When the Body Knows: Interoceptive Accuracy Enhances Physiological But Not Explicit
Differentiation Between Liars and Truth-Tellers

Gunderson, C. A.¹, ten Brinke, L. M.^{2*}, Sokol-Hessner, P.^{1*}

1. Department of Psychology, University of Denver, Denver, CO, United States. 2. University of British
Columbia, Okanagan, BC, Canada

** co-senior authorship*

Acknowledgments: Ali Watson, Eric Andrews, and Thanh Viet Anh Vo for assistance with data collection.

Abstract

Recent research suggests that people experience distinct physiological reactions to lies versus truths. It is unclear, however, if this experience is incorporated into greater truth-lie judgment accuracy. We hypothesized individuals with high interoceptive accuracy—those with greater access to bodily experiences and stronger physiological responses to emotional stimuli—might be particularly likely to accurately discriminate high-stakes, emotional lies and truths.

Participants ($n = 71$) completed two study sessions: the first assessed their interoceptive accuracy with heartbeat detection measures and the second assessed their deception detection ability while measuring their physiological reactivity. Interoceptive accuracy was associated with a greater difference in vasoconstriction to liars (vs. truth-tellers), suggesting that interoception was positively associated with physiological sensitivity to deception. Interoceptive accuracy, however, was unrelated to deception detection accuracy. While better interoception provides enhanced physiological signals that could better discriminate lies from truths, it does not improve deception detection accuracy.

Statement of Relevance

For decades, researchers have been searching for individual differences that might make someone a particularly accurate lie detector. We hypothesized that trait interoceptive accuracy might be associated with increased deception detection accuracy for high-stakes, emotional lies. Although we find that interoceptive accuracy is associated with increased physiological reactions to liars compared to truth-tellers, this does not translate into increased accuracy on a deception detection task. Although highly interoceptive individuals do not make for natural lie detectors, they may be promising candidates for a training intervention. Specifically, if participants used their physiological experiences to optimally inform truth-lie judgments, lie detection accuracy would increase by up to 12-13% on average, and potentially more for certain individuals. Future research may consider individual differences that affect deception detection trainability, as opposed to focusing on naive accuracy rates.

When the Body Knows: Interoceptive Accuracy Enhances Physiological But Not Explicit Differentiation Between Liars and Truth-Tellers

Deception is a common aspect of human communication (DePaulo et al., 1996). While many lies are minor falsehoods told for prosocial reasons (e.g., to spare someone's feelings), some lies are major and self-serving (e.g., a false alibi to conceal criminal behavior), and can cause grave harm if undetected (Ekman, 2009; Vrij, 2008). Despite the importance of being able to discriminate liars from truth-tellers, research suggests that people are poor lie detectors. In a seminal meta-analysis, Bond and DePaulo (2006) reported that people performed at 54% accuracy on lie-detection tasks, when 50% accuracy would be expected by chance alone. These findings raise the dual questions of why lie detection is so poor when it is so important, and how people could become better lie detectors.

One possible reason lie detection appears so poor is that most of the tasks used to measure deception detection accuracy involve low-stakes, laboratory-created stimuli which may differ qualitatively from liars and truth-tellers in real, high-stakes contexts where failed detection is consequential (e.g., von Hippel & Trivers, 2011). Although debate continues about which factors would increase detectability of lies (Hartwig & Bond, 2014), Wright Whelan and colleagues (2014) had participants discriminate real deceptive murderers from genuinely-distressed individuals, all pleading for the safe return of their missing relative. They reported an average accuracy of 70.75%—far greater than previous meta-analytic findings (Bond & DePaulo, 2006; cf. Levine, 2015). In a direct comparison, ten Brinke, Lee and Carney (2019) also found that participants' ability to detect these high-stakes emotional lies (60%) exceeded their ability to detect laboratory-created mock crime lies (45%; Study 1; see also O'Sullivan et al., 2009).

Improved accuracy in the detection of real, high-stakes liars (vs. truth-tellers) may be associated with automatic reactions that occur outside of conscious control, and appear to be associated with behavioral cues to deception (ten Brinke, Lee & Carney, 2019). Although people report holding stereotypical (and often incorrect) beliefs about general behavioral cues to deception (Global Deception Research Team, 2006), ten Brinke and Porter (2012) identified various behavioral cues to deception in this high-stakes context (i.e., emotional facial expressions, verbal and linguistic cues), potentially providing observers with reliable signals upon which to base their explicit veracity decisions (Hartwig & Bond, 2011). Recent research suggests that observers experience increased vasoconstriction and greater generalized arousal when observing deceptive murderers versus genuinely-distressed individuals, a pattern not found for low-stakes laboratory lies (vs. truths; ten Brinke, Lee, & Carney, 2019). However, it is unclear whether these physiological reactions are epiphenomenal or whether people might use these reactions to improve their lie-detection accuracy for real, affectively-laden high-stakes (vs. low-stakes, laboratory-created) lies.

