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REVIEW

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Does deception involve more cognitive control than truth-telling? Meta-analyses of N2 and MFN ERP studies

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Abstract

A number of psychological theories propose that deception involves more cognitive control than truth-telling. Over the last decades, event-related potentials (ERPs) have been used to unravel this question, but the findings are mixed. To address this controversy, two meta-analyses were conducted to quantify the results of existing studies reporting N2 or medial frontal negativity (MFN) associated with deception. In total, 32 papers consisting of 1091 participants were included, which yielded 32 effect sizes for N2 and 7 effect sizes for MFN. We found that deception was associated with a more negative N2 and MFN than truth-telling with medium and large effect sizes ($r = .25$ and .51, respectively). We also found that the deception paradigm modulated the results ($p = .043$), but found no evidence for publication bias. Our findings indicate that deception involves more cognitive control than truth-telling. Our review also identifies gaps in this literature, including a need for more ERP studies using spontaneous deception.

KEYWORDS

cognitive control, deception, ERPs, MFN, N2

1 | INTRODUCTION

Imagine children being caught with chocolate on their face and being asked "Did you eat the chocolate cookies?". What happens in the children's brain when denying having eaten the cookies? The question on the neurocognitive mechanism underlying deception have attracted attention from multiple disciplines, including philosophy, psychology, and law, and private companies that are interested to use that knowledge for deception detection (Miller, 2009).

Liyang Sai and Jiayu Cheng contributed equally.

Some psychological theories, like the cognitive load theory, and the Activation-Decision-Construction-Action Theory (ADCAT) of deception, propose that deception is cognitively more challenging than truth-telling (e.g., Masip et al., 2016; Vrij et al., 2006; Walczyk et al., 2014). More specifically, these theories posit that to make a deceptive response, individuals typically need to inhibit their truthful response and make a deliberate false response that conflicts with the truth.

Event-related potentials (ERPs) have been used to put these theories to the test. Originally, the bulk of ERP research focused on the P300 (for a meta-analytic review see Meijer et al., 2014). Although P300 is suggested to reflect cognitive control in some paradigms (e.g., König et al., 2021; Xie et al., 2020), most published studies on deception link P300 with stimulus recognition and use P300 as an index to assess whether a suspect recognizes crime-related items (Rosenfeld, 2020). More recently, ERP studies have focused on two other ERP components that might be associated with cognitive control, including the N2 and the medial frontal negativity (MFN). The N2 is a negative component that occurs 200–350 ms after the onset of the stimulus at frontal-central electrodes, and has consistently been observed during tasks requiring cognitive control (Enriquez-Geppert et al., 2010; Folstein & Van Petten, 2008), such as the Flanker task and the Stroop task (Dubreuil-Vall et al., 2019; Huster et al., 2010; Huster et al., 2013). For example, researchers have consistently found that incongruent trials typically produce a larger fronto-central N2 than congruent stimuli in the Flanker task (Falkenstein et al., 1999; Gehring et al., 1992; Purmann et al., 2011). Moreover, findings from functional Magnetic Resonance Imaging (fMRI) studies and dipole source localization analyses show that the N2 is likely to reflect the activity of the anterior cingulate cortex (ACC) (Botvinick et al., 1999; Hinault et al., 2019; Nieuwenhuis et al., 2003), which has been found to be associated with cognitive control components such as conflict detection and response monitoring (Kopp et al., 1996; Ridderinkhof et al., 2004; van Veen & Carter, 2002; Yeung & Cohen, 2006), rather than novelty effects or motor inhibition per se (Huster et al., 2013). On the other hand, MFN is a negative deflection that occurs 0–100 ms after a behavioral response at frontal-central electrodes (Gehring & Knight, 2000; Johnson et al., 2008). Like N2, several studies have shown that MFN is generated in or near the ACC and has a vital role in response conflicts and monitoring (e.g., Gehring & Willoughby, 2002; Johnson et al., 2004; Nieuwenhuis et al., 2004).

Since N2 and MFN signal cognitive control, several studies investigated whether deception is associated with a more negative N2/MFN than truth-telling. The findings for the N2 are mixed. Some studies found that deception elicited a more negative N2 than truth-telling (Hu et al., 2015; Pfister et al., 2014), while several others found no significant impact (Gamer & Berti, 2012; Ganis et al., 2016; klein Selle et al., 2021). This led some authors to conclude that the significant findings were an artifact of the specific stimuli used questioning the reliability of the anterior N2 enhancement as a reliable index of concealed information (Ganis et al., 2016). At first sight, the findings about the MFN seem to be more consistently in line with the enhanced need for cognitive control for deception than for truth-telling, but a systematic review is needed to confirm that impression.

