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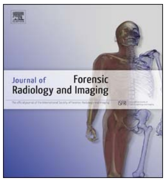

Deception detection based on neuroimaging: Better than the polygraph?

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ABSTRACT

Polygraph tests have been used to detect deception for almost a century. Yet for almost as long, the validity of these tests has been criticized. Over the last decade, the use of brain imaging – most notably fMRI - for the detection of deception has attracted increased attention. The expectation is that fMRI can overcome – at least some of - the shortcomings of the polygraph. In this review, we discuss whether this expectation is warranted. Based on our review of the empirical evidence, we argue that fMRI deception research has boosted the theory development of deception. But for practical purposes, fMRI research has thus far done surprisingly little to solve or circumvent the problems than have been associated with deception research for ages.

1. Introduction

The use of brain imaging technology to detect deception has attracted increased attention over the last decade. Take, for example, the following case. In 2003, in the United Kingdom, a 42-year-old woman was convicted of a crime against a child in her care. She served her prison term, yet continued to profess her innocence, even after she was released. Four years after the conviction, psychiatrist Sean Spence administered a deception test based on functional magnetic imaging (fMRI) to assess her credibility. Whilst in the scanner, the woman was presented with statements about the incident (e.g., 'You were innocent of the charges') to which she responded by pressing buttons marked 'yes' or 'no'. Based on the neuroimaging data, Spence and colleagues concluded that her functional anatomical parameters behaved as if she were innocent [49].

Before we evaluate the validity of deception tests such as the one described above, it is worth noting that it is not a coincidence that a medical doctor performed this test. In the earlier days of fMRI research it were the medical specialists – most notably the psychiatrists and radiologists - who had both the interest in deception and the access to fMRI scanners, and they are responsible for much of the early work (e.g., [25,27]). At a later stage, neuroscientists, legal, and ethical scholars became involved in the field. In many of their publications, the 'new' fMRI based deception detection is contrasted with the 'old' polygraph, and it is implicitly or explicitly assumed that fMRI can overcome – some of – the shortcomings of the polygraph (e.g., [6,25,28,11]).

In this contribution, we discuss whether this expectation is warranted: Can fMRI based deception detection help to overcome the shortcomings of the polygraph? We discuss they key difficulties with polygraph testing. We then evaluate to what extent fMRI based deception detection has overcome the problems related to polygraph testing detection. Our analyses will show that fMRI deception research has boosted the theory development of deception. fMRI based deception detection, however, faces largely the same problems as lie detection through the use of a polygraph. For practical purposes, fMRI research has done surprisingly little to solve or circumvent the problems than have been associated with deception research for ages.

2. The polygraph and its questioning formats

The polygraph as we still know it today was first introduced in the 1920's by physiologist and police officer John Larsson from the University of California, Berkley [30]. He developed a machine that simultaneously measured blood pressure, pulse, respiration, and palmar sweating, and used this machine in over a 100 cases to evaluate whether the defendant was telling the truth or not. The polygraphs used today do not fundamentally differ from the one developed by Larsson in the 1920s. The lengthy rolls of paper that the physiological signals were recorded on have been replaced by laptop computers, but the machines still record multiple physiological signals, typically cardiovascular measures, respiration and skin conductance.

The physiological signals measured by the polygraph – or by the fMRI scanner for that matter - can be regarded as an outcome measure. A meaningful interpretation of an outcome measure fully depends on the level of control over the independent variable. For example, to

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establish whether a form of treatment is effective, a double blind placebo controlled trial is preferred. Only under such controlled circumstances do the treatment and the control groups differ on only one dimension, namely that of the treatment, and can any change in outcome measure be attributed to the treatment. In a similar fashion, the validity of deception detection techniques to a large degree depend on to what extent the questioning format isolates deception. Before one can meaningfully discuss the validity of polygraph or fMRI based deception test, a short evaluation of the most used question formats is crucial. This is why we will shortly explain the three main question formats used in research and/or practice, namely the Control Question Test, the Concealed Information Test, and the Differentiation of Deception test.

The question format most widely used by law enforcement agencies worldwide is the Control Question Test (CQT; [45]). In this type of test, the suspect answers relevant and control questions whilst physiological reactions are being recorded. The relevant questions refer specifically to the incident under investigation (e.g., “In the night of Nov, 3, did you stab X?”). The responses to this question are compared to those elicited by the control questions. These control questions have a more generic nature, but also deal with undesirable behavior (e.g., “In the first 25 years of your life, have you ever done anything illegal?”). The rationale behind the CQT is that for guilty suspects the relevant questions will pose the biggest threat, and will therefore elicit the strongest physiological responses. An innocent suspect, on the other hand, is thought to perceive the control questions as most threatening, and these questions will therefore elicit the strongest physiological responses [42].

