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2 Detecting concealed information using autonomic measures

Matthias Gamer

Overview: Already in the first empirical demonstration of the Concealed Information Test (CIT), it was shown that electrodermal responses can be used to detect concealed knowledge with high accuracy. This chapter summarizes the huge number of studies on autonomic measures in the CIT that have been conducted in the last decades. Taken together, it is now well established that the recognition of crime-related items results in larger skin conductance responses, respiratory suppression, heart rate deceleration and reductions of pulse volume amplitudes when compared to neutral control items. This response pattern results from a coactivation of the sympathetic and the vagal branch of the autonomic nervous system and it is at least in part related to the orienting response. Recent studies have shown that the validity of the CIT can be further increased by systematically combining electrodermal, respiratory and heart rate responses by means of a logistic classification function. Finally, important questions for future research on autonomic measures in the CIT are outlined.

Introduction

More than fifty years ago, Lykken (1959) demonstrated that phasic skin conductance changes can be used to detect concealed knowledge with high validity. In this influential study, four groups of participants were examined. One group was asked to commit two mock crimes (a murder and a theft), thereby gaining knowledge of several crime-related details. Two more groups carried out only one of these mock crimes while remaining ignorant to the relevant details of the other scenario and a fourth group was exposed to neither of these mock crimes. Subsequently, all participants were tested for both scenarios by asking for knowledge of critical items that resembled details of the mock crime scene (e.g., certain objects and their placement in the room where the crime was committed). These items were presented along with several equally plausible neutral (control) alternatives in a question format that is highly similar to multiple-choice tests. Solely by using the amplitude of galvanic skin responses elicited by each test item as the dependent measure, Lykken was able to correctly identify 100 percent of the innocent participants and he detected concealed knowledge in 88 percent of cases where a mock crime was committed. On the one hand, concealed crime-related knowledge led to larger skin conductance responses to relevant items as compared to neutral alternatives. On the other hand, non-systematic responses to these item types were observed when the examinee was innocent with respect to the scenario tested. One year later Lykken (1960) showed that these differential skin conductance responses to concealed knowledge and neutral items are remarkably stable against the effects of faking. Lykken called this novel approach of testing whether an examinee was involved in a crime the Guilty Knowledge Test (GKT). Recently, it has also been referred to as the Concealed Information Test (CIT).

Until now, most studies on the CIT exclusively focused on electrodermal measures but already since the late 1960s, other physiological measures reflecting the activity of the autonomic nervous system were utilized (Podlesny and Raskin, 1977, 1978; Thackray and Orne, 1968). After some inconclusive results in the beginning, there seems to be consensus nowadays that the concealment of knowledge results in larger skin conductance responses (SCRs), respiratory suppression, heart rate deceleration and reductions of pulse volume amplitudes when compared to neutral control items (see Figure 2.1).

The purpose of this chapter is to review the validity of different peripheral physiological measures and to discuss psychological mechanisms that may affect these bodily responses. Furthermore, a model is derived on how to combine these different measures in order to enhance the validity of the CIT. Finally, I am going to put forward some suggestions for future research on applied and basic research questions in this domain.

Electrodermal measures

Since the very beginning of systematic research on the CIT, it has been shown that the amplitudes of skin resistance (Lykken, 1959, 1960) or skin conductance responses (Horneman and O'Gorman, 1985; Waid *et al.*, 1979) are larger for relevant items than for neutral control items when an examinee is concealing knowledge. This is not only true for mock crime studies resembling realistic field conditions (Davidson, 1968). It was also found when examinees were instructed to conceal knowledge of previously chosen cards (Ben-Shakhar, 1994) or numbers (Horvath, 1978, 1979), memorized code words (Waid *et al.*, 1978; Waid