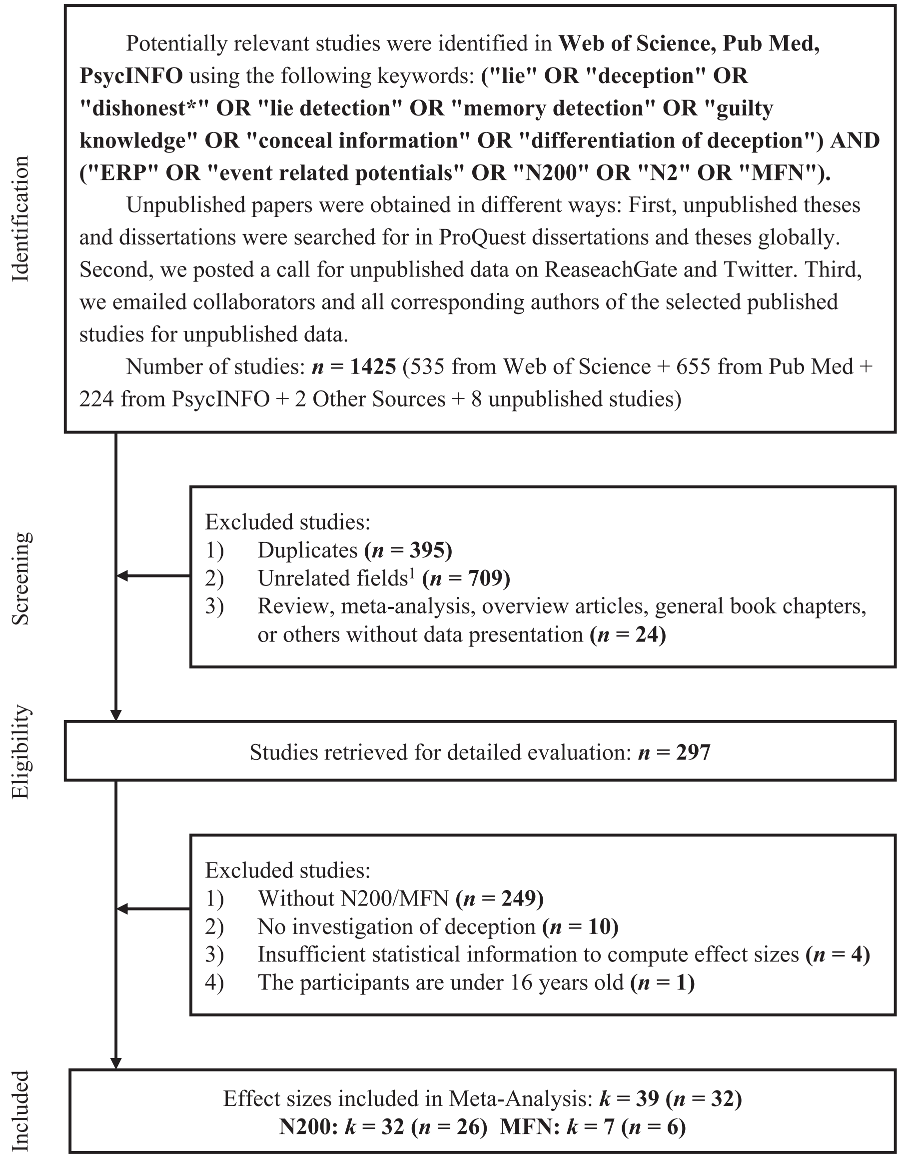
We conduct two meta-analyses to investigate whether deception is associated with more negative N2 and MFN than truth telling, and thus testify to the idea that deception requires greater cognitive control than truth-telling. Besides, we aimed to identify the different moderators that might explain the potential heterogeneity among the included studies. One important moderator we focus on is the deception paradigm. Studies have used one of three paradigms, which remarkably differ in important aspects and therefore seem a likely possible moderator. First, in the Differentiation of Deception (DoD) task, participants are instructed to lie or tell the truth (typically as fast as possible). For instance, they may be asked to lie when the question (e.g., Is your name Lucy? is presented in yellow and tell the truth when the question is presented in blue) (Hu et al., 2011; Pfister et al., 2014; Wu et al., 2009). Second, in the concealed information test (CIT), participants are instructed to deny the recognition of the items that they are familiar with (also typically as fast as possible) (Gamer & Berti, 2010; Ganis et al., 2016; Leue et al., 2012). Third, in what we call "spontaneous deception tasks", participants can freely (and typically self-paced) decide to deceive or be truthful, with deception leading to a higher monetary gain. For instance, in Sai et al. (2018), participants played a coin guessing game in which they were more likely to win money when falsely directing their opponent to the incorrect location of the coin. These three paradigms differ in several aspects (e.g., speeded vs. self-paced decisions and monetary incentives for cheating or not). Verschuere and Shalvi (2014) have theorized that one particularly relevant difference may be that truth-telling may be the default in DoD and CIT whereas the default may be to choose for self-profit (hence deception) rather than truth-telling for the spontaneous deception task (relatedly see Sai et al., 2021). Hence, we looked at deception paradigm as a possible moderator of the findings on N2.