Although the use of the CQT is widespread, its merits have been debated for decades. A full review of this debate is outside the scope of the current manuscript, and can be found elsewhere (e.g., [2,38,39]). We focus here on the main criticisms voiced against the CQT. At the core of the debate surrounding the CQT is the general assumption that the relevant questions will elicit stronger emotions – and thus larger responses – only in guilty suspects. Critics argue that this assumption has no basis in psychological or psychophysiological research, nor is it convincing in its inner logic [13,22,35]. It is easily imaginable that an innocent suspect recognizes the relevant questions as most pertinent, and will therefore show large responses.[1] Simply put; the relevant and control questions differ on a number of dimensions besides deception, meaning any difference in psychophysiological responding cannot be solely attributed to deception.

The shortcomings of the CQT were recognized in the late fifties of the previous century, amongst others by psychologist David Lykken. Lykken developed an alternative question format, which he named the Guilty Knowledge Test (GKT; [33,34]). This test is nowadays commonly referred to as the Concealed Information Test (CIT; Verschuere, Ben-Shakhar, & Meijer, 2011). In contrast to the CQT, the CIT does not measure deception, but attempts to establish whether an examinee possesses pertinent crime related information. In the CIT, questions presented to the examinee (e.g., ‘the murder weapon was a′) are followed by one relevant alternative (e.g., the actual murder weapon: an ice pick) and several neutral (control) alternatives (e.g., a knife, a letter opener, a pair of scissors, a piercer) presented in random order. These neutral alternatives are chosen such that an innocent suspect would not be able to discriminate them from the relevant alternative. In contrast, a suspect who is familiar with the details of the crime would be able to discriminate between the relevant and the neutral control items, and the relevant items will elicit enhanced physiological responses such as increased skin conductance, a decrease in respiration, and changes in heart rate [36]. In sum, knowledge is inferred from systematic stronger responding to the correct alternatives.

The CIT countered some of the main criticisms of the CQT, most notable the risk of an innocent suspect failing the test (i.e., false positive outcome). Under the assumption that all alternatives are equally plausible, an innocent suspect cannot distinguish between the relevant and the neutral control alternatives, and the false positive rate is expected to follow the laws of probability [35]. The probability of an innocent suspect showing – by chance – the largest response to the correct alternative in one question with five options is expected to be .2. The probability of this happening in three questions is expected to be $.2^3$ =.008, so less than 1%, and one can set the false positive rate at an arbitrary low level by using a sufficiently large number of questions (e.g., 5) and an adequate criterion for inferring guilt (e.g., show the largest response to the correct alternative on at least 4 out of the 5 questions).

Whereas the CIT can be used to detect an examinee's knowledge of crime-related details, when it comes to studying the construct of deception, the test is confounded: knowledgeable participants respond truthfully on the majority of trials – namely presentation of the neutral control alternatives that typically constitute 80% or more of the trials -, while being deceptive only on the minority, i.e., only upon presentation of the relevant alternative [37]. For the purpose of detecting concealed information, this is not problematic, as only the knowledgeable participant can discriminate the relevant from the neutral controls. But, for the scientific study of deception, the CIT is problematic because besides to deception, any differences in responding can also be attributed to a frequency effect.

A third questioning format was developed to specifically study deception by isolating the deceptive response. This paradigm was originally developed by John Furedy and his colleagues using skin conductance (e.g., [14]), and named the Differentiation of Deception test (DoD). In the DoD, examinees are presented with a series of questions and are instructed to give truthful answers to half of them and deceptive answers to the other half. Alternatively, in a more recent variant of the DoD, participants are asked to answer each question twice: once truthfully and once deceptively. This test was labeled the Sheffield Lie Test (e.g., [48]). Because each question is answered both truthfully and deceptively, the DoD isolated deception to a high degree.

