A meta-analysis of the P3 amplitude in tasks requiring deception in legal and social contexts

Anja Leue and André Beauducel

Corresponding author: Prof. Dr. Anja Leue, University of Kiel, Institute of Psychology, Germany, email: leue@psychologie.uni-kiel.de

Date of submission: 28-February-2019

Abstract

In deception tasks the parietal P3 amplitude of the event-related potential indicates either recognition of salient stimuli (larger P3 following salient information) or mental effort (smaller P3 following demanding information). This meta-analysis (*k* = 77) investigated population effect sizes (δ) for conceptual and methodological a-priori moderators (study design, pre-task scenario, context of deception tasks, and P3 quantification). Within-subjects designs show evidence of the underlying cognitive processes, between-subjects designs allow for comparisons of cognitive processes in culprits vs. innocents. Committed vs. imagined mock crime scenarios yield larger δ. Deception tasks with a legal context result in almost twice as large δ than deception tasks with social-interactional and social-biographical contexts. Peak-to-peak P3 quantification resulted in larger δ than other quantifications. Counter-measure techniques in 3-stimulus protocols reduce the discriminability of concealed vs. truthful P3 amplitudes. Depending on stimulus knowledge, deception tasks provide evidence for the salience hypothesis and the mental effort hypothesis, respectively.

Key words: cognitive processes, deception, legal and social context, random-effects meta-analysis, P3 amplitude

1. Introduction

The investigation of dishonest or concealed information by means of verbal criteria (Vrij, 2015), behavioral and physiological data has a research tradition of more than 55 years (e.g., Abe et al., 2014; Ben-Shakhar & Elaad, 2003; Farwell & Donchin, 1991; Furedy & Ben-Shakhar, 1991; Garrigan, Adlam, & Langdon, 2016; Lykken, 1959; Rosenfeld, Nasman, Whalen, Cantwell, & Mazzeri, 1987; Rosenfeld, 2018; Vendemia, 2014). O'Sullivan (2008) emphasized that the literature on deception and lie detection is heterogeneous and can be related to misinforming others, active lying, or concealing information. One opportunity to learn more about the cognitive processes occurring during deception is to disentangle the contexts in that people behave in a deceptive vs. non-deceptive manner and to ask whether more active deception such as lying or misinforming others is related to different cognitive processes than concealing information. Moreover, to disentangle the cognitive processes during socially and forensically relevant behavior like deception time-sensitive parameters as event-related potentials (ERP) are highly promising in social neuroscience (e.g., Amodio, Bartholow, & Ito, 2014; Caccioppo & Decety, 2011; Ganis & Keenan, 2009; Rengifo, 2011).

Therefore, the present meta-analysis aims at showing meta-analytic evidence for two theoretical accounts on cognitive processes in deception tasks for legal and social contexts and by means of the P3 amplitude. The contexts can be differentiated as follows: (a) Deception in legal settings implies that people anticipate, imagine or know that their behavior would have been related to legal consequences in a real-life situation (e.g., being punished for stealing items, being incarcerated). (b) Deception in social-interactional settings means that people are afraid of negative consequences in their social relations (e.g., being criticized, being rejected for their attitudes, not being liked). Thus, deception in social-interactional settings is related to the anticipation of social rejection. (c) Deception in social-biographical settings implies that people typically conceal knowledge of learned items (e.g., meaning of playing cards and games) or (self-chosen) autobiographical items (e.g., names of towns, names of family member, birthday dates, places where known items are located). Thus, investigating deception in different experimental task settings (i.e., instructed contexts and tasks) by means of a meta-analysis helps to learn more about the generalizability of cognitive processes underlying deception and external validity.

1.1. Previous meta-analyses on deception

Over the years, different meta-analyses on deception detection have been conducted. These meta-analyses were based on studies investigating response times (Bond & DePaulo, 2006; Suchotzki, Verschuere, Van Bockstaele, & Ben-Shakhar, 2017), electrodermal measures (Ben-Shakhar & Elaad, 2003; Meijer, Klein Selle, Elber, & Ben-Shakhar, 2014), the P3 amplitude (Meijer et al., 2014), and functional magnet resonance imaging data (Christ, Van Essen, Watson, Brubaker, & McDermott, 2009). These meta-analyses incorporated exclusively deception tasks in legal settings entitled as guilty knowledge tests (GKT) or concealed information tests (CIT, Lykken, 1959, 1974; Verschuere & Ben-Shakhar, 2011). To investigate the accuracy of GKT/CITs after correcting for measurement errors (e.g., unreliability), Ben-Shakhar and Elaad (2003) suggested investigating the following moderators: number and repetitions of GKT questions, type of verbal answer, and kind of motivational instruction. Meijer et al. (2014) investigated the validity of the CIT in a meta-analysis for skin conductance, respiration, heart rate, and P3 data in 35 task conditions. Meijer et al. (2014) focused on the following moderators: paradigm (personal-item vs. mock-crime; complex trial protocol, CTP: yes or no), type of protocol (e.g., number of questions 1 vs. > 1), and unknowledgeable participants (innocent vs. not using innocent subgroups). In sum, prior meta-analyses focused on the investigation of the moderators that are related to the task setting in GKT/CITs. The present meta-analysis aims at including deception tasks of legal and social task settings –not exclusively GKT/CITs– and at addressing a-priori moderators that have not yet been investigated. According to this broad perspective, the common aspect of the studies investigated here is that the participants are instructed to deceive, to conceal knowledge, or to lie. We thereby do not presume that the instruction to deceive, to conceal knowledge, or to lie induces identical cognitive processes.

1.2. Cognitive processes in deception tasks

There is no single theory on cognitive processes in deception tasks (e.g., Verschuere, Ben-Shakhar, & Meijer, 2011; Rosenfeld, 2018; Vendemia, 2014, Figure 3). However, predictions on different cognitive processes activated during deception can be derived from previous deception research and from research of the parietal P3 amplitude of the ERP. The parietal P3 amplitude has been introduced as an indicator of stimulus salience because it is selectively sensitive to resources of a perceptual and cognitive nature (Kok, 2001, p. 558). Stimulus salience in deception tasks means that known stimuli are more salient than unknown (new) stimuli. Therefore, a known stimulus induces a more positive P3 amplitude than an unknown stimulus especially when the knowledge of the stimulus is concealed. Typically, the participants are instructed to learn the known stimuli and to recognize them during the task. Unknown stimuli are not presented before the task (i.e., they are new stimuli). Known stimuli should be more salient than unknown stimuli (Kok, 2001). Moreover, deception should be affectively valent because individuals usually know that not telling the truth is against a social rule and that honesty is a value that confirms ethical standards (see Abe et al., 2014). There is also some evidence in deception studies suggesting smaller P3 amplitudes to concealed compared to non-concealed information (Johnson Jr., Banhardt, & Zhu, 2005; Pfister, Foerster, & Kunde, 2014; Wu, Hu, & Fu, 2009). Those findings can be interpreted in terms of the mental effort concept (Beauducel, Brocke, & Leue, 2006) because concealing knowledge can be regarded as an effortful task. Concealing or deceiving knowledge in the sense of suppressing knowledge at the behavioral level may cost more mental effort than not concealing knowledge. When individuals invest more mental effort the P3 amplitude should be smaller because of an internal dual-task requirement. Internal dual-task requirement means: More cognitive resources are necessary for one process (e.g., suppressing knowledge) and fewer resources are available for another process such as current stimulus processing (Beauducel et al., 2006). Thus, depending on the study design (within-subjects vs. between-subjects), the experimental conditions and the deception task the P3 amplitude is presumed to indicate either recognition of known, salient stimuli (Kok, 2001) or mental effort (Beauducel et al., 2006).

1.3. Pre-task scenario and context of deception task as a-priori moderators

Some deception tasks like GKT/CITs can be differentiated with regard to pre-task scenarios. GKT/CITs with a pre-task scenario ask participants either to commit a mock crime (e.g., stealing a jewel or a wallet) or to imagine they would have committed a mock crime (i.e., a simulated criminal act in an experimental study). Following theories on episodic memory, the commission of real behavior results in more intense memory than the imagination of an event (Schacter, Addis, Hassabis, Martin, Spreng, & Szpunar, 2007). Accordingly, the deception of a committed mock crime should be more salient resulting in a larger population effect size than the deception of an imagined or observed mock crime.