2 | METHOD

2.1 | Literature search

A systematic online database search was performed using Web of Science, PubMed, and PsycINFO, without any

FIGURE 1 PRISMA flow-process diagram of the composition for both meta-analyses. *n* represents the number of papers, and *k* represents the number of effects.



restrictions on the publication year (before September 7, 2021). The search used the following combinations of the keywords in the first and second brackets with the Boolean operator "OR": ("lie" OR "deception" OR "dishonest*" OR "lie detection" OR "memory detection" OR "guilty knowledge" OR "conceal information" OR "differentiation of deception") AND ("ERP" OR "event related potentials" OR "N200" OR "N2" OR "MFN"). We also checked whether there are potentially relevant papers in the reference sections from the papers we found. Figure 1 provides an overview of the selection process and the number of articles identified per step.[1]

Besides, we use the following methods to obtain unpublished data: First, unpublished theses and dissertations were searched for in ProQuest dissertations and theses globally. Second, in October 2021 and December 2021, we published an appeal for unpublished data on ReaseachGate and Twitter. Third, we emailed collaborators and all corresponding authors of the selected published studies for unpublished data.

2.2 | Inclusion criteria

Our inclusion criteria were as follows. We only included studies that (1) the study was an experimental study reporting original data and was published in peer-reviewed journals in English or Chinese before September 7, 2021. Unpublished data included completed but unpublished master's and doctoral dissertations. (2) The study reported precise data for effect sizes or provided us with computable data. (3) The

[1]The final search strategy resulted in 709 papers that were related to biology and chemistry, so they were excluded as unrelated fields to the current meta-analysis.

study sample was adults. (4) The study employed ERP techniques to investigate N2 or MFN associated with deception and truth-telling.

Our inclusion criteria yielded a total of 24 published papers and 8 unpublished papers, which included 39 effect sizes. The list of the studies included are shown in Table 1.

2.3 | Coding of study characteristics

The following variables were coded for each study: (1) number of participants, (2) deception paradigm (CIT vs. DoD vs. Spontaneous deception),[2] (3) type of ERP components (N2 or MFN), (4) stimulus types (word or picture), and (5) publication status (published or unpublished).

2.4 | Effect size calculation

The effect size used in our meta-analysis is the correlation coefficient (r). Within all effect sizes, 13 were reported as partial eta square, 5 as eta square, 13 as Cohen's d, and 1 as f. Partial eta squared were transformed to r using formula $r = \sqrt{\eta p^2}$, and the other effect sizes were transformed to r using online calculators (https://www.psychometrica.de/effect_size.html, Ellis, 2009; Lenhard & Lenhard, 2016).

Moreover, four studies reported using the F value from the ANOVA, another reported the t value of the paired-samples t-test, while another two studies reported the mean score with standard deviation. When the F value was reported for the main effect of deception versus truth-telling, the r value was calculated as $r = \sqrt{\frac{F(1,-)}{F(1,-)+dferror}}$ (Cohen, 1965; Friedman, 1968). When the t value was reported for the effect of deception versus truth-telling, the d value was calculated as $d = \frac{t}{\sqrt{n}}$ (Cohen, 1965; Rosenthal & Rosnow, 1991). When the mean and standard deviation were used, the d value was calculated as $d = \frac{m1-m2}{\sqrt{\frac{(n1-1)\times s1+(n2-1)\times s2}{n1+n2-2}}}$ (Cohen, 1988). Following this, d values were transformed to r using online calculators (www.psychometrica.de) (Ellis, 2009; Lenhard & Lenhard, 2016). A positive effect size r indicated that deception induces a more negative N2 amplitude than truth-telling, while a negative effect size indicated the opposite direction.

[2] In an additional analysis we collapsed DoD and CIT into one category (instructed deception, ID) to contrast it with the spontaneous deception (SD) paradigm and get an ID versus SD contrast.

2.5 | Data analysis

2.5.1 | N2

Since some of the included studies had multiple outcome variables, we estimated a three-level random effect model (Assink & Wibbelink, 2016; Cheung, 2014) by using the *metafor* package in R (Version 4.2.1; Viechtbauer, 2010). The three-level model included three different variance components, including the sampling variance of the individual extracted effect sizes (Level 1), the variance between effect sizes extracted from the same paper (Level 2), and the variance between effect sizes extracted from different papers (Level 3). The formula of Cheung (2014) was then used to estimate the sampling variance (Level 1) of the observed effect, and two separate one-sided log-likelihood-ratio-tests were conducted to estimate whether the variability of levels 2 and 3 were significant (Assink & Wibbelink, 2016). For the overall effect size, the Fisher's z scores were converted back into r coefficients. If one of levels 2 or 3 was significant ($p < .05$), the moderator analysis was conducted to examine the variables to explain these variances (Borenstein et al., 2011). We also used I^2 distribution to measure heterogeneity among studies, which was anticipated due to the small number of included studies, potentially leading to nonsignificant findings (Borenstein et al., 2011). I^2 is the ratio of true heterogeneity to total variation in observed effects that is not directly affected by the number of studies in the analysis (Borenstein et al., 2011; Higgins et al., 2003; Cheung, 2014). Thus, we will also interest in the I^2 distribution at all levels to evaluate heterogeneity. The restricted maximum likelihood estimation method was used to estimate all model parameters. Moreover, we centered continuous variables (e.g., publication year) around their means, and created dummy variables for all categorical variables (paradigm, stimulus types, and publication status), amid conducting the moderator analyses.

Eventually, we used the status of papers (published and unpublished) as the potential moderator, visual inspection of the funnel plot procedure (Duval & Tweedie, 2000), and Egger's regression test to assess the publication bias (Egger et al., 1997).