3. From polygraph to brain imaging

The CQT is fundamentally flawed because the relevant and control question differ on many other dimensions besides deception. The CIT is a valid test to detect knowledge, but not to study or detect deception. The DoD does isolate deception to a high degree. It should therefore not come as a surprise that the fMRI-based lie detection test we started this article with relied on a variant of the DoD paradigm. In fact, the rationale for this test (and its conclusion) was based on the findings of an earlier study by Spence and colleagues [48]. In this earlier study, Spence invited 10 participants, and presented them with a total of 36 autobiographical statements, such as ‘made your bed’ and ‘taken a tablet’ while the fMRI scanner registered their brain activity. Participants answered with key presses labeled ‘yes’ and ‘no’ based on color-coding (e.g., lie in response to green or red). Results revealed that lying – compared to truth telling - was associated with activity in the right ventrolateral prefrontal, left ventrolateral prefrontal and medial premotor area's. Ventrolateral prefrontal activation had previously been shown associated with response inhibition [18]. This pattern – which has been found in many studies since (for reviews see [15,16]) - led the authors to conclude that deception constitutes an executive function, including withholding the truth, and response manipulation and monitoring. In other words, the truthful responding is the default modus of the brain, and when being deceptive, this truth needs to be inhibited, and the deceptive response needs to be selected and executed.

The test of the 42-year-old woman revealed a pattern of brain activation highly similar to that found in the 2001 study: increased

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[1] In as case in which one of the authors acted as an expert witness, the suspect had failed a CQT polygraph test. In court, the suspect noted about the relevant questions: ‘those are the questions you are there for. No wonder the machine goes of. I experienced innocent stress.’

activation in the ventrolateral prefrontal and anterior cingulate cortices when she endorsed the accusers version of the events. This led the authors to conclude that her functional anatomical parameters behave as if she were innocent. The logical reasoning behind this conclusion is as follows: When endorsing the accusation ('yes, I did it'), her brain activation showed inhibition. This inhibition means the 'yes, I did it' is a lie. And if 'yes, I did it' is lie, she is innocent.

The case above illustrates that in order to go from a pattern of brain activation to a decision about whether the suspect is deceptive or not, a number of logical inferences need to be made. As acknowledged by Spence et al. [49], such inferences pose logical problems. For instance, the assumption that lying is associated with inhibition came from a study in which participants came to the laboratory, and lied about past actions on the spot. For that inhibition was required. But the 42-year-old-woman was presented with exemplars of an act she had been denying for years. Would it be possible that she had indeed harmed the child, but years of practice made her false denial the default response? Although up to now, it remains unclear whether such a reversal can indeed take place ([19,20,51,53], 2015; [54]), the logical consequences of such a reversal are interesting. If the lie, rather than the truth, becomes the default response, activation in brain regions associated with inhibition now denotes the truth. Consequently, inhibition concurrent with 'yes, I did it' now denotes she is guilty. This example serves to point out that there is no unique brain area associated with deception. In essence, the logical inference problem is highly similar to the problem underlying the CQT: deception may be associated with emotion but that does not mean emotion by definition signals deception. Likewise, deception may be associated with inhibition, but this does not mean inhibition by definition signals deception.

The use of brain imaging technology to study and detect deception is not limited to the DoD test format. Also, the CIT has been used in combination with brain imaging. This includes fMRI studies (see [15] for a review), but also studies using the P300 component of the event related potential. Specifically, two groups of researchers [12,46] introduced this measure of brain activity to detect concealed information, using the CIT protocol, exchanging respiration and skin conductance measures for measurement of brain activity as measured with the Electro Encephalogram (EEG). Their starting point was the widely known phenomenon that a deviant stimulus in a train of non-deviants (e.g., a series of tone in which 1 out of 5 has a low pitch) elicits a larger positive brainwave elicited approximately 300 ms after stimulus presentation, the so-called P300 component [10]. In a CIT, the correct alternative (e.g., murder weapon) becomes the equivalent of the low tone only for guilty suspects, meaning a P300 to the correct alternative indicates knowledge. It should be noted that both P300 and skin conductance seem to reflect the same psychological process, namely attention towards a significant stimulus [23,40,50]. In essence the P300 based CIT uses the same question format, measures the same psychological process, but switched from skin conductance to P300 as the dependent measure.

In sum, the CQT has exclusively been used in polygraph testing. Neuroscience based recordings (e.g., EEG and fMRI) have employed both the CIT and the DoD, but those two question formats have also been successfully employed with polygraph measures.

4. Establishing accuracy

For forensic techniques, it is of crucial importance to know the error rate. Studies investigating these error rates can be classified into two categories: laboratory studies and field studies. Laboratory studies offer full control of who is deceptive and who is not. Deception can be manipulated by, for example, having participants engage in a mock theft, lie about a playing card, or about their autobiographical information.