In order to use one's physiological reaction to inform truth or lie judgments, people need to have access to these reactions and accurately identify when vasoconstriction, arousal, or both are occurring. As such, individual differences in interoceptive accuracy could lead to improvements in deception detection accuracy. Previous research suggests that interoceptive accuracy is associated with both increased physiological reactivity to emotional stimuli (e.g., Herbert, Pollatos, Flor, Enck, & Schandry, 2010; Pollatos, Herbert, Matthias, & Schandry, 2007) and increased subjective intensity of emotional experiences (Barrett et al., 2004; Critchley et al., 2004, Wiens et al, 2000; Zaki et al., 2012; Sokol-Hessner et al., 2015). Insofar as liars and truth-tellers elicit differential physiological responses in observers (ten Brinke, Lee, & Carney, 2019),

observers' trait interoceptive accuracy may increase objective or experienced physiological reactions. Accordingly, trait interoceptive accuracy may provide observers with greater physiological signals and awareness of those signals, which can be applied to successfully distinguish truths from lies.

In the current study, we examine individual differences in interoceptive accuracy and physiological reactions to real, emotional, high-stakes liars (vs. truth-tellers). We predict that individuals with greater interoceptive accuracy will experience greater objective physiological differences in response to liars versus truth-tellers. Specifically, interoceptive accuracy will be associated with greater vasoconstriction and arousal responses when observing liars versus truth-tellers. Further, we expect that individuals with high interoceptive accuracy will leverage their subjective experience of those reactions to increase their explicit lie-detection accuracy. The study reported in this article was not formally preregistered. Deidentified data, analysis scripts, and materials for the study are publicly available via OSF at <https://osf.io/crqsk/>. The study was IRB-approved and we report all data exclusions (if any), manipulations, and measures.

Method

Participants

A convenience sample of undergraduate participants were recruited for a two-session study that took place on two separate days, in different research labs. In the first session, participants completed the heartbeat detection task to measure interoceptive accuracy, and in the second session, participants completed the lie detection task. We aimed for a final sample size of 80 participants which would yield 80% power to detect a correlation of 0.27, given an alpha of 0.05. This sample size is also similar to (but larger than) samples used in related work (i.e., Study 1 in ten Brinke et al., 2019).

Session One. In total, 82 undergraduate participants were consented into session one over the course of one year. No data exclusions were made based on physiological signal quality. However, two participants withdrew after consent but before completing the session, four participants did not complete the second interoceptive task (the counting task; see below) due to experimenter error, and a heartbeat electrode malfunction recorded no heartbeats for one participant during the counting task. Thus, 80 participants provided data for the first interoceptive measure (the tone task), and 75 for the second (the counting task).

Session Two. Of the 80 participants who completed the first session, 9 did not schedule or attend session two. Additionally, one participant completed session two but not session one. Thus, a total of 72 participants (22 male; 49 female; 1 non-binary; $M_{\text{age}} = 19.46$, $SD_{\text{age}} = 1.67$) completed the second session. Data from several participants, however, were excluded from analyses due to physiological signal quality issues. Specifically, technical difficulties with equipment resulted in a failure to record one participant's physiological data (i.e., both electrodermal activity [EDA] and pulse plethysmography [PPG]). PPG data from nine participants were excluded because a large portion ($> 10\%$) of their PPG waveform was obscured by movement artifacts. Finally, EDA data of nine participants was excluded due to poor connection between the electrode and skin, resulting in erratic recordings. To maximize statistical power, participants were excluded only when there was missing or problematic data; they were otherwise included in analyses.

Procedure

Session 1: Heartbeat Detection Tasks. After providing informed consent, participants were asked to remove wristwatches, turn off their phone, and place both out of sight, to prevent them from using clocks to assist with performance on the heartbeat detection tasks. A white

noise machine was used at a low volume to block external sounds and ensure a similar auditory environment across participants. After completing the Substance Use Questionnaire (see Supplemental Materials), participants were given a \$5 endowment, and an overview of the session's procedures. The experimenter read detailed instructions out loud while participants silently read along; participants were allowed to ask any questions they may have had. Participants then completed a short comprehension quiz of critical task details. Three ECG electrodes were then attached: one unshielded ground was placed below the left clavicle and two shielded electrodes were placed—one below the right clavicle and one on the lower ribcage in line with the ground electrode.

The experimenter subsequently left the room after encouraging participants to spend a few silent minutes relaxing and trying to feel their heartbeat in their body, without physically feeling for their pulse. After five minutes, the experimenter returned, reminded participants of task details, and then initiated the first of two heartbeat detection tasks.

