 9–13. https://doi.org/10.1080/10253890.2021.1999408
Mattarozzi, K., Caponera, E., Russo, P. M., Colonnello, V., Bassetti, M., Farol, & Todorov, A. (2020). Pain and satisfaction: healthcare providers ' facial appearance matters. *Psychological Research*, *0123456789*. https://doi.org/10.1007/s00426-020-01330-3
Mattarozzi, K., Colonnello, V., Thayer, J. F., & Ottaviani, C. (2019). Trusting your heart: long-term memory for bad and good people is influenced by resting vagal tone. *Consciousness and Cognition*, *75*, 102810. https://doi.org/10.1016/j.concog.2019.102810
Okubo, M., Ishikawa, K., Kobayashi, A., Laeng, B., & Tommasi, L. (2015). Cool guys and warm husbands: the effect of smiling on male facial attractiveness for short- and long-term relationships. *Evolutionary Psychology*, *13*(3), 1–8. https://doi.org/10.1177/1474704915600567
Oosterhof, N. N., & Alexander Todorov. (2008). The functional basis of face evaluation. *Proceedings of the National Academy of Sciences of the United States of America*, *171*(1–3), 1024–1031. https://doi.org/10.1016/j.jhazmat.2009.06.118
Panksepp, J. (2004). *Affective neuroscience: The foundations of human and animal emotions.* Oxford university press.
Parak, J., & Korhonen, I. (2015). Accuracy of Firstbeat BodyGuard 2 beat-to-beat heart rate monitor. *Accessed May 8*:2017.
Petrocchi, N., & Cheli, S. (2019). The social brain and heart rate variability: implications for psychotherapy. *Psychology and Psychotherapy: Theory Research and Practice*, *92*(2), 208–223. https://doi.org/10.1111/papt.12224
Porges, S. W., Doussard-Roosevelt, J. A., & Maiti, A. K. (1994). Vagal tone and the physiological regulation of emotion. *Monographs of the Society for Research in Child Development*, *59*, 167–186.
Porges, S. W. (1995). Orienting in a defensive world: mammalian modifications of our evolutionary heritage. *A polyvagal theory Psychophysiology*, *32*(4), 301–318.
Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, *74*(2), 116–143. https://doi.org/10.1016/j.biopsycho.2006.06.009
Sahdra, B. K., Ciarrochi, J., & Parker, P. D. (2015). High-frequency heart rate variability linked to affiliation with a new group. *Plos One*, *10*(6), https://doi.org/10.1371/journal.pone.0129583
Schäfer, G., Prkachin, K. M., Kaseweter, K. A., & Williams, A. C. D. C. (2016). Health care providers' judgments in chronic pain: the influence of gender and trustworthiness. *Pain*, *157*(8), 1618–1625. https://doi.org/10.1097/j.pain.0000000000000536
Schmalenberger, K. M., Eisenlohr-Moul, T. A., Jarczok, M. N., Eckstein, M., Schneider, E., Brenner, I. G., Duffy, K., Schweizer, S., Kiesner, J., Thayer, J. F., & Ditzen, B. (2020). Menstrual cycle changes in vagally-mediated heart rate variability are associated with progesterone: evidence from two within-person studies. *Journal of Clinical Medicine*, *9*(3), 617. https://doi.org/10.3390/jcm9030617
Shackelford, T. K., & Larsen, R. J. (1999). Facial attractiveness and Physical Health. *Evolution and Human Behavior*, *20*(1), 71–76. https://doi.org/10.1016/S1090-5138(98)00036-1
Shahrestani, S., Stewart, E. M., Quintana, D. S., Hickie, I. B., & Guastella, A. J. (2014). Heart rate variability during social interactions in children with and without psychopathology: a meta-analysis. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *55*(9), 981–989. https://doi.org/10.1111/JCPP.12226
Shook, N. J., Fazio, R. H., & Vasey, M. W. (2007). Negativity bias in attitude learning: a possible indicator of vulnerability to emotional disorders? *Journal of Behavior Therapy and Experimental Psychiatry*, *38*(2), 144–155. https://doi.org/10.1016/j.jbtep.2006.10.005
Smith, T. W., Deits-Lebehn, C., Williams, P. G., Baucom, B. R., & Uchino, B. N. (2020). Toward a social psychophysiology of vagally mediated heart rate variability: concepts and methods in self-regulation, emotion, and interpersonal processes. *Social and Personality Psychology Compass*, *14*(3), e12516.
Stellar, J. E., & Keltner, D. (2017). In P. Gilbert (Ed.), *Compassion, Concepts, Research and Applications* (pp. 120–134). London, UK: Routledge.
Tarvainen, M. P., Niskanen, J. P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, *113*(1), 210–220. https://doi.org/10.1016/J.CMPB.2013.07.024
Tarvainen, M. P., Ranta-aho, P. O., & Karjalainen, P. A. (2002). An advanced detrending method with application to HRV analysis. *IEEE Transactions on Biomedical Engineering*, *49*(2), 172–175. https://doi.org/10.1109/10.979357
Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation*, *93*(5), 1043–1065. https://doi.org/10.1161/01.CIR.93.5.1043
Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews*, *36*(2), 747–756. https://doi.org/10.1016/J.NEUBIOREV.2011.11.009
Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*(3), 201–216. https://doi.org/10.1016/S0165-0327(00)00338-4
Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. *Neuroscience and Biobehavioral Reviews*, *33*(2), 81–88. https://doi.org/10.1016/j.neubiorev.2008.08.004
Todorov, A. (2005). Inferences of competence from Faces Predict Election Outcomes. *Science*, *308*(5728), 1623–1626. https://doi.org/10.1126/science.1110589
Todorov, A., Baron, S. G., & Oosterhof, N. N. (2008). Evaluating face trustworthiness: a model based approach. *Social Cognitive and Affective Neuroscience*, *3*(2), 119–127. https://doi.org/10.1093/scan/nsn009
Todorov, A., & Oh, D. (2021). The structure and perceptual basis of social judgments from faces. In B. Gawronski (Ed.), *Advance in experimental social psychology* (pp. 189–245). Academic Press.
Todorov, A., Olivola, C. Y., Dotsch, R., & Mende-Siedlecki, P. (2015). Social Attributions from Faces: determinants, Consequences, Accuracy, and functional significance. *Annual Review of Psychology*, *66*(1), 519–545. https://doi.org/10.1146/annurev-psych-113011-143831
Van den Bergh, O., Brosschot, J., Critchley, H., Thayer, J. F., & Ottaviani, C. (2021). Better safe than sorry: a common signature of General Vulnerability for psychopathology. *Perspectives on Psychological Science*, *16*(2), 225–246. https://doi.org/10.1177/1745691620950690
Vanderhasselt, M. A., & Ottaviani, C. (2022). Combining top-down and bottom-up interventions targeting the vagus nerve to increase resilience. *Neuroscience and Biobehavioral Reviews*, *132*, 725–729. https://doi.org/10.1016/j.neubiorev.2021.11.018
Verosky, S. C., & Todorov, A. (2013). When physical similarity matters: mechanisms underlying affective learning generalization to the evaluation of novel faces. *Journal of Experimental Social Psychology*, *49*(4), 661–669. https://doi.org/10.1016/j.jesp.2013.02.004