When we look at the published laboratory studies, P300 CIT studies typically report individual classification accuracy rates, but only a few fMRI studies report to what extent they could correctly distinguish between deceptive and truthful participants. In the CIT, four studies assessed the accuracy of fMRI using both knowledgeable and unknowledgeable participants [8,17,41,43]. Collectively, these studies yield a weighted average *ROC* value of .94 [37]. For comparison, skin conductance yielded an ROC of .85, and P300 of .88 (See Table 1). To what extent results from such laboratory studies generalize to the real world remains questionable. So even though the estimation of CIT accuracy is the highest for fMRI, it is based on a very small number of studies, the fewest participants, it lacks independent cross validation, and should therefore be treated with caution. A conservative interpretation of these findings would be that there is indication that fMRI based concealed information testing can achieve an accuracy similar to that of polygraph measures. For the DoD, only one study reported both sensitivity and specificity.[2] Kozel et al. [24] found an *area under the Receiver Operating Characteristic curve (ROC)* of .79.[3]

Table 1
Overview of the accuracy of the different measures in the CIT.
Source: Adapted from [37].

Measure	*n*	*ROC*
SCR	3863	.85
ERP	646	.88
fMRI	134	.94

Note: *n* = total number of participants; *ROC* = area under the ROC curve; SCR = skin conductance response; ERP = event-related brain potentials; fMRI = functional magnetic resonance imaging.

The alternative to laboratory studies, that typically lack ecological validity, is to use field data. Although such data has been collected under real life circumstances, it has another important disadvantage; it is hard to establish with 100% certainty whether the suspect was really deceptive or not – the ground truth. Importantly, this ground truth should be independent of the test outcome. If not, the accuracy will be an overestimation of the real accuracy. Take, for example, a confession as a measure of ground truth. If a deception test determines who will be questioned (those who failed the test) and who will not (those who passed the test), confessions will only be elicited in those fail the test. False negative negatives will be excluded from such a sample, as those who pass the test will not be questioned. False positives will be excluded assuming that innocents who fail the test will not (falsely) confess. This way even a test that performs at chance level will show high accuracy when tested against confessions [21]. Moreover, this problem is not limited to confessions. Dependence between test outcome and ground truth may also be present in other measures of ground truth. Investigative authorities may, for example, invest more resources in crime scene analysis once a suspect fails a test. This selection bias is similarly problematic in medical diagnostic procedures. For example, when the validity of a diagnostic procedure (e.g., an MR scan to detect liver cirrhosis) is established by comparing its outcome to that of an autopsy, but these autopsies are only performed following a positive test outcome [4]. In this example, all false negative outcomes would remain undetected, as no autopsy is performed.

So far, fMRI deception studies have been limited to laboratory studies. [29] called for clinical trials of fMRI deception tools. But without an a-priori specification of how these trials will deal with independently determining ground truth, such trials will result in a

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[2] We exclude here the studies that computed sensitivity and specificity based on within subject comparison. See Meijer et al. [37].

[3] ROC curve (*a*) represents the detection efficiency regardless of any specific cutoff point (for a detailed description of generating ROC curves in CIT experiments, see [31]). The area under the ROC curve ranges between 0 and 1, such that an area of 0.5 means that the two distributions (i.e., the detection score's distributions for guilty and innocent examinees) are indistinguishable (i.e., detecting whether an examinee is deceptive or not will be at chance level). An area of 1 means that there is no overlap between the two distributions and thus a perfect classification is possible.

similar discussion that has plagued CQT polygraph testing for decades.

5. Threats to accuracy

Two other points relating to accuracy of (neuroimaging based) deception detection procedures warrant attention. First, one of the factors associated with accuracy are countermeasures. Countermeasures refer to deliberate attempts by the examinee to alter the physiological responses, and thereby obtain a truthful test outcome. Polygraph measures are relatively easy to elicit, for example by imagining an emotional event [26]. It should therefore not come as a surprise that tests based on such measures can be circumvented by eliciting a reaction to the control question in the CQT, the control options in the CIT, or the truth condition of the DoD [3]. More recent research has shown that countermeasures can also be effective against neuroimaging measures. A P300, for example, is elicited by any stimulus that is deviant. Research showed that if the participant attaches meaning to the different neutral control alternative (e.g., by wiggling their toe), these neutral options also become significant, and diagnostic accuracy decreased [32,47]. Ganis et al. [17] demonstrated that comparable countermeasures also worked in an fMRI setting and reduced CIT detection accuracy from 100% to only 33% (see also [52]).