The synchronization task. The first task measuring interoceptive accuracy was a synchronization-style task (Critchley et al., 2004; Eichler & Katkin, 1994; Katkin, Wiens, & Öhman, 2001; Khalsa et al., 2008; Schneider, Ring, & Katkin, 1998; Sokol-Hessner, Hartley, et al., 2015; Wiens & Palmer, 2001; Wiens et al., 2000). On each trial, the screen would display “Attend” for 1 second, then a sequence of 10 tones (800Hz, 100ms square wave tones made using Audacity software) would play. Heartbeats were collected using AcqKnowledge software (version 4.1, Biopac Systems Inc, Goleta, CA) and an MP160 with an ECG100C module (1000Hz gain, norm mode, 35Hz LPN, high-pass filter at 1.0Hz). The software automatically detected R-waves (the peak of the EKG signal during ventricular depolarization) and subsequently triggered the experiment presentation software (PsychToolBox in MATLAB) on

the stimulus computer to play tones at delays of 200ms or 500ms. All tones within a trial were played at the same delay. Previous research shows that tones played at a 200ms delay are generally perceived as in-sync with the heartbeat, while those played at a 500ms delay are perceived as out-of-sync (Wiens et al., 2000). On each trial, participants judged whether all ten tones were in- or out-of-sync with their heartbeats. After the 10 tones finished playing, there was a brief 0.5s fixation cross, participants then had two seconds to indicate either “in sync” or “delayed”. Next, participants had up to three seconds to indicate their confidence in that judgment from “low” to “high” by pressing two keys to move the cursor on an analog scale to the left or right. After three seconds, the cursor on the scale changed color and locked its position. Following a brief intertrial interval (0.75s or 1.25s, $M = 1s$), the next trial would begin. Before data collection began, participants were given six ‘labeled’ practice trials (i.e., the screen would indicate “in sync” or “delayed” while tones of that type played). Participants then completed 160 trials in four blocks of 40 trials each. Between each block, participants had up to 30 seconds to rest. At the conclusion of this task, a random trial was selected, and if participants were correct on that trial, they earned another \$5 in addition to their endowment; if they were incorrect, they merely kept the \$5 endowment; and if they did not respond on that trial, they lost the \$5 endowment.

Better interoceptive performance is indicated by a greater percentage of correct in-sync/delayed judgments, calculated here in a signal detection theory framework using the unitless sensitivity measure of d' (“d-prime”): the difference between participants’ normalized hit rate and false alarm rate ($z(\text{Hits}) - z(\text{False Alarms})$) (Sokol-Hessner et al., 2015).

Confidence ratings allowed the quantification of participants' metacognitive awareness of their interoceptive accuracy (Fleming & Lau, 2014). For more information about confidence and metacognition, see Supplementary Materials.

The counting task. The second task measuring interoceptive accuracy, immediately following the first, was a standard heartbeat counting task (Schandry, 1981; here called the "counting task"). Specifically, participants were asked to count the number of heartbeats they felt during a variable time period. Trials were 25, 30, 35, 40, 45 and 50 seconds long. On each of the six trials, the screen displayed "Count" at the start of a trial and "Time's up!" at the end of a trial. Participants reported the number of heartbeats they counted during the interval. To determine accuracy, the actual number of heartbeats recorded by the ECG on each trial was compared to the number of self-reported heartbeats. Following previous research (Dunn et al., 2010; Schandry, 1981), we calculated an accuracy score for each of the six trials in the counting task as follows: $1 - (|actual - reported|) / ([actual + reported] / 2)$. The mean accuracy score was then taken across the six trials, with higher values indicating greater accuracy (range: 0–1). For clarity, we also report an additional simple metric of performance on the counting task: participants' mean error (the simple difference between reported and actual heartbeats), in units of heartbeats. As expected, this quantity was strongly negatively correlated with the accuracy score ($r = -0.69$, $p = 7.5 \times 10^{-12}$).

After completing both heartbeat detection tasks, participants completed the Multidimensional Assessment of Interoceptive Awareness (version 1; Mehling et al, 2012), the State-Trait Anxiety Inventory (Spielberger et al., 1983), and the Eysenck Personality Questionnaire-Brief Version (Sato, 2005). Participants also completed an in-house post-task

questionnaire specific to this study assessing participants' experience in the task with open-ended questions and ratings. Session one took approximately 90 minutes.

Session 2: Lie Detection Task. Participants provided fully informed consent and a research assistant applied sensors to their left hand to collect electrodermal (EDA) and pulse plethysmography (PPG) data. Participants first watched a ~2 minute baseline video of birds and waves on a beach (Gross & Levenson, 1995). Participants then proceeded to the lie detection task, viewing a total of 32 videos (in two sets) of individuals engaged in real, high-stakes truths and lies. The set of primary interest included 12 emotional pleas wherein an individual appealed for help in finding a missing relative (ten Brinke & Porter, 2012). These are of particular interest since they are highly emotional and interoceptive accuracy is associated with affective responding (Herbert et al., 2010; Pollatos et al., 2007). These *pleaders* were chosen from ten Brinke and Porter's (2012) complete sample ($N = 78$) using stratified random sampling to ensure an equal number of male, female, genuine, and deceptive pleaders. As such, six (3 male, 3 female) were deceptive in their plea, eventually found guilty of killing the person they pleaded to find based on strong physical evidence (e.g., DNA evidence). The remaining six (3 male, 3 female) were not involved in their relative's disappearance and were genuinely pleading for their safe return. Specifically, another individual was convicted of killing the missing person (based on strong physical evidence) or was found in the absence of foul play. On average, these videos were 35.42 sec long ($SD = 40.38$), were in English, and originally shown on television in the U.S., the U.K., Canada, or Australia between 1985–2009.