2.5.2 | MFN

A random effect model was used to estimate the overall effect (Borenstein et al., 2010; Hunter & Schmidt, 2000) for MFN. However, we identified a few studies to rely on the Q statistic (Borenstein et al., 2011; Huedo-Medina et al., 2006). Accordingly, we relied on I^2 to assess the heterogeneity of model. Finally, the publication bias was stated as above.

TABLE 1 Summary of the studies about N2 and MFN included in the meta-analysis and the effect size across studies.

Paper ID	ES ID	Author	Year	*N*	ES	*r*	ERP	Paradigm	Stimulus	P/U
1	1	Cui et al. (2018) condition 1	2018	34	*d*	0.23	N2	SD	Picture	P
1	2	Cui et al. (2018) condition 2	2018	34	*d*	0.13	N2	SD	Picture	P
1	3	Cui et al. (2018) condition 3	2018	34	*d*	0.02	N2	SD	Picture	P
2	4	Fu et al. (2017)	2017	19	*M/SD*	0.08	N2	DoD	Picture	P
3	5	Gamer and Berti (2010) Experiment 1	2010	12	*d*	0.17	N2	CIT	Picture	P
3	6	Gamer and Berti (2010) Experiment 2	2010	12	*d*	0.36	N2	CIT	Picture	P
4	7	Gamer and Berti (2012)	2012	20	*f*	0.02	N2	CIT	Picture	P
5	8	Ganis and Schendan (2013)	2013	17	η^2	−0.84	N2	CIT	Word	P
6	9	Ganis et al. (2016) Experiment 2 conceal detection task	2016	11	η_p^2	0.77	N2	CIT	Picture	P
6	10	Ganis et al. (2016) Experiment 3 conceal detection task	2016	34	η_p^2	−0.14	N2	CIT	Word	P
7	11	Hein and Leue (2021)	2021	30	η_p^2	0.46	N2	CIT	Picture	P
8	12	Hu et al. (2015)	2015	26	η_p^2	0.62	N2	SD	Picture	P
9	13	Hu et al. (2013) high aware condition guilty	2013	15	*t*	0.30	N2	CIT	Word	P
10	14	Hu et al. (2011)	2011	22	*F*	0.50	N2	DoD	Word	P
11	15	Marini et al. (2016)	2016	38	η_p^2	0.42	N2	SD	Picture	P
12	16	Matsuda et al. (2013) condition 1	2013	30	*M/SD*	0.14	N2	CIT	Word	P
13	17	Pfister et al. (2014) Experiment 1&2	2014	16	η_p^2	0.65	N2	DoD	Word	P
14	18	Sai et al. (2018) condition 1	2018	18	*d*	0.36	N2	SD	Picture	P
15	19	Suchotzki et al. (2015)	2015	20	*d*	0.22	N2	DoD	Word	P
16	20	Wu et al. (2009)	2009	15	η_p^2	0.59	N2	DoD	Word	P
17	21	klein Selle et al., (2021)	2021	17	*d*	0.002	N2	CIT	Word	P
18	22	Lin et al. (unpublished 1)	–	60	η_p^2	0.57	N2	CIT	Word	U
19	23	Zheng et al. (unpublished 2)	–	29	*d*	−0.07	N2	CIT	Word	U
20	24	Zheng et al. (unpublished 3)	–	22	*d*	−0.08	N2	CIT	Word	U
21	25	Lin et al. (unpublished 4)	–	30	*d*	0.05	N2	CIT	Word	U
22	26	Lin et al. (unpublished 5)	–	30	*d*	−0.21	N2	CIT	Word	U
23	27	Juan-Zhi et al. (2019)	2019	24	η_p^2	0.10	N2	SD	Picture	P
24	28	Yu (unpublished 6) study3	–	12	η^2	0.60	N2	DoD	Word	U
25	29	Jing (unpublished 7) study3 condition1	–	22	*F*	0.49	N2	SD	Picture	U

(Continues)

TABLE 1 (Continued)

Paper ID	ES ID	Author	Year	N	ES	*r*	ERP	Paradigm	Stimulus	P/U
25	30	Jing (unpublished 7) study3 condition2	–	22	F	0.35	N2	SD	Picture	U
26	31	Li (unpublished 8) study3	–	21	η^2	0.45	N2	DoD	Picture	U
26	32	Li (unpublished 8) study4	–	21	η^2	0.60	N2	DoD	Picture	U
27	33	Johnson et al. (2008)	2008	16	η_p^2	0.81	MFN	DoD	Word	P
28	34	Johnson et al. (2004)	2004	21	F	0.56	MFN	DoD	Word	P
29	35	Leue et al. (2012)	2012	91	η^2	0.53	MFN	CIT	Picture	P
30	36	Scheuble and Beauducel (2020a)	2020	106	η_p^2	0.46	MFN	CIT	Picture	P
31	37	Scheuble and Beauducel (2020b)	2020	99	η_p^2	0.47	MFN	DoD	Word	P
32	38	Scheuble et al. (2021)	2021	61	η_p^2	0.57	MFN	CIT	Picture	P
15	39	Suchotzki et al. (2015)	2015	20	d	0.33	MFN	DoD	Word	P

Note: Year = publication year, N = number of participants, ES = initial effect size before converted effect size (r); ID = Instructed deception, SD = Spontaneous deception; P/U = published paper (P) or unpublished paper (U).