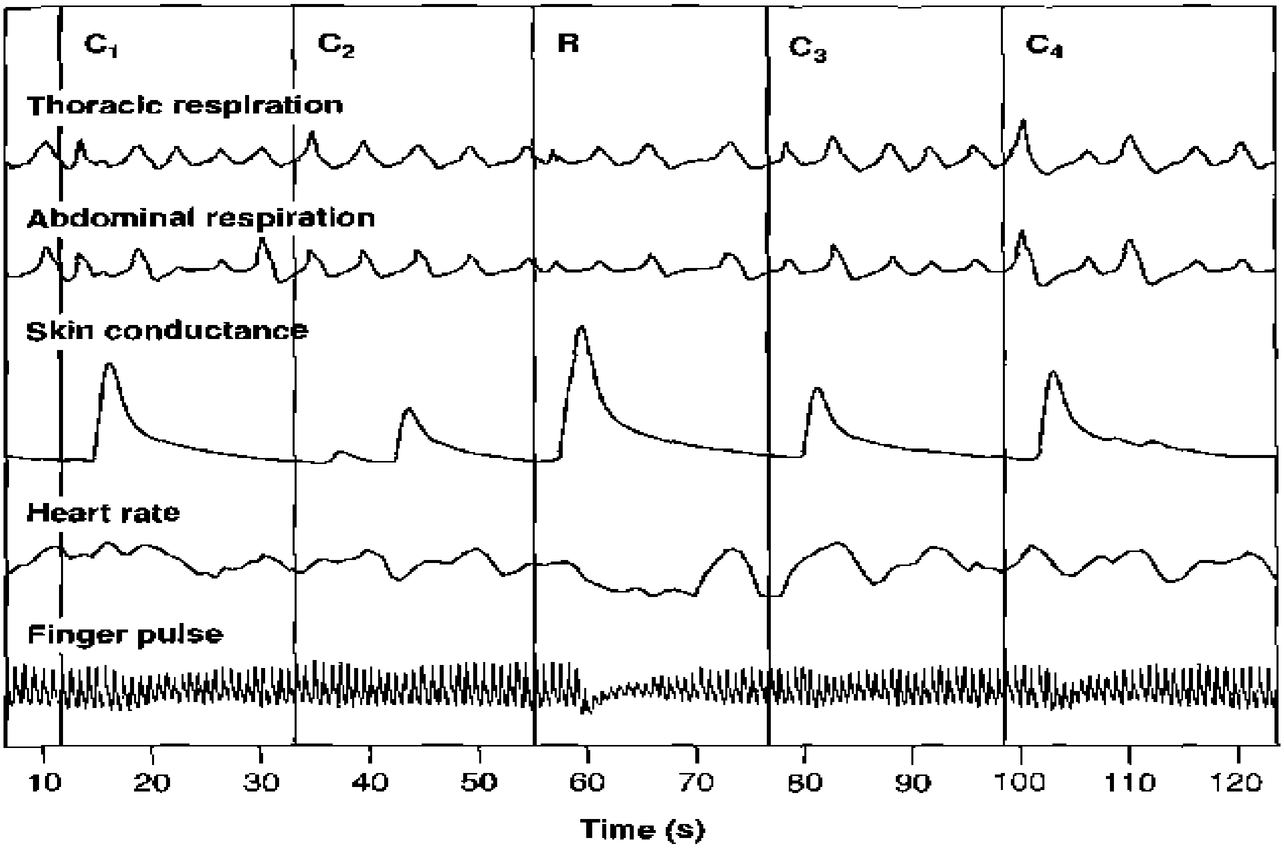

Figure 2.1 Typical response pattern of a participant who committed a mock crime and was instructed to conceal knowledge of all crime-related items in the CIT. R denotes the critical relevant item and C_1 to C_4 represent the neutral control items.

and Orne, 1980), personal details or autobiographic information (Ben-Shakhar *et al.*, 1975; Elaad, 1994). Comparable results were also found in two field studies from Israel that relied on confessions to establish ground truth (Elaad, 1990; Elaad *et al.*, 1992).

With respect to the focus of CIT research on electrodermal measures, it is not surprising that quantitative reviews of CIT validity concentrated on this response system. One extensive review was published by MacLaren (2001).[1] Overall, fifty treatment groups of twenty-two laboratory studies on the CIT were included in this analysis. For the group of $N = 843$ informed subjects, he reported hit rates ranging from 25 percent to 100 percent with a weighted mean of 76 percent (sensitivity). With respect to the specificity, 59 percent to 100 percent of

[1] There was at least one study in the review of MacLaren (2001) that did not solely rely on electrodermal measures (Timm, 1982). However, the validity estimates of most studies were calculated using only skin conductance or skin resistance measures.

N = 404 noninformed participants were correctly classified with a weighted mean of 83 percent. The only moderating variable that could be identified in this analysis was the enactment of a mock crime. Thus, the sensitivity of the CIT was higher (82 percent for N = 666) when guilty subjects carried out a mock crime before undergoing CIT testing compared to those examinees who were otherwise informed about the relevant details.