Participants also watched a set of 20 *game-show contestants*, lying or telling the truth about their intent to defect on their partner in a single-trial Prisoner's dilemma scenario (Oberholzer-Gee et al., 2010). While this context was also 'real' insofar as it was not created in

the laboratory and featured high-stakes with upwards of \$20,000 of potential prize money, it was less emotional than the pleader videos and thus, were not expected to produce the same results. See Supplemental Material for additional details and related analyses.

The sets of stimuli were presented in randomized order, and videos within each set were presented in random order. A black screen with a white fixation point (+) appeared for 0.5s before each video. After watching each video, participants indicated whether each individual was lying or telling the truth and rated their emotional responses (happy, sad, fear, disgust, anger, contempt, surprise; Ekman, 1992) on 7-point Likert scales. Judgments of veracity were used to calculate a percentage accuracy score: $(\text{total number of pleaders correctly classified as liars or truth-tellers}/12) \times 100$. Finally, participants completed a demographic questionnaire and the following (see Supplemental Materials): the *Private Body* subscale the Body Consciousness Scale (Miller, Murphy, & Buss, 1981) and the *Observe* and *Describe* subscales of the Five-Facet Mindfulness Questionnaire (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Session two took approximately 60 minutes.

Physiological waveforms during the lie detection task were collected using Acqknowledge (version 4.1, Biopac Systems Inc, Goleta, CA) and an MP160 with a BN-PPGED amplifier. Signals were acquired at a sampling rate of 5kHz and re-sampled to 1000Hz. For SCL, raw measures were amplified using a gain of 100 uS/Volt. Prior to analysis, an analyst blind to video veracity removed movement artifacts in PPG signals via visual inspection. MindWare BSA Version 3.0 was then used to determine mean finger pulse amplitudes (FPa) over the course of the baseline video and each pleader video. MindWare EDA Version 3.0 was used to measure tonic skin conductance levels (SCL).

Mean SCL and FPa reactivity was calculated by subtracting participants' physiological activity during the baseline video from their physiological reactivity during each genuine and deceptive pleader video. Mean reactivity to deceptive videos was then subtracted from mean reactivity to truth videos. Because more negative FPa indicates greater vasoconstriction, positive (vs. negative) difference scores indicate greater vasoconstriction to liars (vs. truth-tellers). The opposite is true of SCL; positive numbers indicate greater arousal: negative (vs. positive) difference scores indicate greater arousal to liars (vs. truth-tellers).

To assess optimal possible accuracy for each participant—the ideal use of one of their own physiological signals—we used trial-wise SCL and FPa reactivity (separately) in a signal detection theory framework. First, we calculated all possible criterion values (ranging from below each participant's lowest physiological value to above their highest). Second, for each criterion value assessed, we calculated the percent of trials that would have been correctly categorized as deceptive (vs. truthful) using that criterion. As an illustrative example, if a participant had four trials of data wherein the first two were truthful and the last two were deceptive, and if their arousal (SCL) values were 4, 5, 7, and 8 respectively, then their maximum possible percent correct would have been 100% (with a criterion between 5 and 7; a criterion between 4 and 5 would have yielded 75% correct; a criterion below 4 would have yielded 50% correct; and so on). The highest percent correct reflects an ideal (upper-bound) limit on how well the participant could possibly do, using their physiological experience as a guide, if they had an optimally-selected criterion. This value is conceptually related to (but simpler than) the area under the curve (AUC) of a receiver operating characteristic (ROC) curve. To be clear, we did not expect participants to attain these levels of performance in their explicit judgments of

veracity; rather, we used this simple metric to illustrate the potential use of physiological signs to inform veracity judgments.

Results

Interoceptive Accuracy

Synchronization task. Participants' mean d' from the synchronization task was 0.55 ($N = 80$; $SEM = 0.08$; range = -0.41–3.22, one-sample t -test vs. chance performance, $t(79) = 6.87$, $p = 1.3 \times 10^{-9}$, 95% CI_{mean difference} [0.39, 0.71], $d = .77$, 95% CI [.52, 1.02]), indicating a wide range of performance across participants. We also calculated whether each participant performed significantly ($p < .05$) above chance across all 160 trials of the task. We found that exactly 50% of participants ($n = 40$) performed above chance while the other 50% did not perform significantly differently from chance.

Counting Task. We calculated an accuracy score for the counting task following previous research (Dunn et al., 2010; Schandry, 1981). This score ranged between 0–1, with higher values indicating greater accuracy. Across participants, mean accuracy was 0.76 ($N = 75$; $SEM = 0.02$; range -0.18–0.99; without the negative outlier, range was 0.39–0.99), indicating good overall performance on the counting task. Mean count error (observed - reported) was 7.78 ($SEM = 1.19$; range = -25.8–39.7), indicating a tendency to report slightly fewer heartbeats than were observed.