3 | RESULTS

The N2 meta-analysis included 26 papers with 32 effect sizes, while the MFN meta-analysis included 6 papers with 7 effect sizes. Table 1 shows the effect sizes and the different variables of each study.

3.1 | Overall mean effect size

3.1.1 | N2

The three-level meta-analysis model indicated that there was a significant average effect on N2, $r = .25$, $p < .001$, 95% CI = [0.11, 0.37] (see Figure 2 for the forest plot), indicating that deception is associated with a larger N2 amplitude than truth-telling. Moreover, no significant heterogeneity was noticed according to the two log-likelihood-ratio tests (see Table 2), perhaps because it was underpowered. Regarding the total variance, 33.68% attributed to Level 1, less than 1% attributed to level 3 and 66.32% attributed to level 2, suggesting that 66.32% of the reported heterogeneity originated from within the included papers. Therefore, we considered this data suitable for moderation analysis.

3.1.2 | MFN

The random effect model indicated that there was a significant average effect of deception on the MFN component, $r = .51$, $p < .001$, 95% CI = [0.42, 0.60] (see Figure 3 for the forest plot), indicating that deception induced a more negative MFN than truth-telling. Moreover, we refrained from the moderation analysis for MFN since the I^2 indicated that none (0%) of the observed variances between effect sizes were caused by systematic differences between the included studies.

3.2 | Moderator analyses

We first examine deception paradigm, then explored other possible moderators (stimulus types, publication status), to see whether they could account for the heterogeneity in the effect sizes for N2, see Table 3.

3.2.1 | Paradigm types

There was a significant moderating effect of paradigm types on the effect of N2 (F (2, 29) = 3.50, $p = .043$), while deception evoked greater N2 than truth-telling in DoD and SD, but not the CIT. Further analyses showed that the association between deception and N2 was significantly