Deception has been investigated in experimental tasks that comprise different contexts such as legal contexts (GKT/CITs), social-interactional contexts (e.g., tasks that require concealing attitudes), and social-biographical contexts (e.g., concealing knowledge of learned verbal vs. numerical items such as names, birthday dates, location of objects). GKT/CITs incorporate probe, target, and irrelevant stimuli. Probe stimuli are known to participants and they are instructed to conceal knowledge to pre-defined stimuli. Target stimuli are also known to participants and they are instructed to respond truthfully to those stimuli. Irrelevant stimuli are typically unknown to participants and participants are instructed to respond truthfully to these stimuli. Research has shown that stimulus processing in GKT/CITs is related to recognition of known, salient vs. unknown, non-salient stimuli (Gamer & Berti, 2010; Kok, 2001; Leue & Beauducel, 2015; Leue, Lange, & Beauducel, 2012; Meijer, Verschuere, Gamer, Merckelbach, & Ben-Shakhar, 2016). In GKT/CITs, known probe stimuli are presumed to be more salient (more positive P3 amplitude). Unknown irrelevant or known irrelevant stimuli are expected to evoke less intense stimulus salience (less positive P3 amplitude). GKT/CITs allow for the investigation of known (probe) vs. unknown (irrelevant) P3 effects in a within-subjects design in the whole sample or in a subgroup of mock guilty participants. GKT/CITs are related to a legal setting when participants are instructed to commit, imagine or observe a mock crime. In addition to GKT/CITs, active lying has been investigated in other paradigms by means of the parietal P3 amplitude (e.g., Pfister et al., 2014; Suchotzki et al., 2017). Active lying differs from concealing information in GKT/CITs by the fact that response buttons to probe and irrelevant stimuli are not identical but lying to known information requires a different response than truthful responding to known information. That is, lying is characterized by actively suppressing information and providing different responses, whereas concealing information does not require different reactions than responding truthfully. Accordingly, concealing information especially requires to mentally or affectively reduce the legal or ethical meaning of a stimulus (probe).

In deception tasks with a social setting, participants are typically asked to conceal their attitudes or their intentions. These social deception tasks are characterized by the fact that participants know all stimuli. They are instructed to respond truthfully to a subset of known stimuli and to conceal their attitudes or knowledge to another subset of known stimuli (e.g., Dong, Wu, & Lu, 2010; Leue & Beauducel, 2015; Leue et al., 2012). Finally, deception tasks with a social-biographical context require participants to conceal knowledge of stimuli like words, names, dates, playing cards or object locations. In these tasks, participants are asked to conceal their knowledge of specific items and to respond truthfully to other known stimuli entitled as targets and irrelevant stimuli, respectively (e.g., Gamer & Berti, 2010; Kubo & Nittono, 2009).

Thus, in experimental tasks with social contexts, P3 effects to concealed information (concealed P3) are compared with P3 effects to truthful, known information (non-concealed P3) in a within-subjects design. In contrast, in legal settings P3 effects to concealed information (probe P3) are typically compared with P3 effects to unknown, irrelevant stimuli (irrelevant P3) in a within-subjects design. Accordingly, we calculated the population effect sizes and the standard deviations of the population effect sizes for P3 amplitudes of probe vs. irrelevant stimuli and for P3 amplitudes to concealed, known vs. non-concealed, known stimuli. We presumed that deception tasks with a legal setting result in more pronounced population effect sizes compared to deception tasks with a social setting. This prediction derives from the fact that concealing knowledge in a ‘higher stakes’ context should be more salient than concealing knowledge in a ‘lower stakes’ context (Le, 2016; Porter & ten Brinke, 2010). Deception in a ‘higher stakes’ context is associated with serious (anticipated) consequences for the individual who behaves against legal or social rules (e.g., becoming incarcerated, behaving as untrustworthy), whereas deception in a ‘lower stakes’ context is related to minimal consequences (e.g., behaving against task instruction, Le, 2016; Porter & ten Brinke, 2010).

1.4. Counter-measure techniques in 3-stimulus protocols and complex trial protocols

Till date, counter-measure techniques have been exclusively tested in GKT/CITs and for various physiological parameters (Ben-Shakhar, 2011; Peth, Suchotzki, & Gamer, 2016; Rosenfeld, Soskins, Bosh, & Ryan, 2004). Counter-measure techniques can be applied to irrelevant items or to probe items. When counter-measure techniques are successfully applied to probe stimuli, physiological responses to probe stimuli are reduced compared to situations without counter-measure techniques. When counter-measure techniques are applied to irrelevant stimuli, physiological responses to irrelevant stimuli are intensified and become more similar to physiological responses following probe stimuli. To investigate effects of counter-measure techniques we compared population effect sizes obtained in primary studies with and without counter-measure techniques. Successful application of counter-measure techniques should reduce the difference between probe and irrelevant stimuli. Therefore, the population effect size for task conditions with counter-measure techniques should be smaller compared to the population effect size for task conditions that did not apply counter-measure techniques. CTPs have been introduced to avoid the successful application of counter-measure techniques (cf. Hu & Rosenfeld, 2012; Labkovsky & Rosenfeld, 2014; Meixner & Rosenfeld, 2011; Rosenfeld et al., 2008). The population effect size of CTP studies should be larger (i.e., representing a more pronounced probe vs. irrelevant P3 difference) than the population effect size of primary studies with a successful application of counter-measure techniques (cf. 3-stimulus protocol of the GKT/CIT).

1.5. P3 quantification as an a-priori moderator

We investigated whether variations of stimulus salience (i.e., the recognition of rare and/or significant known items) as reflected in the parietal P3 amplitude generalize across different contexts of experimental task settings. The parietal P3 amplitude of the ERP is a positive deflection typically occurring between 300 and 1000 ms post-stimulus (Cuthbert, Schupp, McManis, Hilman, & Bradley, 1995; Johnson, 1986, 1993; Olofsson & Polich, 2007). Some studies entitled this parietal ERP component as the Late Positive Component (LPC, Polich, 2007). Because the parietal P3 and the parietal LPC have not been associated with different processes we refer to the term "P3" component subsequently (Polich, 2007, p. 2128). Studies in the late 1970s and in the 1980s have shown that type of stimulus (i.e., the relevance of a stimulus) and stimulus probability (i.e., the frequency of a stimulus presentation) modulate the P3 amplitude (e.g., Donchin, 1981; Johnson & Donchin, 1978; Johnson, 1986, 1993). Stimulus salience can vary depending on affective valence and depending on whether a stimulus is known or unknown. Known stimuli are presented to participants before the beginning of the task.

Prior studies demonstrated that the quantification method of the ERP has an impact on the reliability of ERP parameters (e.g., Huffmeijer, Bakermans-Kranenburg, Alink, & van Ijzendoorn, 2014; Leue, Klein, Lange, & Beauducel, 2013; Marco-Pallares, Cucurell, Münte, Strien, & Rodriguez-Fornells, 2011; Pollock & Schneider, 1992; Rietdijk, Franken, & Thurik, 2014). In primary studies, mean amplitudes were quantified as the mean number of data points in a time interval and baseline-to-peak P3 amplitudes were calculated as the most positive peak in a time interval relative to baseline (Luck, 2014). Peak-to-peak P3 amplitudes in primary deception tasks were computed in accordance with Rosenfeld, Angell, Johnson, and Qian (1991) as the difference between the most positive P3 peak and the most negative peak of the subsequent ERP component (for details see also Soskins, Rosenfeld, & Niendam, 2001). According to the Spearman-Brown prophecy formula averaging a larger number of data points results in a more reliable component. Accordingly, the reliability of the P3 amplitude depends on the number of averaged epochs. Because the number of averaged data points is larger for peak-to-peak and mean amplitudes we expected that the peak-to-peak and the mean amplitude quantification of the P3 amplitude is more reliable than the baseline-to-peak amplitude. Therefore, we investigate the effect of the quantification method of the P3 on the population effect size and on the standard deviation of the population effect size.