Participants' d' from the synchronization task was moderately correlated with their mean accuracy score from the counting task (Spearman's Rho, $r(73) = 0.34$, $p = .003$), indicating the two interoceptive measures had some shared basis.

Deception Detection Accuracy

On average, participants' accuracy was 54.86% ($N = 72$, $SEM = 1.70$, range: 16.7–91.7) in discriminating genuine from deceptive pleaders. A one-sample t -test indicates that this is significantly greater than chance performance (50%), $t(71) = 2.87$, $p = .005$, 95% $CI_{\text{mean difference}} = [1.48, 8.24]$, $d_z = .34$, 95% $CI [.10, .57]$.

Physiological Reactions to Liars v. Truth-Tellers

Vasoconstriction. Replicating results reported in ten Brinke, Lee, & Carney (2019), participants experienced greater vasoconstriction (i.e., lower FPa) in response to deceptive ($M = -.036$, $SD = .049$) versus genuine pleaders ($M = -.028$, $SD = .047$), $t(62) = 4.97$, $p < .001$, 95% $CI_{\text{mean difference}} [0.005, 0.012]$, $d_z = .63$, 95% $CI [.35, .90]$.

Generalized Arousal. A paired samples t -test, in contrast, revealed that participants did not experience consistently greater arousal to deceptive ($M = 24.43$, $SD = 35.76$) versus genuine pleaders ($M = 24.36$, $SD = 39.26$), $t(62) = 0.04$, $p = .970$, 95% $CI_{\text{mean difference}} [-3.48, 3.35]$, $d_z = .01$, 95% $CI [-.25, .24]$.

Interoceptive Accuracy is Associated with Greater Vasoconstriction to Liars (v. Truth-Tellers)

Pearson correlations were conducted to examine relationships between measures of interoceptive accuracy—using the synchronization-style task (d') and the heartbeat counting task (counting accuracy)—and physiological reactivity difference scores (vasoconstriction, generalized arousal) in participants who completed both sessions ($N = 71$; though note the N available for a specific measure may be less; see Methods: Participants, above). Results are presented in Table 1. Notably, d' was associated with greater differences in PPG reactivity to deceptive (vs. genuine) pleaders, $r(62) = .302$, $p = .017$ (see Figure 1, Panel A). As interoceptive

accuracy increased, so too did the difference in participants' vasoconstriction to liars (vs. truth-tellers).

Table 1. Pearson correlations between measures of interoceptive accuracy and physiological reactivity difference scores.

	1.	2.	3.	4.
1. heartbeat synchronization task (d')	--			
2. heartbeat count task (accuracy)	.337** N = 75	--		
3. vasoconstriction reactivity difference score (truths - lies)	.302** N = 62	.146 N = 60	--	
4. arousal reactivity difference score (truths - lies)	.080 N = 63	-.020 N = 61	.132 N = 57	--

Note: ** $p < .01$, * $p < .05$

Optimal Possible (v. Achieved) Lie Detection Accuracy, Relying on Physiological Reactivity

That some physiological measures appeared to reliably differentiate between liars and truth-tellers—whereas participants' explicit veracity judgments of the same were only slightly above chance (54.86%)—suggests a gap between how well participants could have done based on those physiological signals and how well they actually did. Thus, we sought to quantify both their optimal possible accuracy and the gap between optimal possible accuracy and achieved accuracy in the lie detection task. Assessing participants' possible accuracy—given optimal use of physiological signals—establishes an upper-bound on what we could expect people to achieve under the best of circumstances (See Methods for more information).

If participants had ideal access to their own vasoconstriction reactivity (PPG), and used an individually-optimal criterion to determine truth-teller or liar on the basis of that PPG signal, they could achieve an average accuracy of up to 68% ($N = 62$; $SEM = 1.0$, range 50–83%; see Figure 1, Panel B). In the case of arousal reactivity (skin conductance), the mean optimal possible accuracy was 66% ($N = 63$; $SEM = 1.2$, range 50–92%). However, in practice, people fell well short of this optimal possible accuracy (paired t -tests versus actual accuracy; PPG: $M_{\text{difference}} = 12.9\%$, $t(61) = 31$, $p = 4.7\text{e-}39$; SCL: $M_{\text{difference}} = 11.5\%$, $t(62) = 30$, $p = 1.4\text{e-}38$), indicating that participants' explicit deception detection performance was, on average, significantly suboptimal on an individual basis.

Interoceptive Accuracy Does Not Improve Actual Lie Detection Accuracy

Although interoceptive accuracy was associated with greater differences in physiological reactivity—for vasoconstriction, specifically, in response to deceptive pleaders vs. genuine pleaders—interoceptive accuracy was not associated with deception detection performance. Performance on the heartbeat synchronization task (d') was unrelated to deception detection accuracy (%), $r(69) = -.02$, $p = .868$ (see Figure 1, Panel C). Similarly, performance in the heartbeat counting task was unrelated deception detection accuracy, $r(67) = -.07$, $p = .562$.