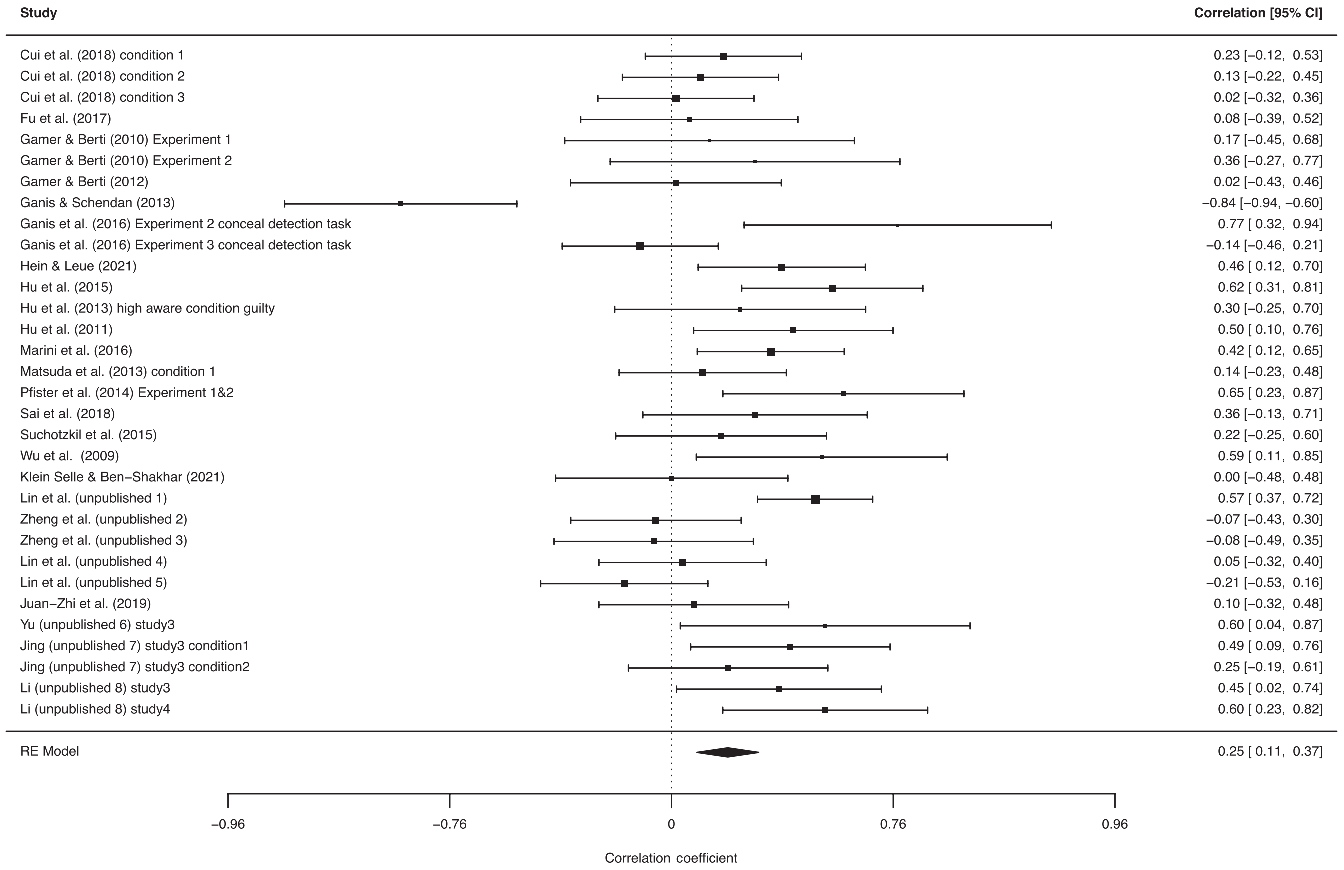


FIGURE 2 Forest plot of the effect sizes for each N2 study. The square location indicates the magnitude and square size indicates the weighting of the single effect size; the length of the lines represent the 95% confidence interval; the diamond at the bottom represents the overall effect and its 95% confidence interval.

smaller ($\beta_1 = .42$, $t_1 = 2.58$, $p = .015$) for the CIT (Fisher's $Z = 0.09$, $t_0 = 0.98$, $p = .337$) than for DoD (Fisher's $Z = 0.51$, $t_0 = 3.83$, $p < .001$). CIT and SD (Fisher's $Z = 0.31$, $t_0 = 2.70$, $p = .011$) did not differ ($\beta_1 = .22$, $t_1 = 1.48$, $p = .150$).[3]

3.2.2 | Stimulus types

While the effect of deception on the N2 seemed larger for pictures than for words (see Table 3), the difference of stimulus types did not reach significance, $F(1, 30) = 2.35$, $p = .136$.

3.3 | Publication bias

3.3.1 | N2

To examine publication bias, we compared the effect of the 8 unpublished papers (10/32 effect sizes) with that of the 18 published papers (see Table 1). We found that publication status did not significantly moderate the effect of N2, $F(1, 30) = 0.10$, $p = .752$ (see Table 3). Moreover, the funnel plot of the effect sizes for N2 distributed relatively evenly around the total effect sizes, indicating that there is no obvious publication bias in the current dataset (see Figure 4). Likewise, the Egger's regression tests also showed no evidence for Funnel plot asymmetry, $\beta_1 = 1.16$, $z = 0.85$, $p = .396$. Thus, there is no serious publication bias in this study.

3.3.2 | MFN

The funnel plot showed no publication bias (Figure 5). Moreover, statistical asymmetry was not indicated by the Egger's regression tests, $\beta_1 = 1.64$, $z = 1.56$, $p = .118$, suggestive of absent publication bias.

4 | DISCUSSION

Unraveling the cognitive processing involved in deception has important implications for understanding of

[3]This was also true when contrasting ID versus SD, ($F(1, 30) = 0.28$, $p = .601$), and deception evoked greater N2 than truth-telling in the paradigms (ID: Fisher's $Z = 0.23$, $t_0 = 2.77$, $p = .009$; SD: Fisher's $Z = 0.31$, $t_0 = 2.47$, $p = .019$).

TABLE 2 Results for the overall mean effect sizes of N2.

ERP type	# papers	# ES	Mean Fisher's *Z* (*SE*)	*t*	Mean *r*	95% CI (for *r*)	QE	% var. at Level 1	% var. at Level 2	Sig. Level 2 variance	% var. at Level 3	Sig. Level 3 variance
N2	26	32	0.25 (0.07)	3.72***	0.25	[0.11, 0.37]	89.54	33.68	66.32	0.20	3.46×10^{-7}	1.00

Note: # Papers = number of papers; # ES = number of effect sizes; Mean Fisher's *Z* = mean effect size (Fisher's *Z*), *SE* = Standard Error; Mean *r* = transformed mean effect size (*r*), 95% CI = 95% Confidence Interval; % Var. = percentage of variance; Sig. = significance.

***$p < .001$.

the human social cognition and the applied purpose of deception detection. Dominant theories hold that deception requires more cognitive control than truth-telling. These theories were validated with various measures, including self-report of an experienced cognitive effort (e.g., Vrij et al., 1996) and often with response time measures (Suchotzki et al., 2017). Within the past years, ERPs were also used to examine this issue. The N2 and MFN ERP are of particular interest because their neural basis is well-established and are good candidates to represent cognitive control (Gehring & Willoughby, 2004; Johnson et al., 2004; Nieuwenhuis et al., 2004). However, current evidence for the N2 is controversial, and no systematic review has been conducted for either the N2 or the MFN. Thus, we conducted the two meta-analyses to answer two key questions: Does deception involve more negative N2 and MFN than truth-telling? And does the deception paradigm moderate the N2/MFN amplitude during deception versus truth-telling.