1.6. Aims and research questions of the present meta-analysis

The present meta-analysis aimed at disentangling salience and effort effects by means of the parietal P3 amplitudes. We proposed on the one hand that experimental conditions in deception tasks with a differentiation of known vs. unknown information facilitate the recognition of stimulus salience (i.e., P3 following known, deceptive stimuli is larger than the P3 following unknown, truthful information). On the other hand, we predicted that experimental conditions in deception tasks with a differentiation of known, deceptive vs. known, truthful information facilitate the mental effort effect (i.e., P3 following known, deceptive is smaller than the P3 following known, truthful information). We investigated evidence for the salience hypothesis and the mental effort hypothesis, respectively, in P3 studies using within-subjects designs and between-subjects designs, respectively. We expect that the differentiation of known versus unknown stimuli that triggers the salience hypothesis primarily occurs in a legal context, whereas the differentiation of known stimuli requiring deceptive responses versus known stimuli requiring truthful responses primarily occurs in social settings. Moreover, we addressed the following research questions by means of overall and a-priori moderator analyses (Table 1): (a) Does the population effect size depend on the context of the deception task (i.e., legal and social) and the corresponding study design (within-subjects design vs. between-subjects design)? These two aspects were investigated within one question because study design is determined by experimental task conditions. (b) Does the pre-task scenario (committed vs. imagined mock crime) influence the population effect size? (c) Do counter-measure techniques reduce the difference between probe and irrelevant stimuli resulting in a smaller population effect size for counter-measure studies compared to deception studies without a counter-measure technique? (d) Do pre-processing parameters of the EEG data (e.g., quantification method) affect the population effect size?

--- Table 1 ---

2. Method

2.1. Literature search

An electronic literature search has been conducted in the data bases PsycInfo, Medline, and Google scholar. We included studies that were published or that were available online until June, 8th, 2018. Former literature searches have been updated in 2015 and 2016. Abstracts that were published in these data bases were screened for the relevant key words: “deception, EEG” and “deception, ERP” resulting in 118 references. The PRISMA flow diagram (Figure 1) summarizes the procedure of the literature search (see also Moran, Schroder, Kneips, and Moser, 2017). In order to keep the literature search as reproducible as possible we restricted our search to these simple two combinations of terms. The use of a complex set of keywords implies that researchers have a population of studies in mind that they aim to map based on the included keywords. However, we had no a-priori mind set of studies and, therefore, the keywords constitute an a-priori definition of the study population.

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2.2. Exclusion of primary studies

Of these 118 references several primary studies had to be excluded because of the following reasons: (1) k = 13 studies investigated electrodermal parameters (e.g., skin conductance level) or cardiovascular parameters (e.g., heart rate), (2) k = 4 studies investigated EEG frequency band data or connectivity data, (3) k = 9 studies investigated exclusively other stimulus-locked ERPs (e.g., N400 amplitude) or stimulus-locked P300 at occipital sites instead of parietal sites (Gibbons, Schnürch, Wittinghofer, Armbrecht, & Stahl, 2018), (4) k = 9 studies investigated response-locked or feedback-locked ERPs (e.g., response-locked medial frontal negativity, feedback-locked P3), (5) k = 2 studies investigated dipole sources in a deception task, (6) k = 9 deception studies did not report ERP findings but discussed the overall investigation of physiological parameters in deception studies or (7) were reviews (k = 3), (8) k = 1 study was not on deception although the P3 was investigated (Spapé, Hoggan, Jaccucci, & Ravaja, 2015), (9) $k = 2$ studies investigated the frontal P3 (Gibbons et al., 2018; Proverbio, Vanutelli, & Adorni, 2013), which conceptually differs from the parietal P3 (Kok, 2001), (10) $k = 3$ studies were performed in a financial context or in an individual vs. collaborative crime context that cannot be mapped on the legal and social context of the present meta-analysis (Lu et al., 2018; Rosenfeld et al., 2017, 2018), and (11) $k = 3$ studies investigated specific memory processes like retrieval and suppression of memory (Bergström, Anderson, Buda, Simons, & Richardson-Klavehn, 2013; Hu, Bergström, Bodenhausen, & Rosenfeld, 2015; Meixner & Rosenfeld, 2014). Thus, a total of 60 references including 77 P3-results were available for statistical analysis (Table S1; see Supplementary Material). We consider each task condition that allowed for the calculation of a P3-related effect size as a primary study (abbreviated with "*k*").

2.3. Coding of study characteristics and calculation of effect size

Study characteristics were independently coded by the first author and three members of her team. Study characteristics were obtained from the Method and Results sections of the published articles. Many publications included a statement that their studies were approved by a local Ethics Committee. As the present meta-analysis referred to the results of the primary studies, the procedures applied in this meta-analysis were not additionally approved by a local Ethics Committee. The authors analyzed the meta-analytic data with the best of their scientific and state-of-the-art knowledge. The following study characteristics were coded (cf., Table S1): sample size of the primary study, gender, features of EEG preprocessing (e.g., quantification of the P3 amplitude, time window of the P3 amplitude, topographical maximum of the P3 amplitude), study design (between-subjects design vs. within-subjects design), and type of deception task (pre-task scenario vs. no pre-task scenario); deception tasks with a legal context (GKT/CIT) or a social context. Coding of the study characteristics was iteratively discussed if coding of the study characteristics did not match. This procedure was chosen in order to sharpen the categories that were used to code study characteristics. Prior to statistical analysis a consensus between the first author and three members of her team was reached for the coding of the study characteristics of the included primary studies.

We were mainly interested in the following statistical findings: (1) task condition main effect, (2) electrode position x task condition interaction or a task condition x stimulus interaction. The effect size of a primary study was positively coded (i.e., confirming the salience hypothesis) when the parietal P3 amplitude was more positive to probe compared to irrelevant pictures (within-subjects design). The effect size of a primary study was negatively coded (i.e., confirming the mental effort hypothesis) when the parietal P3 amplitude was less positive to probe/concealed compared to irrelevant/non-concealed stimuli (within-subjects design). In a between-subjects design we positively coded the effect size of a primary study when the guilty group who was asked to conceal knowledge showed more positive P3 amplitudes than the innocent group who always responded truthfully.

We performed a random-effects meta-analysis that controls for the fact that the studies are heterogeneous at the level of the population effect sizes (i.e., the studies are selected from populations with different effect sizes, Hunter & Schmidt, 2000; for alternatives of random-effects meta-analysis see Hedges, 1983). Statistical values like *t*-scores and descriptives (e.g., *M* and *SD*) were transformed into effect size *d* for each task condition of a primary study. *F*-scores were in a first step transformed into effect size *r* according to the formula reported in Rosenthal and DiMatteo (2001). In a second step, effect size *r* was transformed into effect size *d* based on a formula given in Hunter and Schmidt (2004; see also Schmidt and Hunter, 2014). If no statistical values were reported for non-significant findings effect size *d* was set to zero.

2.4. Correction of measurement error

Hunter and Schmidt (2004) suggested several measurement errors that should be corrected for before population effect sizes are calculated. Here, we corrected for sampling error and for unreliability of the P3 amplitude. Thus, in accordance with Hunter and Schmidt (2004), we conducted an artefact-corrected meta-analysis. We compare the findings of the artefact-corrected meta-analysis with findings of the barebones meta-analysis exclusively correcting for sampling error. Based on Turner and Bernard (2006) population effect sizes *d* and δ can be transformed into Hedges g to compare our findings with meta-analytic findings reporting Hedges *g* or *d** (e.g., Meijer et al., 2014; Suchotzki et al., 2017). We used the formula presented in Hunter and Schmidt (2004, p. 284-285) in order to calculate the approximately unbiased estimator of the effect sizes (d*, sometimes called 'Hedges *g*') and of the approximately unbiased estimator of the standard deviation of effect sizes (SD_d^*).

Reliability studies suggest that ERPs are more reliably measured with a larger number of averaged epochs (e.g., Fabiani, Gratton, Karis, & Donchin, 1987; Leue et al., 2013; Marco-Pallares et al., 2011; Pollock & Schneider, 1992). A higher number of trials per stimulus type typically results in a higher reliability coefficient and a better signal-to-noise ratio. For the P3 amplitude, variations of reliability coefficients have been reported for test-retest reliability (e.g., Huffmeijer et al., 2014) and for internal consistency coefficients such as Cronbach's alpha and split-half reliability in go/nogo tasks (Rietdijk et al., 2014). Because none of the deception-P3 studies reported the reliability of the P3 amplitude we searched for studies reporting the internal consistency of the P3 amplitude in other experimental tasks (see Cohen & Polich, 1997; Pollock & Schneider, 1992; Boudewyn, Luck, Farrens, & Kappenman, 2018). Rietdijk et al. (2014, Figure 2) observed a Cronbach's alpha coefficient of .80 for the P3 amplitude at Pz when 30 trials in a go/nogo task were averaged. Till date the study of Rietdijk et al. (2014) is the only P3 study that reported Cronbach's alpha coefficients of the P3 amplitude for the number of averaged trials. Thus, to correct the unreliability of the P3 amplitude in the deception studies, we used Cronbach's alpha coefficients for the P3 amplitude at Pz of .80 for 30 averaged epochs (Rietdijk et al., 2014, Figure 2) as a starting point. Epoch-specific Cronbach's alpha coefficients for the probe/concealed and the irrelevant/non-concealed P3 amplitude were calculated by means of the Spearman-Brown prophecy formula of each primary study because this formula corrects reliability based on the number of available stimulus events. The Cronbach's alpha coefficient for the probe/concealed P3 amplitude and the Cronbach's alpha coefficient for the irrelevant/non-concealed P3 amplitude were averaged per task condition (because reliability of difference scores is less reliable).