Figure 1. Panel A provides a scatterplot and line of best fit visualizing the relationship between interoception on the synchronization task (d') and the difference in vasoconstriction reactivity to truths and lies. Panel B provides layered histograms, with optimal accuracy that could be achieved using vasoconstriction scores in red and actual deception detection accuracy achieved by participants in grey. Panel C provides a scatterplot and line of best fit visualizing the (lack of) relationship between interoception on the synchronization task (d') and achieved lie detection accuracy. In short, Panel A illustrates that interoceptive performance is associated with a greater physiological signal to discriminate lies from truths. Panel B illustrates how well participants could do by relying on that signal, optimally. Panel C illustrates that more interoceptive participants do not take advantage of their physiological responses to improve their deception detection accuracy.

Additionally, we find that interoceptive accuracy (d') does not moderate the relationship between physiological reactivity difference scores and deception detection accuracy (Model 1; Hayes, 2018). Specifically, the relationship between vasoconstriction difference scores and deception detection accuracy is not moderated by either performance on the heartbeat synchronization task (d'), $F(1, 58) = 2.29$, $p = .106$, $R^2_{change} = .04$, or accuracy on the heartbeat counting task, $F(1, 56) = .19$, $p = .662$, $R^2_{change} = .003$. Similarly, the relationship between arousal difference scores and deception detection accuracy is not moderated by d' , $F(1, 59) = .93$, $p = .338$, $R^2_{change} = .02$, or heartbeat count accuracy, $F(1, 57) = 1.30$, $p = .258$, $R^2_{change} = .02$.

Discussion

Previous research suggests that people may be better at detecting real, emotional, high-stakes lies, relative to laboratory-created truths and lies (e.g., O’Sullivan et al., 2009; Wright Whelan et al., 2014), and that people may experience physiological responses to observing deception (ten Brinke, Lee, & Carney, 2019; see also van’t Veer et al., 2015). We hypothesized that individual differences in trait interoceptive ability may moderate these effects. Specifically, we predicted that more interoceptive individuals may experience greater physiological reactions to lies (vs. truths) and would have the access necessary to incorporate this experience into their truth-lie judgments, achieving greater deception detection accuracy. Overall, participants experienced greater vasoconstriction while watching deceptive versus genuine pleaders and, consistent with our hypotheses, we found that interoceptive accuracy (measured by the heartbeat synchrony task) was associated with a greater difference in vasoconstriction to liars (vs. truth-tellers). These results are consistent with previous research suggesting that trait interoceptive ability is associated with stronger physiological responses to emotional stimuli (e.g., Herbert et al., 2010; Pollatos et al., 2007) and extends these findings to suggest that individuals with high interoceptive accuracy are also more sensitive to subtle cues to emotional deception.

By calculating the optimal criterion for each participant, we determined that participants could achieve an average of 68% accuracy on the deception detection task by relying on their PPG reactivity. Although there was no mean difference in EDA (specifically, skin conductance level) responses to liars and truth-tellers, an optimal decision-making criteria on that reaction would produce a similar average deception detection accuracy of 66%. However, achieved accuracy fell far short of this level (55%) and—contrary to hypotheses—highly interoceptive participants did not outperform others on this task; interoceptive accuracy (d') was unrelated to achieved deception detection accuracy. These findings suggest that even when people ostensibly

have access to internal signals that may indicate deception, they do not incorporate those signals into their judgments. Although van 't Veer et al. (2015) did not measure interoception directly, they also found no relationship between physiological reactivity (i.e., finger temperature) and veracity judgments, despite evidence indicating that physiological reactions to truths and lies differ. We build on this work to show that even for individuals who experience larger physiological reactions and are most attuned to their body, these experiences and abilities do not translate into deception detection accuracy.

Limitations and Future Directions

The current findings suggest that interoceptive individuals do not leverage their somatic experience to achieve greater lie detection accuracy; however, this investigation provides little insight into why this relationship may not exist. ten Brinke, Vohs, and Carney (2016) argue that people are not solely concerned with optimizing accuracy when making deception detection judgments, and that reputational costs associated with calling someone a liar may reduce people's willingness to do so, even if their suspicion is aroused (Bergsieker, Leslie, Constantine, & Fiske, 2012; Dunning et al., 2014). Future research might examine whether interoceptive individuals are more likely to report feeling suspicious in response to liars versus truth-tellers, and whether that tracks with their physiological reactivity. For example, vasoconstriction might track positively with suspicion, but may not rise to the threshold necessary to call someone a liar or may be uncorrelated with deception detection accuracy (ten Brinke, Vohs, & Carney, 2016). That said, training participants to attend to their physiological reaction can impact their deception detection judgments. ten Brinke, Lee and Carney (2019) found that brief interoception training led to improved deception detection (increase of 5% and 6%; Experiments 4 & 5, respectively) compared to a no-training control condition. Namely, training led to a decreased truth bias,

although findings were equivocal on sensitivity. These findings indicate that decision criterion can be manipulated, and that more complex training interventions such as biofeedback may help participants to move their criterion closer to optimal use.