An extensive meta-analysis on the validity of electrodermal measures in the CIT was carried out by Ben-Shakhar and Elaad (2003). However, instead of reporting hit rates that depend on a single arbitrarily chosen cutoff, these authors used measures from signal detection theory (the effect size d and the area A under the receiver operating characteristic [ROC] curve) to determine the validity of the CIT across all possible cutoff points (cf. Lieblich *et al.*, 1970). Overall, 169 experimental conditions of eighty laboratory studies with N = 5,198 subjects were included in the meta-analysis. Across all studies, CIT detection efficiency was high ($d = 1.55$, $A = 0.82$) and considerably larger than the lower limit of "large effect sizes" ($d = 0.80$; see Cohen, 1988). Replicating the results of MacLaren (2001), it was found that electrodermal measures had higher validity when participants carried out a mock crime. Moreover, a larger number of CIT questions as well as a high level of motivation were associated with larger effect sizes. The mode of responding had a significant effect on CIT validity only when the motivation to pass the test was low. In this case, a deceptive verbal response increased the electrodermal differentiation of relevant and control items in the CIT. When confining the analysis to those ten experimental conditions that were conducted under optimal conditions (N = 222), effect sizes were found to increase to $d = 3.12$ and $A = 0.95$.

Taken together, these results confirm the high validity of electrodermal measures for the detection of concealed knowledge. On the neurophysiological level, skin conductance changes strongly correlate with sympathetic nerve activity (Wallin, 1981), thus indicating that the electrodermal responses in the CIT result from a differential sympathetic activation following relevant and neutral control items when the examinee is able to differentiate between these item categories. In a variety of experimental settings, SCR amplitudes exhibit important characteristics of the orienting response (OR; Sokolov, 1963). Namely, SCR amplitudes show response decrement (habituation) to stimulus repetition, recovery to a change stimulus and a dishabituation following the change stimulus (Barry, 1996). Furthermore, SCR amplitudes increase with stimulus intensity and significance (Jackson, 1974; Siddle *et al.*, 1979). This link between SCR amplitudes and the OR led to the assumption that the CIT primarily relies on the OR. According to this notion, relevant items embedded in the CIT questions have a sort of significance or signal value for guilty subjects thereby eliciting stronger orienting responses that are more resistant to habituation than responses to neutral control items (Lykken, 1974). Although recent research has questioned whether the OR concept is sufficient to fully explain the physiological response pattern in the CIT (Gamer *et al.*, 2008b; Verschuere *et al.*, 2007b), this theoretical framework still allows for explaining a variety of different influences on the electrodermal responses in the CIT (cf. Ben-Shakhar and Furedy, 1990, pp. 111ff., and Chapter 7 of this volume).

Respiratory measures

In CIT studies, respiration is typically recorded by measuring changes in the volume of thorax and abdomen. This can be accomplished by attaching pneumatic or piezo-electric transducers around the chest and the abdomen with belts or Velcro straps. The signal of these transducers has an arbitrary unit when the stretch of the transducer is not calibrated, thus direct comparisons between participants are not possible.

Early studies on the validity of respiratory measures reported that neither respiratory rate nor amplitude allow for a valid differentiation of guilty and innocent participants in the CIT (Bradley and Ainsworth, 1984; Podlesny and Raskin, 1978; Thackray and Orne, 1968). However, this situation changed substantially after Timm (1982) proposed a different method of quantifying respiratory responses. Instead of scoring respiratory rate and amplitude separately, he suggested to measure the total length of the respiration tracing in a fixed period of time following stimulus presentation (e.g., 10 or 15 s). Using this method, one gets an integrative estimate of respiratory activity, called respiration line length (RLL). This measure is reduced when breathing gets slower as well as when the respiratory amplitude is reduced. It can therefore account for intra- and inter-individual differences in respiratory responsiveness that might have been responsible for the negative results that were found in earlier CIT studies. It has now been repeatedly demonstrated in laboratory (e.g., Ben-Shakhar *et al.*, 1999; Bradley and Rettinger, 1992; Gamer *et al.*, 2006; Verschuere *et al.*, 2007a) as well as in field studies (Elaad *et al.*, 1992) that RLL is smaller for relevant items as compared to neutral CIT items when the examinee is concealing knowledge. Since the RLL might be disproportionally affected by the start of measurement, it has been suggested to slowly increase the weight that is given to RLL segments at the beginning of the measurement window (typically in the first second) and correspondingly reduce the weights at the end of the scoring interval (Timm, 1982). Although this approach has been routinely adapted in CIT studies (e.g., Elaad, 2009), validity estimates do not seem to differ from a simple RLL scoring using similar weights for the whole measurement period (Gamer *et al.*, 2006).