A threat specific to the CIT is that false negatives can be caused by the fact that a knowledgeable suspect does not remember the pertinent information (e.g., [7]). For example because it was forgotten, or because it was never encoded. False positives, on the other hand, can be caused by information leakage; the suspects is aware of the pertinent information, but because this information leaked in a previous interview or through the media. Like polygraphic measures, both P300 and fMRI measures have been shown sensitive to such leakage effects [43,56].

6. Neuroscience based deception detection: better than the polygraph?

Neuroscience based lie detection has attracted great attention. Numerous authors posed the question whether such tests are better than the polygraph test. We have explained that before a meaningful answer to this question can be formulated, the questioning format needs to be defined. The CQT polygraph test is fundamentally flawed, not because the peripheral physiological measures are poor indices of emotion, but because the relevant and control question differ on many dimensions besides deception. At a superficial level, one can argue that neuroscience based deception detection is indeed better than the polygraph, simply because it does not employ the flawed CQT questioning format.

Like there is no unique physiological response associated with deception, there is no unique brain region associated with deception. Decisions are determined by logical inferences: deception is inferred from cognitive control (e.g., inhibition) in the DoD, and knowledge is inferred from attentional orienting in the skin conductance or P300 based CIT. Logical inferences allow for logical errors, regardless of whether the dependent measures are recorded with a polygraph or with an MRI scanner. Moreover, to the extent that the polygraph and fMRI measures tap similar psychological mechanisms [23,50], only limited incremental validity can be expected. Although we have limited our review to P300 and fMRI measures, similar reasoning applies to other neuroimaging methods such as positron emission tomography (e.g., [1]) and functional near infrared spectroscopy [9].

Just like polygraph measures, fMRI and P300 measures are susceptible to countermeasures, meaning that the use of neural measures has not solved this issue. Critiques voiced towards the CIT are mainly of a practical nature, for example that the test can only be used in a small number of cases [44]. Such critiques cannot be countered by switching to neuroscientific measures. And for practical purposes, more easy and cost effective measures such as skin conductance should be preferred.

We realize that the pictured painted may per perceived as pessimistic. Let us therefore end on a positive note. Historically, the field of deception research has been plagued by a lack of theory development (NRC, 2003). Starting early this century, neuroimaging studies – and especially the fMRI studies – have introduced theoretical concepts of cognitive control, and played an important role in the development of the contemporary cognitive approach to deception detection [5,55]. Yet for practical purposes, it has done little to solve problems that have plagued deception research for decades. The logical inference problems associated with deception research are solved by introducing proper controls in the questioning format, not by new introducing new technology.

References

[1] N. Abe, M. Suzuki, E. Mori, M. Itoh, T. Fujii, Deceiving others: distinct neural responses of the prefrontal cortex and amygdala in simple fabrication and deception with social interactions, J. Cogn. Neurosci. 19 (2) (2007) 287-295, http://dx.doi.org/10.1162/jocn.2007.19.2.287.

[2] G. Ben-Shakhar, A critical review of the control questions test (CQT), in: M. Kleiner (Ed.)Handbook of Polygraph Testing, Academic Press, Waltham, MA, 2002, pp. 103–126.

[3] G. Ben-Shakhar, Countermeasures, in: B. Verschuere, G. Ben-Shakhar, E. Meijer (Eds.), Memory detection: Theory and application of the Concealed Information Test, Cambridge University Press, Cambridge, UK, 2011.

[4] C.B. Begg, R.A. Greenes, Assessment of diagnostic tests when disease verification is subject to selection bias, Biometrics (1983) 207–215. http://dx.doi.org/10.2307/2530820.

[5] I. Blandón-Gitlin, E. Fenn, J. Masip, A.H. Yoo, Cognitive-load approaches to detect deception: searching for cognitive mechanisms, Trends Cogn. Sci. 18 (9) (2014) 441-444, http://dx.doi.org/10.1016/j.tics.2014.05.004.

[6] M. Bles, J.D. Haynes, Detecting concealed information using brain-imaging technology, Neurocase 14 (2008) 82–92. http://dx.doi.org/10.1080/13554790801992784.

[7] D. Carmel, E. Dayan, A. Naveh, O. Raveh, G. Ben-Shakhar, Estimating the validity of the guilty knowledge test from simulated experiments: the external validity of mock crime studies, J. Exp. Psychol. 9 (2003) 261–269. http://dx.doi.org/10.1037/1076-898X.9.4.261.