2.5. Statistical analysis

We used the meta-analysis software of Schmidt and Le (2004, 2014). When a primary study included more than one P3-finding for the same sample of different experimental conditions (e.g., words, objects), we averaged the effect sizes across experimental conditions because the single effect sizes would depend on the same sample (e.g., Cutmore, Djakovic, Kebbell, & Shum, 2009; Meek, Phillips, Bowswell, & Vendemia, 2013). When a primary study reported effects for a within-subjects effect and for a between-subjects effect, effect sizes were separately coded for the within-subjects effect and for the between-subjects effect (e.g., Meixner & Rosenfeld, 2011). This was due to the fact that the within-subjects effect refers to the comparison of probe/concealed P3 vs. irrelevant/non-concealed P3. The between-subjects effect refers to P3 effects (probe minus irrelevant) in a guilty subgroup (concealing knowledge) compared to an innocent subgroup (responding truthfully). We separately calculated effect sizes of primary studies without countermeasure effects, with counter-measure effects, and for studies applying CTPs (e.g., Hu, Hegemann, Landry, & Rosenfeld, 2012; Labkovsky & Rosenfeld, 2012; Meixner, Haynes, Winograd, Brown, & Rosenfeld, 2009; Meixner & Rosenfeld, 2010; Winograd & Rosenfeld, 2011, Table S1, column "deception task / CM"). When primary studies reported P3 findings for different quantification methods (e.g., baseline-to-peak P3, mean P3, peak-to-peak P3), we calculated the effect size separately for each quantification method of the primary study (e.g., Johnson & Rosenfeld, 1992).

We describe the results in terms of the population effect size (δ), the standard deviation of the population effect size (SD_δ), the lower and upper 90% credibility interval, and the percentage of variance in corrected population effect size (δ) attributable to all artefacts (% Var. Acc. for). A ratio of δ/SD_δ larger than 2 indicates that the effect size is always positive in the population (i.e., probe/concealed P3 is larger than irrelevant/non-concealed P3) and, thus, confirms the salience hypothesis (Hunter & Schmidt, 2004, p. 65). According to Hunter and Schmidt (2004) moderator analysis should be conducted when the artefact-corrected population effect size explained less than 75% of the variance.

The fail-safe number was calculated in accordance with Orwin (1983) and Rosenthal (1979). The fail-safe number developed by Orwin (1983) is based on *d* and indicates how many unpublished primary studies would be necessary to reduce an observed population effect size *d* of the bare-bones meta-analysis to a given effect size (e.g., a small effect size of *d* = .10). Although the calculation of the fail-safe number has been criticized (Borenstein, Hedges, Higgins, & Rothstein, 2009), Heene (2010) illustrated that the fail-safe number is still a convincing tool to evaluate the robustness of meta-analytic findings.

3. Results

3.1. Frequencies and descriptive statistics

All included primary studies (*k* = 77) investigated variations of P3 amplitudes with a parietal topographical maximum in deception tasks. Most of the primary studies conducted a within-subjects design (*k* = 54) or a within-subjects design in the guilty subgroup (*k* = 14) and investigated whether the concealed/deceptive-P3 amplitude was larger than the irrelevant/non-concealed-P3 amplitude. A subset of *k* = 9 studies conducted a between-subjects design. Of the studies that applied a within-subjects design, *k* = 47 studies demonstrated evidence for the salience hypothesis (positive population effect size, Table 2) and *k* = 7 studies demonstrated results for the mental effort hypothesis (negative population effect size, Table 2). These seven studies revealing evidence for the mental effort hypothesis included tasks in that participants were instructed to lie to pre-defined stimuli and to respond truthfully to other pre-defined stimuli. The difference between concealing information and lying in the studies analyzed here is realized through different sets of pre-defined buttons. Of the 77 primary studies that reported the number of ERP epochs, we calculated Cronbach's alpha for the concealed/deceptive P3 amplitude and the non-concealed/non-deceptive P3 amplitude by means of Spearman-Brown prophecy formula (Supplement Table S1). Overall, the P3 amplitudes were often of a moderate to high reliability (Nunnally and Bernstein, 1994).

In order to investigate the research questions outlined above, separate moderator analyses were performed in studies without counter-measure techniques for task design (within-subjects vs. between-subjects design; section 3.2.), for type of deception tasks (legal or social) and task setting (referring to pre-task scenario; section 3.3.), and for quantification of P3-amplitudes (section 3.4.). Finally, we performed a moderator analysis for primary studies that applied counter-measure techniques (section 3.5.).

3.2. Overall analysis

For the k = 77 primary studies a medium positive population effect size δ of 0.72 was observed suggesting that a more positive P3-amplitude to concealed/deceptive information compared to non-concealed/non-deceptive information occurred in most experimental task conditions (Table 2). The mean population effect sizes of the barebones meta-analysis (d_m = 0.65), the approximately unbiased estimator (d^*_m = 0.63), and the artefact-corrected meta-analysis (δ = 0.72) were rather similar so that we focus on the artefact-corrected meta-analysis subsequently. The ratio of the population effect size and the standard deviation of the population effect size (δ/SD_δ) across all studies was smaller than 2 (see Table 2, 0.72/0.56) demonstrating that not all results in the primary studies confirmed the salience hypothesis. The percentage of explained variance accounted for by all artefacts was smaller than 75% suggesting that moderators might explain further variance.

When the effects of artefacts were removed, the population effect sizes of primary studies with a between-subjects design always confirmed the salience hypothesis as indicated by an SD_δ of zero (i.e., this subset of primary studies was very homogeneous). With regard to study design, primary studies with a within-subjects design resulted in highest population effect sizes (δ = 0.81) relative to studies that applied a within-subjects design in (guilty) subgroups (δ = 0.62) or a between-subjects design (δ = 0.38).

--- Table 2 ---

3.3. Moderator analysis: Type of deception task

In studies using a within-subjects design and without counter-measure effects (Table 3) it was investigated whether the concealed/deceptive P3-amplitude is larger than the non-concealed/non-deceptive P3-amplitude. As the different effect size estimates were very similar, we focus again on the artefact-corrected estimates. Population effect sizes were highest for GKT/CITs with a committed mock crime scenario (*k* = 9). The ratio of δ/SD_δ was larger than 2 for GKT/CITs with a mock crime scenario (δ/SD_δ: 0.94/0.40 = 2.35) and with a committed mock crime scenario (δ/SD_δ: 1.10/0.24 = 4.58) indicating that the concealed/deceptive P3 amplitudes were significantly larger than the non-concealed/non-deceptive P3 amplitudes. The population effect size was larger for GKT/CITs with committed mock crime scenarios compared to imagined or observed mock crime scenarios (δ/SD_δ: 0.59/0.43 = 1.37). Thus, the concealed/deceptive P3 amplitudes were substantially larger than the irrelevant/non-concealed/non-deceptive P3 amplitudes in GKT/CITs with committed mock crime scenarios but not in GKT/CITs with imagined or observed mock crime scenarios. Population effect sizes for deception tasks within a social-interactional context (δ = 0.63) and for deception tasks in a social-biographical context were moderate to high (δ = 1.01, Table 3). For deception tasks in a social context the ratio of δ/SD_δ was substantial (δ/SD_δ: 0.63/0.26 = 2.42, i.e., the salience hypothesis was mostly confirmed). Deception in card games and verbal/numerical tasks that did not evoke a legal context also revealed moderate to high population effect sizes and the study subset was very homogeneous (SD_δ = 0; i.e., salience hypothesis was always confirmed according to the population effect sizes). Deception tasks with a forensic scenario" (Table 3) include studies of Meek et al. (2013) activating a police setting, Johnson et al. (1992, two effect sizes) asking for antisocial acts and Rosenfeld et al. (2009) instructing participants to give a falsified ID.