Until now, it has not been systematically examined whether RLL is similarly affected by variations of the CIT paradigm as are electrodermal measures. A recent analysis of field cases in Japan, however, indicates that the extent of a respiratory apnea following relevant CIT items is larger when the question is directly related to a (serious) crime (Suzuki *et al.*, 2004). A smaller response was found for more peripheral details such as the precise time the crime was committed. By contrast, the electrodermal data only showed a main effect of critical vs. neutral CIT items. These data indicate that respiratory suppression might be more sensitive to emotional factors than electrodermal measures. As a consequence, RLL validity might be higher in the field as compared to laboratory settings (cf. Elaad *et al.*, 1992).

Respiration is regulated by a complex interplay of central and autonomic (mainly parasympathetic) structures as well as by peripheral feedback circuits (Lorig, 2007). In contrast to electrodermal measures, respiration is under voluntary control which might cause a problem for CIT examinations when examinees try to manipulate their breathing pattern. Although it has been shown that respiration might not be as affected by mental countermeasures as electrodermal responses (Ben-Shakhar and Dolev, 1996), conflicting results have been reported for physical countermeasures (Honts *et al.*, 1996; see also Chapter 11 of this volume). In these studies, examinees were not explicitly instructed to alter their breathing pattern. Thus, it is still unclear whether a direct manipulation of respiratory responses can serve as an effective countermeasure to reduce the sensitivity of the CIT.

Although it is still debated whether respiratory responses can be considered as a formal index of the OR (Barry, 1996), it has been reported that respiratory suppression exhibits some important characteristics that are related to the OR framework. For example, a reduction of breathing can be observed following unexpectedly presented stimuli (Stekelenburg and van Boxtel, 2002) and responses tend to habituate with stimulus repetitions (Barry, 1983). These characteristics also play an important role in OR accounts on CIT responding which may thus explain the validity of RLL measures to some degree.

Cardiovascular measures

The validity of several cardiovascular measures has been examined in the CIT setting. One of the most common and important measures in the traditional lie detection approach utilizing the Comparison Question Test (CQT) is the so-called cardio channel (Kircher and Raskin, 1988; Podlesny and Raskin, 1977). This measurement is accomplished by applying a cuff that is typically inflated to a pressure somewhere between systolic and diastolic blood pressure to the upper arm. Changes in pressure are recorded by connecting the inflated cuff with latex tubing to an amplifier. Most likely, cardio recordings reflect changes in relative blood pressure (Posey *et al.*, 1969). In CIT settings, it has been repeatedly demonstrated that this cardio signal has no validity for the differentiation of guilty and innocent subjects (Elaad and Ben-Shakhar, 1989; Gamer *et al.*, 2006; Podlesny and Raskin, 1978). Moreover, it has been shown that the electrodermal differentiation of relevant and neutral CIT items might be reduced because of the discomfort caused by the inflated blood pressure cuff (Horvath, 1978). For these reasons, it can be recommended to abstain from using this device in CIT examinations but future research will show whether continuously measured blood pressure using more sophisticated noninvasive techniques might allow for the detection of concealed knowledge (Podlesny and Kircher, 1999).

A more promising cardiovascular measure in CIT applications at the moment is the phasic heart rate. After some disappointing results in the beginning (Balloun and Holmes, 1979; Podlesny and Raskin, 1978), it is now well established that concealed knowledge results in a relative decrease of heart or pulse rate in comparison to neutral control items (e.g., Ambach *et al.*, 2008; Bradley and Ainsworth, 1984; Bradley and Janisse, 1981; Gamer *et al.*, 2006; Verschuere *et al.*, 2005, 2007a).