[8] Q. Cui, E.J. Vanman, W. Dongtao, W. Yang, J. Lei, Q. Zhangg, Detection of deception based on fMRI activation patterns underlying the production of a deceptive response and receiving feedback about the success of the deception after a mock murder crime, Soc. Cogn. Affect. Neurosci. 9 (2014) 1472–1480. http://dx.doi.org/10.1093/scan/nst134.

[9] X.P. Ding, X. Gao, G. Fu, K. Lee, Neural correlates of spontaneous deception: a functional near-infrared spectroscopy (fNIRS) study, Neuropsychologia 51 (4) (2013) 704–712. http://dx.doi.org/10.1016/j.neuropsychologia.2012.12.018.

[10] E. Donchin, Surprise! … surprise?, Psychophysiology 18 (1981) 493–513. http://dx.doi.org/10.1111/j.1469-8986.1981.tb01815.x.

[11] M.J. Farah, B. Hutchinson, E.A. Phelps, A.D. Wagner, Functional MRI-based lie-detection: scientific and societal challenges, Nat. Rev. Neurosci. 15 (2014) 123–131. http://dx.doi.org/10.1038/nrn3665.

[12] L.A. Farwell, E. Donchin, The truth will out: Interrogative polygraphy ("lie detection") with event-related potentials, Psychophysiology 28 (1991) 531–547. http://dx.doi.org/10.1111/j.1469-8986.1991.tb01990.x.

[13] K. Fiedler, J. Schmid, T. Stahl, What is the current truth about polygraph lie detection? Basic Appl. Soc. Psychol. 24 (2002) 313-324, http://dx.doi.org/10.1207/S15324834BASP2404_6.

[14] J.J. Furedy, C. Davis, M. Gurevich, Differentiation of deception as a psychological process: a psychophysiological approach, Psychophysiology 25 (1988) 683–688. http://dx.doi.org/10.1111/j.1469-8986.1988.tb01908.x.

[15] M. Gamer, Mind reading using neuroimaging: is this the future of deception detection?, Eur. Psychol. 19 (2014) 172–183. http://dx.doi.org/10.1027/1016-9040/a000193.

[16] G. Ganis, Deception detection using neuroimaging, in: P.A. Granhag, A. Vrij, B. Verschuere (Eds.), Detecting Deception: Current Challenges and Cognitive Approaches, John Wiley & Sons, Ltd, Chichester, UK, 2014.

[17] G. Ganis, J.P. Rosenfeld, J. Meixner, R.A. Kievit, H.E. Schendan, Lying in the scanner: covert countermeasures disrupt deception detection by functional magnetic resonance imaging, Neuroimage 55 (2011) 312–319. http://dx.doi.org/10.1016/j.neuroimage.2010.11.025.

[18] H. Garavan, T.J. Ross, E.A. Stein, Right hemispheric dominance of inhibitory control: an event-related fMRI study, Proc. Natl. Acad. Sci. USA 96 (14) (1999) 8301-8306, http://dx.doi.org/10.1073/pnas.96.14.8301.

[19] N. Garrett, S.C. Lazzaro, D. Ariely, T. Sharot, The brain adapts to dishonesty, Nat. Neurosci. 19 (2016) 1727-1732, http://dx.doi.org/10.1038/nn.4426.

[20] X. Hu, H. Chen, G. Fu, A repeated lie becomes a truth? The effect of intentional control and training on deception, Front. Psychol. 3 (2012) 488. http://dx.doi.org/10.3389/fpsyg.2012.00488.

[21] W.G. Iacono, Can we determine the accuracy of polygraph tests? (201), in: P.K. Ackles, J.R. Jennings, M.G.H. Coles (Eds.), Advances in Psychophysiology, JAI