Our findings indicate that deception is associated with a more negative N2 and MFN than truth-telling with medium and large effect sizes, respectively ($r = .25$ and .51). These results support cognitive control theories of deception and suggest that deception involves greater cognitive control than truth-telling (DePaulo et al., 2003; Vrij et al., 2006; Vrij et al., 2011; Zuckerman et al., 1981). However, the current findings should be interpreted with caution because of the estimated significant heterogeneity for the N2 analysis and the small number of analyzed studies for MFN ($N = 6$, $k = 7$ studies). In relation to our findings, Sai et al. recently conducted a re-analysis of neuroimaging studies and argued that increased cognitive control associated with deception in fMRI studies may not necessarily be attributed to the decision to make a deceptive response. It may be related to the instructed nature of deception used in most studies (Sai et al., 2021). The authors also found that the brain regions, that are classically associated with cognitive control (e.g., DLPFC), which have been taken as proof for the increased cognitive control with deception, were more strongly activated during instructed than spontaneous deception, suggesting that it may be an artifact of the experimental instructions. They also found that spontaneous deception was associated with more activation in the "conflict" regions, including the VLPFC and the ACC compared with the instructed deception. The findings of this meta-analysis show that the significantly negative association between deception and N2/MFN than truth-telling is not an artifact of the instructions because such association was observed during spontaneous deception. However, this finding might not be conclusive because of the small number of included studies that used spontaneous deception, indicating the need for further studies that should consider developing

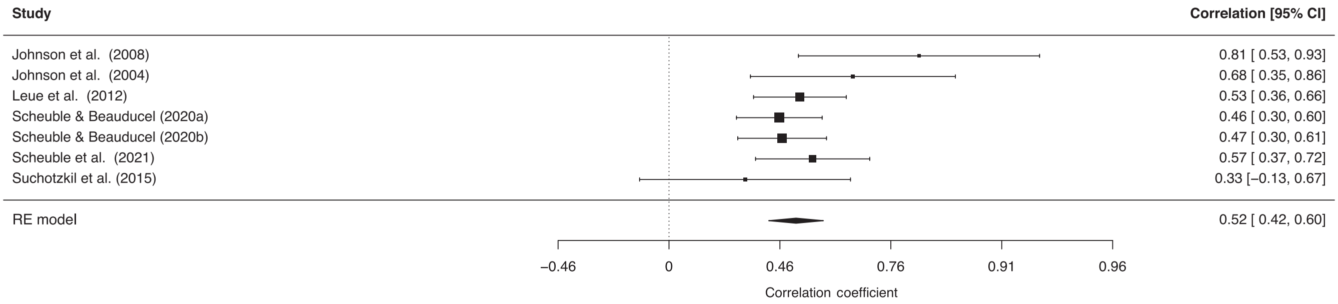


FIGURE 3 Forest plot of the effect sizes for each MFN study. The square location indicates the magnitude and square size indicates the weighting of the single effect size; the length of the lines represent the 95% confidence interval; the diamond at the bottom represents the overall effect and its 95% confidence interval.

TABLE 3 Results for the overall mean effect sizes and moderator variables of the relation between N2 and deception.

Moderator variables	#Papers	#ES	β_0 (Fisher's z)	t_0	β_1	t_1	$F(df_1, df_2)$
Overall effect size	26	32	.25	3.72***			
Paradigm types							$F(2,29)=3.50$ $p=.043$
CIT (RC)	13	15	.09	0.98			
DoD	7	8	.51	3.83***	.42	2.58*	
SD	6	9	.31	2.70*	.22	1.48	
Stimulus types							$F(1,30)=2.35$ $p=.136$
Picture (RC)	11	17	.35	3.82***			
Word	15	15	.15	1.49	−.21	−1.53	
Publication status							$F(1,30)=0.10$ $p=.752$
Published (RC)	18	22	.24	2.83**			
Unpublished	8	10	.29	2.35*	0.05	0.32	

Note: #Papers = number of papers, #ES = number of effect sizes, $F(df_1, df_2)$ = omnibus test, (RC) = reference category, SD = Spontaneous deception, Fisher's z = mean effect size (Fisher's z), t_0 = difference in mean Fisher's z with zero, t_1 = difference in mean Fisher's z with reference category.

*$p < .05$; **$p < .01$; ***$p < .001$.

novel paradigms to dissociate deception-associated cognitive control from other control processing (e.g., executing experimental instructions), and directly compare spontaneous versus instructed deception.

Furthermore, it has been argued that whether the truth-telling or deception require more cognitive control may differ per individual. For instance, Speer et al. (2020) found that individuals who lie frequently require more cognitive control to make a truthful decision while individuals who lie rarely require more cognitive control to make a deceptive decision. Specifically, most people mostly tell the truth and a very small portion of the population (5%) lies very frequently (Serota et al., 2010). Future studies with everyday versus frequent liars are needed to consider how this individual difference variable affects the cognitive mechanisms underlying deception.