When participants are required to verbally respond to each item immediately, a biphasic response can be typically observed before heart rate returns to baseline again (see left panel of Figure 2.2). This response consists of an initial acceleration followed by a subsequent deceleration that is more pronounced for relevant than for neutral CIT items given the examinee is able to differentiate between these item categories. The initial acceleration is typically missing or less pronounced when examinees remain silent (Gamer, *et al.*, 2008b; Verschuere *et al.*, 2004). It has thus been speculated that this heart rate increase is related to the preparation of the answer and the act of answering whereas the subsequent deceleration seems to be more related to the enhanced direction of attention toward the environment or to one's own bodily responses when guilty subjects are confronted with critical details (Gamer *et al.*, 2006; Raskin and Hare, 1978). To directly test the contribution of both processes to the heart rate pattern, one can delay the verbal response to the test items (Willrich *et al.*, 2003). Indeed, when requiring a verbal

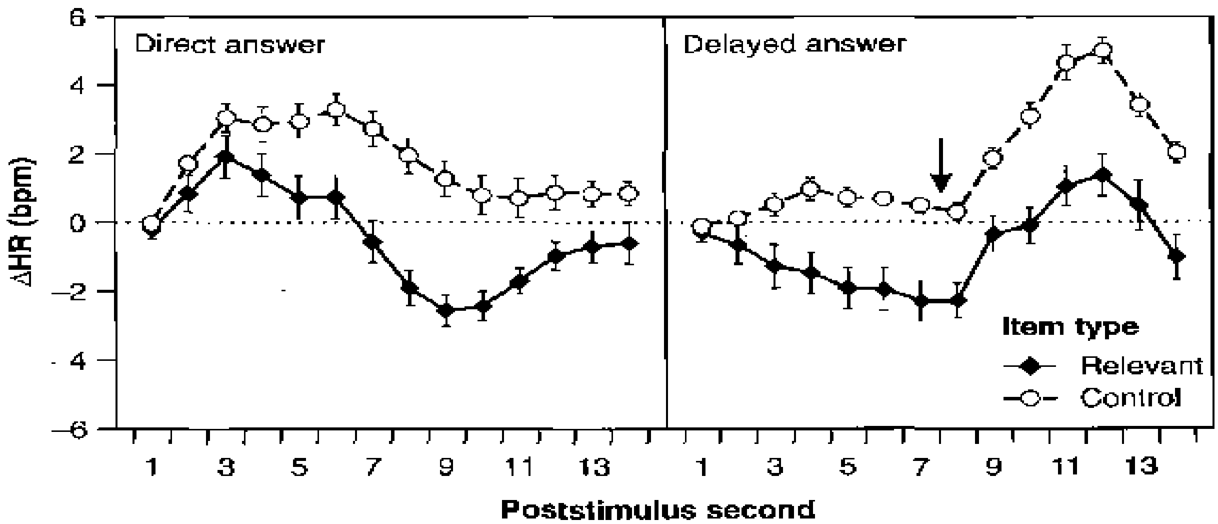

Figure 2.2 Phasic heart rate changes of participants who committed a mock crime and subsequently accomplished a CIT. The left panel shows heart rate responses as a function of item type for a group of $N = 30$ subjects who verbally denied each item immediately (Study 1 of Gamer *et al.*, 2008a). The right panel depicts the heart rate changes for a different group of $N = 36$ subjects who were instructed to deny only after the offset of the visually presented details that were shown for 7 s (Willrich *et al.*, 2003). The onset of the answer period is marked with an arrow.

response only several seconds after stimulus onset, concealed items elicit an immediate heart rate deceleration that differs from a small accelerative response elicited by neutral items. In the subsequent period of the verbal answer, a non-discriminative accelerative response to both item types can be observed (see right panel of Figure 2.2). Thus, the biphasic heart rate response that can be observed when answering directly seems to result from a temporal overlap of verbalization and attentional processes with the former being non-diagnostic and the latter allowing for a valid differentiation of guilty and innocent examinees (cf. Verschuere *et al.*, 2009).

A third cardiovascular measure that has attracted considerable attention in laboratory studies on the CIT is the finger pulse as measured by photoplethysmographic techniques. On the one hand, pulse rate can be derived from these recordings (e.g., Bradley and Ainsworth, 1984; Verschuere *et al.*, 2009); on the other hand, finger pulse amplitudes can be measured that reflect the degree of constriction of peripheral blood vessels. Using a CIT, Podlesny and Raskin (1978) showed that concealed relevant items elicit substantial peripheral vasoconstriction peaking around 8 s after stimulus onset. By contrast, neutral items were only accompanied by a moderate reduction of finger pulse amplitudes. More recently, Elaad and Ben-Shakhar (2006) suggested computing the overall length of the finger pulse signal as a combined estimate of pulse amplitude and rate changes. This can be accomplished similar to the calculation of the respiration line length and has been labeled finger pulse waveform length (FPWL). Several CIT studies showed that FPWL is consistently smaller for concealed as compared to neutral items but across studies, validity estimates seem to be slightly lower than for electrodermal measures (Ambach *et al.*, 2008; Elaad and Ben-Shakhar, 2006, 2008; Verschuere *et al.*, 2009). In contrast to the original claim that FPWL integrates pulse rate and amplitude changes, it was recently shown that FPWL validity seems to largely rely on the latter variable (Vandenbosch *et al.*, 2009).