These paradigms are more complex and include other stimulus types (e.g., misinformation) compared to CITs which we classified as "deception tasks in a legal context" (Table 3).

---- Table 3 ----

3.4. Moderator analysis: Quantification of the P3 amplitude

Again, the population effect sizes of the barebones meta-analysis, the approximately unbiased estimator of mean effect sizes, and the artefact-corrected effect sizes were very similar (Table 4). We investigated population effects depending on the quantification of the P3 amplitude in deception tasks with a within-subjects design. A substantial ratio of δ/SD_δ (1.24 / 0.28 = 4.43) was exclusively observed for a peak-to-peak quantification of P3 amplitudes indicating that the salience hypothesis was confirmed when the P3 amplitude was quantified by means of a peak-to-peak method. To investigate the population effect size for the peak-to-peak quantified P3 amplitudes we conducted separate moderator analyses in GKT/CITs with a mock crime scenario (k = 8) and GKT/CITs without a mock crime scenario (k = 12). Table 4 illustrates that the peak-to-peak quantification of the P3 amplitude resulted in a more homogeneous study set in GKT/CITs with a mock crime scenario (SD_δ = 0) compared to GKT/CITs without a mock crime scenario (SD_δ = 0.41).

---- Table 4 ---

3.5. Counter-measure effects

All studies using a 3-stimulus protocol (probe, target, irrelevant) with counter-measure techniques (k = 10) applied counter-measure techniques to irrelevant stimuli so that the magnitude of irrelevant-P3 amplitudes should become similar to the magnitude of probe-P3 amplitudes. The ratio of δ/SD_δ was smaller than 2 for primary studies that investigated counter-measure effects (δ/SD_δ: 0.55/0.47 = 1.17, Table 5) suggesting that the probe/concealed P3 amplitude was not larger than the irrelevant/non-concealed P3 amplitude in 3-stimulus-protocols. This finding supports assumptions on counter-measure effects presuming that physical and mental counter-measure techniques reduce the difference between probe/concealed and irrelevant/non-concealed P3 amplitudes. The CTP studies (k = 13) incorporated a 2 × 2 combination of task scenario (mock crime vs. no mock crime) and counter-measure techniques (yes vs. no): within-subjects CTPs with mock crime and counter-measure techniques (*k* = 2), CTPs with mock crime and without counter-measure techniques (*k* = 3), CTPs without mock crime and without counter-measure techniques (*k* = 1; Rosenfeld, Tang et al., 2009), and CTPs without mock crime and with counter-measure techniques in within-subjects designs (*k* = 7). We observed an artefact-corrected population effect size of δ = 1.12 for all available CTP studies (Table 5). This population effect size was almost twice as large as the population effect size for studies with a 3-stimulus protocol with counter-measure techniques (δ = 0.55). CTPs without a mock crime scenario and with counter-measure techniques (*k* = 7) revealed a substantial ratio of δ/SD_δ (1.40/0.52 = 2.69). Thus, the predicted P3 difference (P3-probe > P3-irrelevant) was confirmed in CTP studies without mock crimes and with counter-measures. Moreover, the population effect size in the CTP subset of *k* = 7 studies was more than twice as large than in 3-stimulus protocol studies with counter-measure techniques. The standard deviation of the population effect size of CTP studies (SD_δ = 0.52) was comparable to the standard deviation of the population effect size of counter-measure studies (SD_δ = 0.47). Despite a comparable standard deviation of the population effect size, the probe P3 was substantially larger than the irrelevant P3 in CTPs confirming the salience hypothesis. These findings also indicate that the probe vs. irrelevant difference of the P3 amplitudes remains in CTPs (without mock crime scenarios) despite of applied counter-measure techniques. In line with Meijer et al. (2014), our findings show that the CTP-without mock crime and with counter-measures (which all incorporated autobiographical items) have a larger population effect size (δ = 1.40; Table 5) than the GKT/CIT with mock crime (δ = 0.94; Table 5).

---- Table 5 ----

3.6. Fail-safe number

The calculation of the fail-safe number revealed three very robust barebones population effect sizes (Table 2, last column: fail safe number). A total of *k* = 351 to *k* = 424 unpublished studies would be necessary to reduce several population effect sizes to a small effect size of *d* = 0.10. In other words, the number of unpublished studies should be six to seven times larger to reduce the observed barebones population effect sizes to a small effect size of *d* = .10 (Cohen, 1966). It is rather unlikely that such a large number of unpublished studies with non-significant results exists for all deception studies investigating P3 effects (*k* = 424), applying a within-subjects design (without counter-measure effects, *k* = 351). The evidence for the salience hypothesis is also very robust because *N* = 362 unpublished primary studies would be necessary to reduce the population effect size to a small effect of .10. Another subset of population effect sizes suggested robust results with a number of *k* = 21 to *k* = 57 unpublished task conditions being necessary to reduce the observed population effect size to a small effect size of *d* = 0.10 (Table 2). For this subset we cannot rule out that a relevant number of unpublished studies exists that could reduce the observed population effect size to a small effect size of *d* = 0.10. As nonsignificant findings could have a reduced likelihood to be published it might be possible that a substantial number of unpublished studies exist (cf., Ferguson & Heene, 2012).

Table 3 indicates that the population effect sizes for deception tasks in a legal context (*k* = 117), for deception tasks in social contexts (*k* = 141), and for legal GKT/CITs with a committed mock crime (*k* = 74) were substantial and very robust. The number of unpublished studies would have been seven to eight times larger than *k* to reduce the population effect size to a *d* of 0.10. For the moderator P3 quantification (Table 4), the population effect sizes are robust for the peak-to-peak P3 quantification across deception tasks (*k* = 263) and for the mean P3 amplitudes (*k* = 37). The number of unpublished studies would have been three to about ten times larger than the published studies to reduce the population effect sizes to *d* = 0.10. Similarly, in Table 5 the number of unpublished CTP studies without mock crime and with counter-measure effects should have been 11 times larger than *k* to reduce the population effect size to a *d* of 0.10.

4. Discussion

This meta-analysis presents the following main findings: The ratio of the overall population effect size was smaller than 2 suggesting that the salience hypothesis was not always confirmed (Table 2, research question a). In studies using a within-subjects design the artefact-corrected population effect size was almost twice as large as in studies applying a between-subjects design (Table 2). In line with research question (a), we demonstrated that the population effect sizes for GKT/CITs with imagined or observed mock crime and with committed mock crime scenarios were about twice higher than population effect sizes in social contexts (Table 3). The ratio of δ/SD_δ was substantial for GKT/CITs with mock crime scenarios and deception in social contexts suggesting that the salience hypothesis was always confirmed in these studies. Additionally, it is noteworthy that the population effect size in legal deception tasks ($\delta = 0.98$, Table 3) was positive and more pronounced than the population effect size in deception tasks comprising social contexts ($\delta = 0.73$, Table 3) suggesting that recognition of stimulus salience is more likely in GKT/CITs whereas a combination of recognition of stimulus salience and mental effort might account for the smaller population effect size in deception tasks with social contexts. In deception tasks with social contexts all stimuli are known and there are no real unknown stimuli (e.g., playing cards of 9, 10 are typically known to people who have ever played cards). Thus, the P3 difference between concealed information and truthful information might be due to a combined effect of recognition of stimulus salience (enhancing the P3 amplitude) and mental effort (reducing the P3 amplitude).

In accordance with research question (b), we found that committing a mock crime was more salient compared to the imagination of a mock crime (Table 3). With regard to the quantification method of the P3 amplitude (research question c), the population effect size of the peak-to-peak quantification was about three to four times as large compared to baseline-to-peak quantification and mean amplitude quantification (Table 4). Moreover, the standard deviation of the population effect size for peak-to-peak quantification was only half as large as for the baseline-to-peak quantification suggesting that the latter quantification results in more noise. In contrast, the standard deviation of the population effect size for the mean amplitudes was nearly comparable to the standard deviation of the population effect size for baseline-to-peak quantification. As presumed in research question (d), the population effect size for 3-stimulus protocols with countermeasure techniques (Table 5) was smaller compared to the population effect size for deception tasks in a legal context without counter-measures (Table 3). CTP studies suggested a population effect size that was twice as large as the population effect size observed for 3-stimulus CITs with a successful application of counter-measure techniques (Table 5).