Conclusion

Although interoceptive performance was associated with greater physiological reactivity to lies versus truth, and optimal use of this information would produce deception detection accuracy that far exceeded chance, interoceptive individuals did not leverage their increased body accuracy to improve their judgments of veracity. Findings advance previous research on the physiological reactivity of interoceptive individuals to reveal that they are sensitive even to subtle cues to deceptive emotion. Again, however, attempts to find accurate lie detectors are stymied, suggesting that truth-lie judgments may be influenced by more than just the desire for accuracy.

References

- Baer, R. A., Smith, G. T., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment, 13*(1), 27–45.
<https://doi.org/10.1177/1073191105283504>
- Barrett, L. F., Quigley, K. S., Bliss-Moreau, E., & Aronson, K. R. (2004). Interoceptive sensitivity and self-reports of emotional experience. *Journal of Personality and Social Psychology, 87*(5), 684–697. <https://doi.org/10.1037/0022-3514.87.5.684>
- Bergsieker, H. B., Leslie, L. M., Constantine, V. S., & Fiske, S. T. (2012). Stereotyping by omission: Eliminate the negative, accentuate the positive. *Journal of Personality and Social Psychology, 102*(6), 1214–1238. <https://doi.org/10.1037/a0027717>
- Bond, C. F., & DePaulo, B. M. (2006). Accuracy of deception judgments. *Personality and Social Psychology Review, 10*(3), 214–234. https://doi.org/10.1207/s15327957pspr1003_2
- Critchley, H. D., Wiens, S., Rotshtein, P., Öhman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience, 7*(2), 189–195.
<https://doi.org/10.1038/nn1176>
- DePaulo, B. M., Kashy, D. A., Kirkendol, S. E., Wyer, M. M., & Epstein, J. A. (1996). Lying in everyday life. *Journal of Personality and Social Psychology, 70*(5), 979–995.
- Dunn, B. D., Galton, H. C., Morgan, R., Evans, D., Oliver, C., Meyer, M., Cusack, R., Lawrence, A. D., & Dalgleish, T. (2010). Listening to your heart: How interoception shapes emotion experience and intuitive decision making. *Psychological Science, 21*(12), 1835–1844.
<https://doi.org/10.1177/0956797610389191>

- Dunning, D., Anderson, J. E., Schlösser, T., Ehlebracht, D., & Fetchenhauer, D. (2014). Trust at zero acquaintance: More a matter of respect than expectation of reward. *Journal of Personality and Social Psychology*, 107(1), 122–141. <https://doi.org/10.1037/a0036673>
- Eichler, S., & Katkin, E. S. (1994). The relationship between cardiovascular reactivity and heartbeat detection. *Psychophysiology*, 31(3), 229–234. <https://doi.org/10.1111/j.1469-8986.1994.tb02211.x>
- Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, 6(3–4), 169–200. <https://doi.org/10.1080/02699939208411068>
- Ekman, P. (2009). *Telling lies: Clues to deceit in the marketplace, politics, and marriage* (4th ed.). W.W. Norton.
- Fleming, S. M., & Lau, H. C. (2014). How to measure metacognition. *Frontiers in Human Neuroscience*, 8. <https://doi.org/10.3389/fnhum.2014.00443>
- Gross, J. J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition & Emotion*, 9(1), 87–108. <https://doi.org/10.1080/02699939508408966>
- Hartwig, M., & Bond, C. F. (2011). Why do lie-catchers fail? A lens model meta-analysis of human lie judgments. *Psychological Bulletin*, 137(4), 643–659. <https://doi.org/10.1037/a0023589>
- Hartwig, M., & Bond, C. F. (2014). Lie detection from multiple cues: A meta-analysis. *Applied Cognitive Psychology*, 28(5), 661–676. <https://doi.org/10.1002/acp.3052>
- Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (Second edition). Guilford Press.

- Herbert, B. M., Pollatos, O., Flor, H., Enck, P., & Schandry, R. (2010). Cardiac awareness and autonomic cardiac reactivity during emotional picture viewing and mental stress. *Psychophysiology*, 47(2), 342–354. <https://doi.org/10.1111/j.1469-8986.2009.00931.x>
- Katkin, E. S., Wiens, S., & Öhman, A. (2001). Nonconscious fear conditioning, visceral perception, and the development of gut feelings. *Psychological Science*, 12(5), 366–370. <https://doi.org/10.1111/1467-9280.00368>
- Khalsa, S. S., Rudrauf, D., Damasio, A. R., Davidson, R. J., Lutz, A., & Tranel, D. (2008). Interoceptive awareness in experienced meditators. *Psychophysiology*, 45(4), 671–677. <https://doi.org/10.1111/j.1469-8986.2008.00666.x>
- Levine, T. R. (2015). New and improved accuracy findings in deception detection research. *Current Opinion in Psychology*, 6, 1–5. <https://doi.org/10.1016/j.copsyc.2015.03.003>
- Mehling, W. E., Price, C., Daubenmier, J. J., Acree, M., Bartmess, E., & Stewart, A. (2012). The Multidimensional Assessment of Interoceptive Awareness (MAIA). *PLoS ONE*, 7(11), e48230. <https://doi.org/10.1371/journal.pone.0048230>
- Miller, L. C., Murphy, R., & Buss, A. H. (1981). Consciousness of body: Private and public. *Journal of Personality and Social Psychology*, 41(2), 397–406. <https://doi.org/10.1037/0022-3514.41.2.397>
- Oberholzer-Gee, F., Waldfogel, J., & White, M. W. (2010). Friend or Foe? cooperation and learning in high-stakes games. *Review of Economics and Statistics*, 92(1), 179–187. <https://doi.org/10.1162/rest.2009.10174>