With respect to the autonomic regulation of cardiovascular responses, one has to differentiate between heart rate changes and peripheral vasoconstriction. The former is under control of both the sympathetic and parasympathetic branch of the autonomic nervous system with the vagal system exerting a much wider range of control over cardiac chronotropy (Berntson *et al.*, 2007). The vascular smooth muscles in the bodily periphery, however, are primarily under control of the sympathetic nervous system. Thus, the heart rate decelerations that were observed for concealed CIT items can in principle result from either a reduction of sympathetic activity or an increase of vagal innervation. As these changes were found to occur very rapidly after stimulus presentation, it seems more likely that they are mediated by the vagal nervous system that was shown to respond much faster to behaviorally relevant events than the sympathic nervous system. Taken together, concealing information results in a relative reduction of the heart rate simultaneously to an increase of skin conductance and peripheral vasoconstriction. This indicates that both branches of the autonomic system are coactivated in the CIT (cf. Berntson *et al.*, 1991).

Similar to the electrodermal responses, it has been suggested that the OR is the critical psychophysiological mechanism that underlies the cardiovascular response and especially the heart rate pattern in the CIT (Verschuere *et al.*, 2004). Two arguments can be put forward against this explanation: first, electrodermal measures that are regarded to be the key index of an OR neither correlate with heart rate responses across individual CIT questions (Gamer *et al.*, 2008b) nor across subjects (Gamer *et al.*, 2008a). Second, skin conductance and heart rate responses show a differential course of habituation across CIT questions. SCRs tend to decrease across the test, whereas heart rate responses remain stable

(Gamer *et al.*, 2008b). Thus, simple OR theories do not fully account for the physiological response pattern and it might be necessary to widen the focus to a broader theory of information processing that incorporates the OR account as well as other psychophysiological mechanisms that have been proposed to explain decelerative heart rate responses to behaviorally relevant stimuli (Wölk *et al.*, 1989).

Other measures

Few studies also examined the diagnostic potential of other physiological measures that are related to the activity of the autonomic nervous system. For example, it was shown that pupil responses allow for a valid detection of concealed knowledge with concealed items eliciting larger pupil dilatation than neutral ones (Bradley and Janisse, 1981; Janisse and Bradley, 1980; Lubow and Fein, 1996). Although pupil responses are modulated by sympathetic as well as vagal influences, post-stimulus dilatation was found to be highly correlated with skin conductance responses (Bradley *et al.*, 2008). Thus, the pupil changes that were found in the CIT seem to reflect the same differential sympathetic activation for concealed and neutral items that was also found with respect to the electrodermal activity.

Based on a brief report of deception-related changes in facial temperature (Pavlidis *et al.*, 2002), a recent study also examined whether concealed knowledge can be detected from subtle changes of facial skin surface temperature (Pollina *et al.*, 2006). By utilizing thermography to measure infrared emission from the human face, it was found that examinees who committed a mock crime showed larger temperature increases to critical CIT items as compared to neutral ones in a region directly below the eyes. Such differential responses could be examined briefly after stimulus onset and were absent in a group of uninformed examinees. Using an individual classification approach, concealed knowledge could be identified in more than 90 percent of participants in this particular study. These small increases in facial temperature can in principle reflect changes in underlying muscle activity or blood microcirculation but face flushing seems to be primarily mediated by the sympathetic nervous system (Drummond and Lance, 1987) and might therefore be strongly correlated to electrodermal responses. However, facial thermography may be interesting for covert measurements of physiological changes in the CIT as it does not require attaching sensors to the examinee.