4.1. Cognitive processes in deception tasks

Our findings support a differentiation of 'lower stakes' and 'higher stakes' deception contexts. Deception tasks in legal contexts demonstrate 'higher stakes' situations compared to deception tasks in social-biographical contexts as card games and social-interactional contexts representing 'lower stakes' situations (Le, 2016; Porter & ten Brinke, 2010). The salience hypothesis was confirmed and effect sizes were substantial for deception tasks in a legal context (δ/SD_δ: 0.98 / 0.39 = 2.51) and for deception tasks in social contexts (δ/SD_δ: 0.73 / 0.25 = 2.92, Table 3). This finding illustrates that the salience hypothesis is a valuable account to explain at least one essential cognitive process during deception. The fact that the standard deviation of the population effect size was not zero reveals that some heterogeneity remained in the study subsets. This might be due to the fact that other cognitive processes beyond stimulus salience and mental effort (Beauducel et al., 2006; Kok, 2001) such as orienting and inhibition (Klein Selle, Verschuere, Kindt, Meijer, & Ben-Shakhar, 2016, 2017), encoding, switching, updating, storing etc. (Oberauer, Süß, Wilhelm, & Wittmann, 2003; Verschuere & Ben-Shakhar, 2011) may account for the P3 differences to deceptive vs. truthful stimuli. As deception tasks in social settings do typically not incorporate unknown stimuli it is likely that the parietal P3 amplitude difference between probe/concealed and irrelevant/non-concealed stimuli in legal settings is at least partly due to familiarity effects (known vs. unknown stimuli). Thus, recognition of known/salient stimuli seems to be a cognitive process during deception that depends on the relation of known compared to unknown or known irrelevant information.

It should also be noted that deception tasks in a social context also resulted in robust P3 findings (Table 3). Thus, P3-related cognitive processes on deception can be well studied in tasks applying a within-subjects design that represent a legal context (e.g., GKT/CITs with mock crime comparing probe-P3 amplitudes vs. irrelevant-P3 amplitudes) but also in a social context (e.g., concealing attitudes, trustworthiness). The negative population effect size for the P3 has been exclusively observed in primary studies that instructed participants to lie and that compared P3 effects of known, concealed vs. known, truthful stimuli (k = 7, Table 2). This demonstrates that mental effort modulates P3 effects when deception/lying occurs in a context of known stimuli and requires active suppression of information. The differentiation of known, concealed vs. known, unconcealed information by means of P3 variations is more likely in social settings or in tasks with previously learned verbal/numerical stimuli that did not activate a specific context (Table 3).

4.2. Quantification of the P3 amplitude in deception tasks

The peak-to-peak quantification as suggested by Rosenfeld et al. (1991) and Soskins et al. (2001) contributed most to the confirmation of the salience hypothesis. The peak-to-peak quantification method uses averaged segments of ERP data points in order to determine the difference between the most positive peak and the most negative peak within a time interval of interest. Although the peak-to-peak quantification enhances the effect sizes in line with the salience hypothesis, the difference between two peaks as a P3 measure might incorporate processes that do not exclusively represent characteristics of the P3 amplitude. The baseline-to-peak quantification is less suitable in order to investigate P3 differences during deception because this quantification method demonstrated comparably large heterogeneity of the population effect sizes (Table 4) and the findings are not very robust. The peak-to-peak quantification of the P3 amplitude results in reduced variability (cf., SD_{δ}) and a higher percentage of variance that is attributable to measurement errors (e.g., sample size, unreliability of P3 measurement) compared to baseline-to-peak and mean P3 amplitude.

4.3. CTPs and counter-measure effects

The fact that the ratio of the population effect size and the standard deviation of the population effect size (δ/SD_{δ}) was smaller than 2 in counter-measure studies (Table 5) suggests that the application of physical and mental counter-measure techniques to irrelevant/non-deceptive stimuli has an impact on the difference between probe/concealed-P3 amplitude and irrelevant/non-concealed P3-amplitude. When counter-measure techniques are applied to irrelevant/non-concealed stimuli, the magnitude of the irrelevant/non-concealed P3 will be enhanced so that differences between probe/concealed P3 amplitude and irrelevant/non-concealed P3 amplitude are less likely to be detected (see Ben-Shakhar, 2011 for counter-measure effects of other physiological parameters). Thus, in contrast to prior assumptions that ERPs would be immune against counter-measure effects (Ben-Shakhar, 2002), the findings of our meta-analysis demonstrate that the P3 amplitude following irrelevant/non-concealed P3 amplitudes can be modulated by counter-measure effects at least in 3-stimulus protocols. Future research might investigate whether earlier ERPs like N1, P2, or N2 amplitude are less likely to be affected by counter-measure techniques.

Due to a comparably small number of primary studies with counter-measure techniques we could not investigate whether counter-measure effects generalize across different types of deception tasks and whether physical and mental counter-measure techniques affect the P3-magnitude differently across stimulus type (e.g., probe vs. irrelevant). However, the ratio of the population effect size and the standard deviation of the population effect size (δ/SD_{δ}) for the CTP tasks demonstrates that the probe vs. irrelevant difference between P3 amplitudes remains and supports the salience hypothesis. The P3 amplitude in CTPs without mock crimes appear to be immune against counter-measures although participants were instructed to apply counter-measure techniques. That is why CTPs should be preferred over 3-stimulus-protocols when it cannot be excluded that participants perform counter-measure techniques.

4.4. Lessons learned from prior meta-analyses and from the present meta-analysis

Prior meta-analyses focused on the investigation of GKT/CITs (cf., Meijer et al., 2014). In contrast, the present meta-analysis investigates the generalization of P3-findings across different types of deception tasks in a legal context and in tasks activating social contexts. Moreover, our meta-analysis compared population effect sizes of the barebones, the artefact-corrected meta-analysis, and transformations of d into Hedges g (Tables 2 to 5) and referred to the investigation of a-priori moderators like study design (within-subjects vs. between-subjects design), type of deception task, and quantification method of the P3 amplitude after correcting for measurement errors. To study cognitive processes (e.g., recognition of salient stimuli vs. mental effort) and to identify robust concealed/deceptive vs. non-concealed/non-deceptive P3-effects within individuals the best practice would be to apply a within-subjects design. A between-subjects design should be used to compare P3 variations of individual cases and normative groups (e.g., culprits and innocents). Due to population effect size and the ratio of δ/SD_δ the P3 amplitude should be quantified by means of peak-to-peak technique as suggested by Rosenfeld et al. (1991).

In comparison to Meijer et al. (2014, Tables 4a, 4b, and 5) who reported a larger effect size of the corrected d_m^* = 1.89, we found an artefact-corrected population effect size of d_m^* of 0.81 (Table 3). This difference in the population effect sizes can be explained by the fact that Meijer et al. (2014) reported corrected population effect sizes for autobiographical CITs including CTP studies and mock crime CITs also including CTPs. Our data show CTP studies (even with counter-measures) do not reduce the difference between probe and irrelevant P3 amplitudes (Table 5). Thus, Meijer et al. (2014) did not disentangle CITs with and without CTPs. By reporting population effect sizes separately for CITs without counter-measures, with counter-measures, and CTPs (Tables 3 and 5 in the present meta-analysis) we extend the meta-analysis of Meijer et al. (2014). We demonstrate that the population effect size for concealed vs. non-concealed information in CTP studies is larger than the population effect size for 3-stimulus protocols. That is, the differentiation of concealed vs. non-concealed information for the P3 amplitude is robust in CTP studies (Table 5), whereas counter-measure techniques reduce the discriminability between concealed vs. non-concealed information for the P3 amplitude (population effect size in CTP studies is more than twice as large than in counter-measure studies: d = 1.40 vs. d = 0.55). This is important news especially for single case analysis in practical fields (cf., Owaga, Matsuda, & Tsuneoka, 2015). In a nutshell, the prior meta-analyses and our meta-analysis provide a valuable conceptual and empirical framework on deception by means of different types of deception tasks and physiological parameters such as electrodermal parameters (Ben-Shakhar & Elaad, 2003; Meijer et al., 2014), P3 parameters (Meijer et al., 2014 and the present meta-analysis), behavioral parameters (Suchotzki et al., 2017), and fMRI data (Christ et al., 2009; Garrigan et al., 2016).