In addition, our moderator analyses showed that the increased N2 effect associated with deception was only found in the DoD task and spontaneous deception task, but not in the CIT. This finding raised the questions that the N2 effect found in some CIT studies may not be explained by increased cognitive control associated with deception per se (Gamer & Berti, 2010), but could be an artifact of the specific stimuli used and a lack of stimuli counterbalancing (Ganis et al., 2016). Further studies should counterbalance the stimuli across the truthful versus deceptive conditions, and consider finding ways to increase cognitive control when guilty participants conceal crime-related items to improve the utility of N2 in the CIT (Hu et al., 2013). However, it should be noted that although the most of current studies we have included have similar latencies between 200– and 350 ms after the onset of the stimulus at frontal-central electrodes, there are still

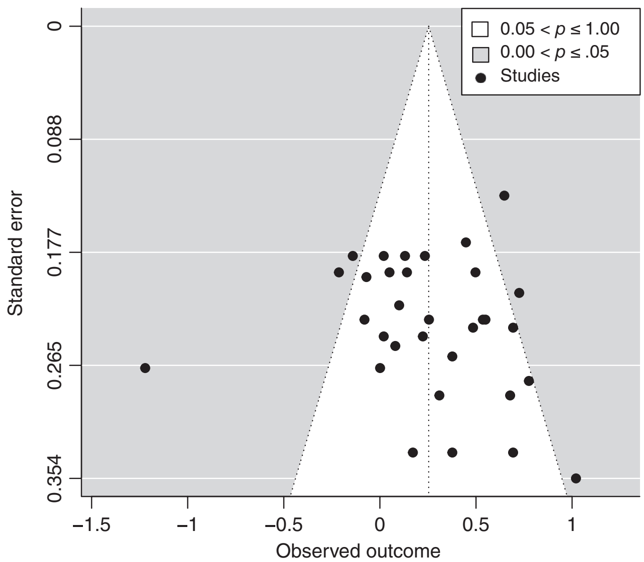


FIGURE 4 Funnel plot of effect size (*r*) against standard error, the filled circles indicate studies included in our meta-analysis of N2. The study of Ganis and Schendan (2013) seems an outlier (large effect in the opposite direction), yet excluding it does not alter the findings (see https://osf.io/ja9b5/?view_only=7446c2f294de407c8192c2c499054cb0).

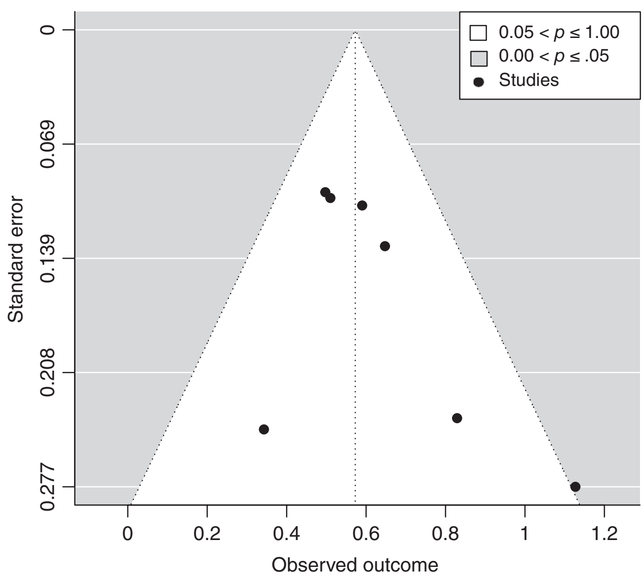


FIGURE 5 Funnel plot of effect size (*r*) against standard error, the filled circles indicate studies included in our meta-analysis of MFN.

heterogeneities, such as time windows (e.g., 100–300 ms, 200–350 ms, 250–400 ms, etc.), electrode sites (e.g., Fz, Cz, FCz, or combining a group of sites), and analysis methods (e.g., mean amplitude, mean peak amplitude). These heterogeneities may affect our results, and we call for future studies to adopt a more consistent N2 standard to explore the role of cognitive control in deception.

It should be noted that the increased cognitive control associated with deception may also affect the P300 amplitude because a more frontal-centrally P300 amplitude is also found to be related to cognitive control in a variety of cognitive task, with decreased P300 amplitude associated with more cognitive control (e.g., König et al., 2021; Xie et al., 2020). To data, there are only four deception studies that examined this issue and they found that deception was associated with decreased P300 amplitude than truth-telling (Hu et al., 2011; Johnson et al., 2003; Sai et al., 2018; Wu et al., 2009), suggesting deception involves more cognitive control than truth-telling. More studies are needed to examine the association between deception and this frontal-centrally P300 in the future.

5 | CONCLUSIONS

In sum, deception as it has been realized in the present studies requires more cognitive control than truth-telling. In addition, our findings encourage applied research to evaluate the extent to which the N2 and particularly the MFN, may aid deception detection when combined with established measures such as RTs, SCR, or the P300 (Meijer et al., 2014; Suchotzki et al., 2017).

AUTHOR CONTRIBUTIONS

Liyang Sai: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; visualization; writing – original draft; writing – review and editing. **Jiayu Cheng:** Data curation; formal analysis; investigation; methodology; resources; software; validation; visualization; writing – original draft; writing – review and editing. **Siyuan Shang:** Data curation; formal analysis; methodology; software; supervision; validation. **Genyue Fu:** Funding acquisition; project administration; resources; supervision. **Bruno Verschuere:** Supervision; validation; writing – review and editing.

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DATA AVAILABILITY STATEMENT

The data and code for this study have been deposited in the Open Science Framework (https://osf.io/ja9b5/?view_only=7446c2f294de407c8192c2c499054cb0).

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