In principle, other measures of autonomic nervous system activity that have not been discussed so far might be useful for the detection of concealed information. For example, the T-wave amplitude of the electrocardiogram which is related to sympathetic activation (Furedy, 1985; Rashba *et al.*, 2002) or the changes in heart rate variability that reflect sympathetic as well as vagal innervation (Berntson *et al.*, 1997) might serve as physiological indicators of information concealment. However, it seems unlikely that such new autonomic measures will fundamentally change our view of physiological responding in the CIT since electrodermal, respiratory and heart rate measures already allow for indirectly assessing a wide range of autonomic system activity including different aspects of sympathetic and parasympathetic outflow. For the same reason, one should not expect dramatic increases of CIT validity based on new autonomic indices. Thus, it seems more promising to combine physiological measures across different response systems.

Combining autonomic responses

As I outlined above, electrodermal, respiratory and cardiovascular measures have high validity for the detection of concealed information. These measures can be easily recorded simultaneously with standard (computerized) polygraphs but the question emerges of whether such a multimodal approach is really useful in CIT settings. Do diagnoses get better when adding more physiological measures? How should we combine different channels in order to maximize the validity of the final diagnosis?

A simple approach that was adopted by several studies is to average (standardized) response differences between relevant and neutral control items across physiological channels. Given the absolute value of this score is high, one can assume that the examinee was able to differentiate between relevant and neutral CIT items. Values around zero indicate non-systematic responses to these item types which would allow for inferring that the examinee is innocent. Indeed, it was shown that CIT validity can be increased above the best single measure by pooling electrodermal and respiratory responses in laboratory (Ben-Shakhar and Dolev, 1996; Ben-Shakhar and Elaad, 2002; Ben-Shakhar *et al.*, 1999) and field settings (Elaad *et al.*, 1992). Comparable results were obtained for combinations of electrodermal, respiratory and cardiovascular measures (Elaad, 2009; Elaad and Ben-Shakhar, 2006, 2008), but conflicting results were also reported (Verschuere *et al.*, 2007a).

The main shortcoming of such an averaging approach is that differential contributions of several physiological measures are not adequately taken into account. Although field experts disagree about the most valid physiological index with respect to traditional lie detection approaches relying on the CQT, they tend to assign different weights to the physiological channels. For example, some examiners suggested to mainly rely on respiratory measures (Slowik and Buckley, 1975). Other researchers have shown that electrodermal responses have higher validity than respiratory and cardiovascular measures in the CQT and consequently proposed a set of optimal weights for the prediction of the truth status with larger weights being assigned to electrodermal responses (Kircher and Raskin, 1988).

We tested the utility of such a flexible classification approach in CIT settings and found high validity coefficients when assigning larger weights to electrodermal and respiratory measures as compared to heart rate responses (Gamer *et al.*, 2006). This approach relied on a stepwise logistic regression model that has fewer restricted assumptions than comparable statistical methods such as discriminant analysis. In its implementation in CIT settings, the logistic regression function that allows for determining the probability of information concealment $P(Y = 1)$ given a vector of physiological response differences between relevant and neutral items X for each examinee i is:

$$P(Y_i = 1 \mid X_i = x_i) = \frac{e^{\beta_0 + \sum_j \beta_j x_{ij}}}{1 + e^{\beta_0 + \sum_j \beta_j x_{ij}}}$$

The regression constant is β_0 and β_j represent different weights for each of j physiological channels. In the analysis, parameter weights are adjusted to maximize the differentiation of guilty and innocent subjects. The result is a value P for each participant that corresponds to the probability that this examinee is concealing knowledge.

We recently cross-validated the classification model that was originally proposed by Gamer *et al.* (2006) on data from 7 studies with 275 guilty and 53 innocent examinees (Gamer *et al.*, 2008a). It turned out that the weighted combination of SCR amplitudes, respiration line length and heart rate responses yielded slightly (but significantly) larger validity coefficients than the best single measure (for weights of the classification function see Table 2.1). These results were stable across different protocols and various samples. Similar results have been reported for trial-by-trial classifications within each participant (Ambach *et al.*, 2008). From these data, it can be recommended to record multiple physiological measures in CIT examinations and to combine them in a weighted manner. However, it remains to future research to determine whether this classification function also allows for deriving accurate diagnoses in the field context that largely differs from laboratory research especially with respect to motivational and emotional conditions.