4.4. Limitations and future directions

The present meta-analysis is based on studies of the P3 amplitude when participants are instructed to deceive, to conceal information, or to lie. Although participants may deceive, conceal information, or lie at the behavioral level, the P3 amplitude may also represent processes that are to some degree independent from deception, concealing, or lying at the behavioral level. As deception tasks might differ in the cognitive processes required to perform the task (including encoding, switching, updating, storing, Oberauer et al., 2003; Verschuere & Ben-Shakhar, 2011), future ERP-meta-analyses on deception could benefit from moderator analyses that refer to further cognitive processes beyond recognition of known/salient stimuli and mental effort. Moreover, moderators beyond those investigated here could be conceived in future meta-analyses on deception (e.g., differentiation of number of stimuli per picture type and number of iterations per picture type, cross-classification of task conditions, relevance of instructions). Future research needs to further our knowledge on additional P3-related cognitive processes like suppression and memory retrieval based on physiological and behavioral data in deception tasks (cf. Vendemia, 2014).

As too few studies investigated individual differences and sex differences during deception (Leue & Beauducel, 2015; Leue et al., 2012), we did not investigate individual differences as moderators in the present meta-analysis. Leue et al. (2012) as well as Leue and Beauducel (2015) demonstrated that trait-anxiety modulates P3-related processes during deception. Moreover, they reported that injustice sensitivity, a trait dimension that describes individual differences of sensitivity for injustice from different perspectives (perpetrator, victim, beneficiary, Schmitt, Baumert, Gollwitzer, & Maes, 2010) also modulates P3-related processes during deception. Individuals with a higher vs. lower sensitivity to injustice and women compared to men showed more positive probe P3 amplitudes than irrelevant P3 amplitudes. Thus, future research should more intensely study the relation between trait-like individual differences and deception, the differentiation of cognitive and memory processes (Bergström et al., 2013; Hu et al., 2015; Meixner & Rosenfeld, 2014), the relevance of financial incentives (Rosenfeld, Labkovsky, Davydova, Ward, & Rosenfeld, 2017; Rosenfeld, Sitar, Wasserman, & Ward (2018), and individual vs. collaborative crimes (Lu et al., 2018).

To avoid non-reporting of statistical values we encourage an adaptation of the publication practice increasing the opportunity that even non-significant findings get a higher chance to be published. From a methodological perspective, it is of interest to compare different descriptive and quantitative techniques (e.g., trim and fill, funnel plot, fail-safe number, *p*-curve analysis) to control for publication bias (Duval & Tweedie, 2000; Heene, 2010; Orwin, 1983; Simonsohn, Simmons, & Nelson, 2015). To correct measurement errors of the P3 amplitude more closely in conjunction with the P3 quantification method, future studies should take reliability of difference scores into account when peak-to-peak P3 quantification is applied (e.g., Overall & Woodward, 1975).

5. Conclusion

The present artefact-corrected meta-analysis (k = 77 primary studies) investigated P3-related deception with regard to the salience hypothesis and the mental effort hypothesis. Our findings demonstrate that deception tasks with a legal context result in larger population effect sizes especially when combined with a committed mock crime as pre-task scenario compared to other deception tasks. The salience hypothesis (larger concealed vs. non-concealed P3) was mainly confirmed in studies with a within-subjects design and demonstrates effects of stimulus familiarity versus dual task effects (storing knowledge and concealing knowledge) during deception. The mental effort hypothesis (smaller concealed vs. non-concealed P3) represents dual task effects during deception especially in primary tasks with instructed lying. Our findings also demonstrate that peak-to-peak P3 quantification leads to larger effect sizes than other quantification methods (mean P3, baseline-to-peak P3). The P3 amplitude can be modulated by mental and physical counter-measure techniques if no CTP is applied. Deception tasks with a between-subjects design result in smaller population effect sizes than deception tasks with a within-subjects design. Whereas the within-subjects design helps to elucidate cognitive processes during deception, the between-subjects design is important for the differentiation of individuals or subgroups who conceal knowledge or who do not. Finally, the present meta-analysis reveals that it could be promising to measure the difference between concealed knowledge and truthful knowledge by means of the P3 amplitude even in social settings. Future research should further elucidate the modulating role of individual differences and further contextual and task-specific factors during deception and the experimental conditions for familiarity and dual task effects during deception.

Acknowledgement

We are grateful to Katharina Bodenheim, Franziska Clemens, and Nils Lennart Lang-Keller for their assistance during literature search and coding of study characteristics.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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Table 1. Summary of a-priori moderators in deception studies

Type of a-priori moderator	Description of a-priori moderator
Task design	Between-subjects vs. within-subjects design
Task setting	Type of GKT/CIT pre-task scenario: committed mock crime imagined mock crime no mock crime
Context of experimental deception task	legal context social context Counter-measure techniques
EEG pre-processing	Quantification of P3 amplitude
Individual differences	Sex Trait-anxiety Injustice sensitivity

Note. Because too few studies investigated individual differences of deception (e.g., Leue & Beauducel, 2015; Leue et al., 2012), effects of individual differences (e.g., injustice sensitivity, trait-anxiety) on the probe-irrelevant P3 difference could not be calculated in this meta-analysis.

Table 2. Results of the random-effects barebones and artefact-corrected meta-analysis for overall effect and the moderator study design.

	Barebones meta-analysis							Artefact-corrected meta-analysis				
	k	*N*	d_m	d_m^*	SD_d	SD_d^*	*% Var. S.E.*	δ	SD_δ	*% Var. acc. for*	*90% CV*	Fail safe number
Overall	77	2,453	0.65	0.63	0.47	0.46	37.47	0.72	0.56	35.39	0.00-1.44	424
Within-subjects-design, no counter-measure	54	1,626	0.75	0.73	0.47	0.46	39.43	0.81	0.59	34.85	0.06-1.56	351
Evidence for salience hypothesis	47	1,489	0.87	0.85	0.32	0.31	58.40	0.95	0.44	44.10	0.38-1.51	362
Evidence for mental effort hypothesis	7	137	-0.49	-0.47	0.00	0.00	100.00	-0.52	0.00	100.00	-0.52--0.52	41
Within-subjects design (guilty subgroup), no counter-measure	14	525	0.51	0.50	0.54	0.53	27.99	0.62	0.62	29.38	-0.17-1.41	57
Between-subject design, no counter-measure	9	302	0.33	0.32	0.00	0.00	100.00	0.38	0.00	100.00	0.38-0.38	21

Notes. Parameters of the artefact-corrected meta-analysis are corrected for Spearman-Brown estimated reliability coefficients and sample size. *dm* = sample size corrected mean effect size. d_m^* = approximately unbiased estimator of mean effects sizes, sometimes called 'Hedges *g*'. SD_d = sample size corrected standard deviation of the mean effect size. SD_d^* = approximately unbiased estimator of standard deviation. δ = population effect size. *k* = number of primary studies. *N* = sample size across primary studies. SD_δ = standard deviation of the population effect size. % Var. acc. for = percentage of variance in corrected population effect attributable to artefacts. % Var. S.E. = percentage of variance attributable to sampling error. *90% CV* = lower and upper 90% credibility interval.

Table 3. Results of the random-effects barebones and artefact-corrected meta-analysis for the moderator type of deception task.

			Barebones meta-analysis					Artefact-corrected meta-analysis				
Within-subjects design and without counter-measures (k = 40)	k	N	d_m	d_m^*	SD_d	SD_d^*	*% Var. S.E.*	δ	SD_δ	*% Var. acc. for*	*90% CV*	Fail safe number
Deception tasks in a legal context	16	525	0.83	0.81	0.24	0.23	70.66	0.98	0.39	57.39	0.48-1.48	117
GKT/CIT with mock crime	12	368	0.83	0.81	0.26	0.25	67.40	0.94	0.40	55.30	0.43-1.45	88
GKT/CIT with committed mock crime	9	274	0.92	0.90	0.06	0.06	97.84	1.10	0.24	79.66	0.80-1.41	74
GKT/CIT with imagined / observed mock crime	3	94	0.59	0.57	0.42	0.41	42.91	0.59	0.43	42.96	0.04-1.14	15
Deception task with forensic scenario	4	157	0.81	0.79	0.15	0.15	83.15	1.13	0.31	70.57	0.74-1.52	28

Deception tasks in social contexts	24	644	0.69	0.67	0.24	0.23	73.21	0.73	0.25	74.84	0.42-1.05	141
Deception of faces/attitudes in a social context	11	372	0.59	0.58	0.26	0.25	64.97	0.63	0.26	66.98	0.29-0.96	54
Card games	5	67	0.41	0.38	0.00	0.00	100.00	0.47	0.00	100.00	0.47-0.47	16
Verbal and numerical recognition tasks of biographical data	8	205	0.95	0.92	0.00	0.00	100.00	1.01	0.00	100.00	1.01-1.01	68

Notes. Parameters of the artefact-corrected meta-analysis are corrected for Spearman-Brown estimated reliability coefficients and sample size. *dm* = sample size corrected mean effect size. d_m^*= approximately unbiased estimator of mean effects sizes, sometimes called 'Hedges *g*'. SD_d = sample size corrected standard deviation of the mean effect size. SD_d^* = approximately unbiased estimator of standard deviation. δ = population effect size. *k* = number of primary studies. *N* = sample size across primary studies. SD_δ = standard deviation of the population effect size. % Var. acc. for = percentage of variance in corrected population effect attributable to artefacts. % Var. S.E. = percentage of variance attributable to sampling error. *90% CV* = lower and upper 90% credibility interval.