Press, Greenwich, CT, 1991, p. 201.
[22] W.G. Iacono, Effective policing: Understanding how polygraph tests work and are used, Criminal Justice and Behavior 35 (10) (2008) 1295-1308, http://dx.doi.org/10.1177/0093854808321529.
[23] N. klein Selle, B. Verschuere, M. Kindt, E.H. Meijer, G. Ben-Shakhar, Orienting versus inhibition in the Concealed Information Test: different cognitive processes drive Different physiological measures, Psychophysiology (2015). http://dx.doi.org/10.1111/psyp.12583 (Advance online publication).
[24] F.A. Kozel, K.A. Johnson, E.L. Grenesko, S.J. Laken, S. Kose, X. Lu, M.S. George, Functional MRI detection of deception after committing a mock sabotage crime, J. Forensic Sci. 54 (2009) 220–231. http://dx.doi.org/10.1111/j.1556-4029.2008.00927.x.
[25] F.A. Kozel, L.J. Ravell, J.P. Lorenbaum, A. Shastri, J.D. Elihai, M.D. Horner, M.S. George, A pilot study of functional magnetic resonance imaging brain correlates of deception in healthy young men, J. Neuropsychiatry Clin. Neurosci. 16 (2004) 295–305. http://dx.doi.org/10.1176/jnp.16.3.295.
[26] Kunzendorf, R.G., Sheikh, A.A. (Eds.), The Psychophysiology of Mental Imagery: Theory, Research, and Application (Vol. 3). Baywood Pub Co., 1990.
[27] D.D. Langleben, L. Schroeder, J.A. Maldjian, R.C. Gur, S. McDonald, J.D. Ragland, A.R. Childress, Brain activity during simulated deception: an event-related functional magnetic resonance study, Neuroimage 15 (3) (2002) 727-732, http://dx.doi.org/10.1006/nimg.2001.1003.
[28] D.D. Langleben, J.W. Loughhead, W.B. Bilker, K. Ruparel, A.R. Childress, S.I. Busch, R.C. Gur, Telling truth from lie in individual subjects with fast event-related fMRI, Hum. Brain Mapp. 26 (2005) 262–272. http://dx.doi.org/10.1002/hbm.20191.
[29] D.D. Langleben, J.C. Moriarty, Using brain imaging for lie detection: where science, law, and policy collide, Psychol. Public Policy Law 19 (2013) 222–234. http://dx.doi.org/10.1037/a0028841.
[30] J.A. Larson, Lying and Its Detection, University of Chicago Press, Chicago, 1932.
[31] I. Lieblich, S. Kugelmass, G. Ben-Shakhar, Efficiency of GSR detection of information as a function of stimulus set size, Psychophysiology 6 (1970) 601–608. http://dx.doi.org/10.1111/j.1469-8986.1970.tb02249.x.
[32] G. Lukács, B. Weiss, V.D. Dalos, T. Kilencz, S. Tudja, G. Csifcsák, The first independent study on the complex trial protocol version of the P300-based concealed information test: Corroboration of previous findings and highlights on vulnerabilities, Int. J. Psychophysiol. 110 (2016) 56-65, http://dx.doi.org/10.1016/j.ijpsycho.2016.10.010.
[33] D.T. Lykken, The GSR in the detection of guilt, J. Appl. Psychol. 43 (1959) 385–388. http://dx.doi.org/10.1037/h0046060.
[34] D.T. Lykken, The validity of the guilty knowledge technique: the effects of faking, J. Appl. Psychol. 44 (1960) 258–262. http://dx.doi.org/10.1037/h0044413.
[35] D.T. Lykken, A Tremor in the Blood: Uses and Abuses of the Lie Detector, Plenum Press, Berlin, Germany, 1998.
[36] E.H. Meijer, N. klein Selle, L. Elber, G. Ben-Shakhar, Memory detection with the Concealed Information Test: a meta analysis of skin conductance, respiration, heart rate, and P300 data, Psychophysiology 51 (2014) 879–904. http://dx.doi.org/10.1111/psyp.12239.
[37] E.H. Meijer, B. Verschuere, M. Gamer, H. Merckelbach, G. Ben-Shakhar, Deception detection with behavioral, autonomic, and neural measures: conceptual and methodological considerations that warrant modesty, Psychophysiology (2016). http://dx.doi.org/10.1111/psyp.12609.
[38] E.H. Meijer, B. Verschuere, The polygraph: current practice and new approaches, in: P.A. Granhag, A. Vrij, B. Verschuere (Eds.), Detecting Deception: Current Challenges and Cognitive Approaches, John Wiley & Sons, Ltd, Chichester, UK:, 2015.