Wilson, J. P., & Rule, N. O. (2015). Facial trustworthiness predicts Extreme Criminal-Sentencing outcomes. *Psychological Science*, *26*(8), 1325–1331. https://doi.org/10.1177/0956797615590992

Weinberger, D. A. (1990). The construct validity of the repressive coping style. In J. Singer (Ed.), *Repression and dissociation*. Chicago: University of Chicago Press.

Wendt, J., Weymar, M., Junge, M., Hamm, A. O., & Lischke, A. (2019). Heartfelt memories: cardiac vagal tone correlates with increased memory for untrustworthy faces. *Emotion*, *19*(1), 178–182. https://doi.org/10.1037/emo0000396

Williams, D. W. P., Cash, C., Rankin, C., Bernardi, A., Koenig, J., & Thayer, J. F. (2015). Resting heart rate variability predicts self-reported difficulties in emotion regulation: a focus on different facets of emotion regulation. *Frontiers in Psychology*, *6*(MAR), 261. https://doi.org/10.3389/fpsyg.2015.00261

Willis, J., & Todorov, A. (2006). Making up your mind after a 100-Ms exposure to a Face. *Psychological Science*, *17*(7), 592–598.

Zammuto, M., Ottaviani, C., Laghi, F., & Lonigro, A. (2021). The heart in the mind: a systematic review and Meta-analysis of the Association between theory of mind and Cardiac Vagal Tone. *Frontiers in Physiology*, *12*, 1035. https://doi.org/10.3389/FPHYS.2021.611609/BIBTEX

Zebrowitz, L. A., Bronstad, M. P., & Lee, H. K. (2007). The contribution of face familiarity to ingroup favoritism and stereotyping. *Social Cognition*, *25*(2), 306–338. https://doi.org/10.1521/soco.2007.25.2.306

Zebrowitz, L. A., Bronstad, M. P., & Lee, H. K. (2007). The contribution of face familiarity to ingroup favoritism and stereotyping. *Social Cognition*, *25*(2), 306–338. https://doi.org/10.1521/soco.2007.25.2.306