- O'Sullivan, M., Frank, M. G., Hurley, C. M., & Tiwana, J. (2009). Police lie detection accuracy: The effect of lie scenario. *Law and Human Behavior*, 33(6), 530–538.
<https://doi.org/10.1007/s10979-008-9166-4>
- Pollatos, O., Herbert, B. M., Matthias, E., & Schandry, R. (2007). Heart rate response after emotional picture presentation is modulated by interoceptive awareness. *International Journal of Psychophysiology*, 63(1), 117–124.
<https://doi.org/10.1016/j.ijpsycho.2006.09.003>
- Sato, T. (2005). The Eysenck Personality Questionnaire Brief Version: Factor structure and reliability. *The Journal of Psychology*, 139(6), 545–552.
<https://doi.org/10.3200/JRLP.139.6.545-552>
- Schneider, T. R., Ring, C., & Katkin, E. S. (1998). A test of the validity of the method of constant stimuli as an index of heartbeat detection. *Psychophysiology*, 35(1), 86–89.
<https://doi.org/10.1111/1469-8986.3510086>
- Sokol-Hessner, P., Hartley, C. A., Hamilton, J. R., & Phelps, E. A. (2015). Interoceptive ability predicts aversion to losses. *Cognition and Emotion*, 29(4), 695–701.
<https://doi.org/10.1080/02699931.2014.925426>
- Spielberger, C., Gorsuch, R., Lushene, R., Vagg, P., & Jacobs, G. (1983). Manual for the state-trait inventory STAI (form Y). *Mind Garden, Palo Alto, CA, USA*.
- ten Brinke, L., Lee, J. J., & Carney, D. R. (2019). Different physiological reactions when observing lies versus truths: Initial evidence and an intervention to enhance accuracy. *Journal of Personality and Social Psychology*, 117(3), 560–578.
<https://doi.org/10.1037/pspi0000175>

- ten Brinke, L., & Porter, S. (2012). Cry me a river: Identifying the behavioral consequences of extremely high-stakes interpersonal deception. *Law and Human Behavior*, 36(6), 469–477. <https://doi.org/10.1037/h0093929>
- ten Brinke, L., Vohs, K. D., & Carney, D. R. (2016). Can ordinary people detect deception after all? *Trends in Cognitive Sciences*, 20(8), 579–588.
<https://doi.org/10.1016/j.tics.2016.05.012>
- The Global Deception Research Team. (2006). A world of lies. *Journal of Cross-Cultural Psychology*, 37(1), 60–74. <https://doi.org/10.1177/0022022105282295>
- van't Veer, A. E., Stel, M., van Beest, I., & Gallucci, M. (2014). Registered report: Measuring unconscious deception detection by skin temperature. *Frontiers in Psychology*, 5.
<https://doi.org/10.3389/fpsyg.2014.00442>
- von Hippel, W., & Trivers, R. (2011). Reflections on self-deception. *Behavioral and Brain Sciences*, 34(1), 41–56. <https://doi.org/10.1017/S0140525X10003018>
- Vrij, A. (2008). *Detecting lies and deceit: Pitfalls and opportunities*. John Wiley & Sons.
- Wiens, S., Mezzacappa, E. S., & Katkin, E. S. (2000). Heartbeat detection and the experience of emotions. *Cognition & Emotion*, 14(3), 417–427.
<https://doi.org/10.1080/026999300378905>
- Wiens, S., & Palmer, S. N. (2001). Quadratic trend analysis and heartbeat detection. *Biological Psychology*, 58(2), 159–175. [https://doi.org/10.1016/S0301-0511\(01\)00110-7](https://doi.org/10.1016/S0301-0511(01)00110-7)
- Wright Whelan, C., Wagstaff, G. F., & Wheatcroft, J. M. (2014). High-stakes lies: verbal and nonverbal cues to deception in public appeals for help with missing or murdered

relatives. *Psychiatry, Psychology and Law*, 21(4), 523–537.

<https://doi.org/10.1080/13218719.2013.839931>

Zaki, J., Davis, J. I., & Ochsner, K. N. (2012). Overlapping activity in anterior insula during interoception and emotional experience. *NeuroImage*, 62(1), 493–499.

<https://doi.org/10.1016/j.neuroimage.2012.05.012>