[39] National Research Council, The polygraph and lie detection. Committee to review the scientific evidence on the Polygraph. Division of Behavioral and Social Sciences and Education. The National Academies Press, Washington, D.C., 2003.
[40] S. Nieuwenhuis, E.J. De Geus, G. Aston-Jones, The anatomical and functional relationship between the P3 and autonomic components of the orienting response, Psychophysiology 48 (2011) 162–175. http://dx.doi.org/10.1111/j.1469-8986.2010.01057.x.
[41] I. Nose, J. Murai, M. Taira, Disclosing concealed information on the basis of cortical activations, NeuroImage 44 (2009) 1380–1386. http://dx.doi.org/10.1016/j.neuroimage.2008.11.002.
[42] H. Offe, S. Offe, The comparison question test: does it work and if so how? Law Hum. Behav. 31 (3) (2007) 291-303, http://dx.doi.org/10.1007/s10979-006-9059-3.
[43] J. Peth, T. Sommer, M.N. Hebart, G. Vossel, C. Büchel, M. Gamer, Memory detection using fMRI—Does the encoding context matter?, NeuroImage 113 (2015) 164–174. http://dx.doi.org/10.1016/j.neuroimage.2015.03.051.
[44] J.A. Podlesney, Is the guilty knowledge technique applicable in criminal investigations? A review of FBI records, Crime. Lab. Dig. 20 (1993) 57–61.
[45] J.E. Reid, A revised questioning technique in lie-detection tests, J. Crim. Law Criminol. 37 (1947) 542–547. http://dx.doi.org/10.2307/1138979.
[46] J.P. Rosenfeld, A. Angell, M. Johnson, J.H. Qian, An ERP-based, control-question lie detector analog: algorithms for discriminating effects within individuals' average waveforms, Psychophysiology 28 (1991) 319–335. http://dx.doi.org/10.1111/j.1469-8986.1991.tb02202.x.
[47] J.P. Rosenfeld, M. Soskins, G. Bosh, A. Rayan, Simple, effective countermeasures to P300-based tests of detection of concealed information, Psychophysiology 41 (2004) 205–219. http://dx.doi.org/10.1111/j.1469-8986.2004.00158.x.
[48] S.A. Spence, T.F. Farrow, A.E. Herford, I.D. Wilkinson, Y. Zheng, P.W. Woodruff, Behavioural and functional anatomical correlates of deception in humans, NeuroReport 12 (2001) 2849–2853. http://dx.doi.org/10.1097/00001756-200109170-00019.
[49] S.A. Spence, C.J. Kaylor-Hughes, M.L. Brook, S.T. Lankappa, I.D. Wilkinson, 'Munchausen's syndrome by proxy'or a 'miscarriage of justice'? An initial application of functional neuroimaging to the question of guilt versus innocence, Eur. Psychiatry 23 (4) (2008) 309-314, http://dx.doi.org/10.1016/j.eurpsy.2007.09.001.
[50] K. Suchotzki, B. Verschuere, J. Peth, G. Crombez, M. Gamer, Manipulating item proportion and deception reveals crucial dissociation between behavioral, autonomic, and neural indices of concealed information, Hum. Brain Mapp. 36 (2015) 427–439. http://dx.doi.org/10.1002/hbm.22637.
[51] K. Suchotzki, B. Verschuere, B. Van Bockstaele, G. Ben-Shakhar, G. Crombez, Lying takes time: a meta-analysis on reaction time measures of deception, Psychol. Bull. (2017), http://dx.doi.org/10.1037/bul0000087.
[52] M.R. Uncapher, J.T. Boyd-Meredith, T.E. Chow, J. Rissman, A.D. Wagner, Goaldirected modulation of neural memory patterns: implications for fMRI-based memory detection, J. Neurosci. 35 (22) (2015) 8531-8545, http://dx.doi.org/10.1523/JNEUROSCI.5145-14.2015.
[53] B. Van Bockstaele, B. Verschuere, T. Moens, K. Suchotzki, E. Debey, A. Spruyt, Learning to lie: Effects of practice on the cognitive cost of lying, Front. Psychol. 3 (2012) 526. http://dx.doi.org/10.3389/fpsyg.2012.00526.
[54] B. Verschuere, A. Spruyt, E.H. Meijer, H. Otgaar, The ease of lying, Conscious. Cogn. 20 (2011) 908–911. http://dx.doi.org/10.1016/j.concog.2010.10.023.
[55] A. Vrij, R. Fisher, S. Mann, S. Leal, Detecting deception by manipulating cognitive load, Trends Cogn. Sci. 10 (4) (2006) 141–142. http://dx.doi.org/10.1016/j.tics.2006.02.003.
[56] M.R. Winograd, J.P. Rosenfeld, The impact of prior knowledge from participant instructions in a mock crime P300 concealed information test, Int. J. Psychophysiol. 94 (2014) 473-481, http://dx.doi.org/10.1016/j.ijpsycho.2014.08.002.