Table 4. Results of the random-effects barebones and artefact-corrected meta-analysis for the moderator quantification of P3 amplitude.

			Barebones meta-analysis					Artefact-corrected meta-analysis				
Within-subjects design and without counter-measures (*k* = 52)	*k*	*N*	d_m	d_m^*	SD_d	SD_d^*	*% Var. S.E.*	δ	SD_δ	*% Var. acc. for*	*90% CV*	Fail safe number
Baseline-to-peak P3 amplitude (across tasks)	15	443	0.25	0.24	0.41	0.40	45.26	0.26	0.47	44.00	-0.34-0.86	23
Peak-to-peak P3 amplitude (across tasks)	26	888	1.11	1.08	0.00	0.00	100.00	1.24	0.28	69.76	0.88-1.60	263
Mean / adaptive mean P3 amplitude (across tasks)	11	274	0.44	0.43	0.35	0.34	57.44	0.46	0.43	52.73	-0.09-1.01	37

Notes. Parameters of the artefact-corrected meta-analysis are corrected for Spearman-Brown estimated reliability coefficients and sample size. Included studies incorporate *k* = 45 studies supporting the salience hypothesis and *k = 7* studies supporting the mental effort hypothesis. The seven studies that support the mental effort hypothesis (i.e., indicated negative population effect sizes) used either baseline-to-peak quantification (*k* = 5) or mean P3 quantification (*k* = 2). The number of studies was too small in order to analyze the effects of P3 quantification separately for the seven studies. *dm* = sample size corrected mean effect size. d_m^*= approximately unbiased estimator of mean effects sizes, sometimes called ‘Hedges *g*’. SD_d = sample size corrected standard deviation of the mean effect size. SD_d^* = approximately unbiased estimator of standard deviation. δ = population effect size. *k* = number of primary studies. *N* = sample size across primary studies. SD_δ = standard deviation of the population effect size. % Var. acc. for = percentage of variance in corrected population effect attributable to artefacts. % Var. S.E. = percentage of variance attributable to sampling error. *90% CV* = lower and upper 90% credibility interval. *k* = 2 primary studies did not report the quantification method of the P3 amplitude.

Table 5. Results of the random-effects barebones and artefact-corrected meta-analysis for the moderator counter-measure effects in GKT/CIT and autobiographical CTP studies (collapsed across study design).

	Barebones meta-analysis							Artefact-corrected meta-analysis				
	k	*N*	d_m	d_m^*	SD_d	SD_d^*	*% Var. S.E.*	δ	SD_δ	*% Var. acc. for*	*90% CV*	Fail safe number
3-stimulus protocol with counter-measure techniques	10	360	0.44	0.43	0.44	0.43	37.03	0.55	0.47	41.36	-0.05-1.14	34
CTP	13	491	1.03	1.01	0.20	0.20	74.97	1.12	0.21	77.32	0.86-1.39	121
CTP with counter-measure techniques (without mock crime, within-design)	7	320	1.29	1.27	0.13	0.13	86.85	1.40	0.52	34.93	0.74-2.06	83

Notes. CTP = Complex Trial Protocol. Parameters of the artefact-corrected meta-analysis are corrected for Spearman-Brown estimated reliability coefficients and sample size. *dm* = sample size corrected mean effect size. d_m^*= approximately unbiased estimator of mean effects sizes, sometimes called ‘Hedges *g*’. SD_d = sample size corrected standard deviation of the mean effect size. SD_d^* = approximately unbiased estimator of standard deviation. δ = population effect size. *k* = number of primary studies. *N* = sample size across primary studies. SD_δ =

standard deviation of the population effect size. % Var. acc. for = percentage of variance in corrected population effect attributable to artefacts. % Var. S.E. = percentage of variance attributable to sampling error. *90% CV* = lower and upper 90% credibility interval.

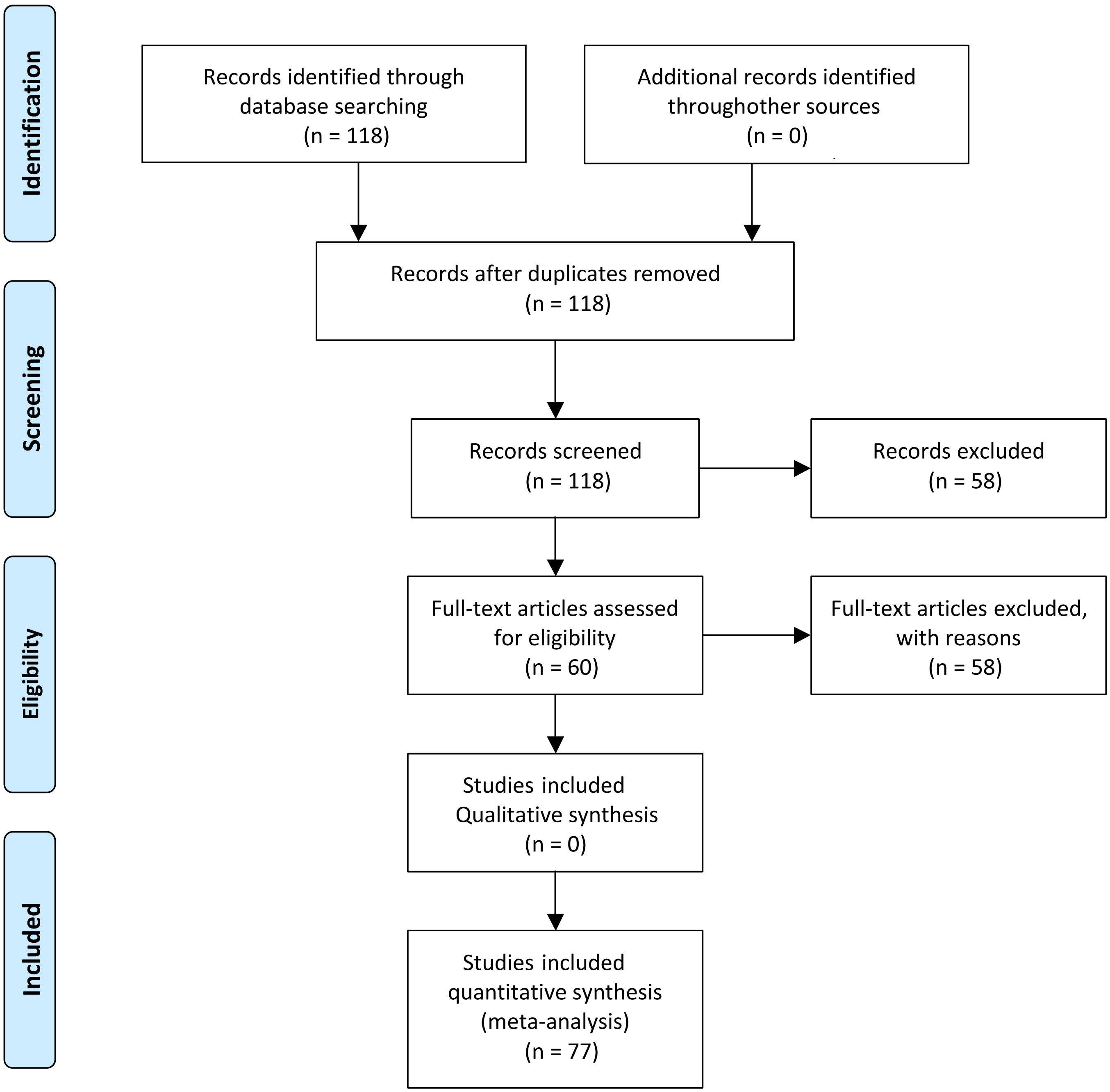

Figure 1. Prisma flow diagram (from: Moher et al., 2009).