Table 2.1 *Weights and quantification details of physiological measures that were integrated in the logistic regression model for the prediction of the truth status*

Measure	Quantification	Time window	β	SE	Wald
SCR	Largest skin conductance increase	0.5 to 10.5 s	4.24	1.38	9.51
Respiration	Respiration line length	0 to 10 s	−6.31	2.18	8.37
Phasic HR	Mean HR change in relation to last prestimulus second	0 to 15 s	−1.97	0.88	5.08
(Constant)			−3.92	1.11	12.52

Note: Limits of the measurement window are relative to stimulus onset; SCR = skin conductance response, HR = heart rate, SE = estimated standard error of regression coefficients. Nagelkerke's R^2 values increased from 0.58 via 0.80 to 0.85, when RLL and mean HR were included into the regression model in addition to the SCR measure (data set from Gamer *et al.*, 2006).

Taken together, the combination of several autonomic measures enhances CIT validity. From the scientific perspective, however, it is not fully clear why this is the case. The simplest explanation is that each physiological response cannot be measured with perfect reliability. Thus, a combined measure would always allow for a better differentiation of guilty and innocent examinees given that measurement errors across physiological channels are not highly correlated. A more plausible explanation, however, is related to psychophysiological mechanisms that are reflected in these measures. As outlined above, electrodermal, respiratory, and cardiovascular measures seem to differentially reflect sympathetic and parasympathetic outflow and they cover slightly different aspects of psychological processes such as the OR. Moreover, some measures seem to be more sensitive to habituation than others (e.g., Gamer *et al.*, 2008b) and physiological responsiveness across data channels might vary between individuals (Foerster, 1985). This can be as extreme as around 5 percent to 10 percent of the normal population do not show any skin conductance response to non-aversive external stimulation (so-called non-responders, Gruzelier *et al.*, 1981). As a consequence, correlations between electrodermal, respiratory, and cardiovascular measures in the CIT rarely exceed values of $r = 0.30$ (Gamer *et al.*, 2008a). It is thus beneficial to combine these measures in order to cover different aspects of information concealment as well as to incorporate individual differences in physiological responsiveness.

Summary and conclusions

Taken together, examinees that are concealing information can be validly differentiated from unaware participants by comparing electrodermal, respiratory, and cardiovascular responses to relevant and neutral items in the CIT. A combination of skin conductance response amplitudes, respiration line length, and heart rate changes by means of a logistic regression model further enhances the validity of the test. Both branches of the autonomic nervous system contribute to these physiological responses that are closely – but not exclusively – related to the orienting response.

Open questions for future research are twofold. From the applied perspective, it would be interesting to test whether other measures that are not directly related to the activity of the autonomic nervous system provide incremental validity. The main problem, however, stems from substantial procedural differences to the standard CIT format when utilizing behavioral measures, event-related brain potentials or neuroimaging techniques. Most importantly, more item repetitions are necessary for these latter applications and the interstimulus interval is typically reduced such that a reliable quantification of autonomic responses is impeded. However, recent research indicates that it might be promising to examine such combinations as it was shown that behavioral measures (Meijer *et al.*, 2007), event-related brain potentials (Gamer and Berti, 2010), and functional magnetic resonance imaging data (Gamer *et al.*, 2007; Gamer *et al.*, in press) may in part reflect different psychological processes than electrodermal responses when examinees are concealing information. They may thus provide incremental validity in the CIT.

A second line of research that has been largely neglected until now is related to the mechanisms and experimental conditions that affect different autonomic measures. Extensive meta-analytic research has only been conducted for electrodermal data so far (Ben-Shakhar and Elaad, 2003) and it remains largely unknown whether the same conditions that affect skin conductance measures also modulate respiratory and cardiovascular responses. At the moment it seems unlikely that different autonomic measures respond uniformly in CIT examinations. For example, there is evidence for certain respiratory patterns in field examinations that rarely occur in the laboratory whereas electrodermal responses do not seem to differ substantially between these conditions (Suzuki *et al.*, 2004). Moreover, skin conductance and heart rate responses show a different habituation pattern in a CIT examination which might indicate that both measures reflect partly different psychological processes (Gamer *et al.*, 2008b). To gain more insight into this research question, it would be necessary to examine very large samples of participants while carefully manipulating experimental conditions that might differentially affect electrodermal, respiratory, and cardiovascular measures.

To sum up, autonomic measures can be easily recorded in the CIT, they can be objectively analyzed and they were shown to be highly valid. Each upcoming technique aiming to detect concealed information on an individual basis should be compared to this standard with respect to practicability and validity.

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