The validity of the online thought-probing procedure of mind wandering is not threatened by variations of probe rate and probe framing

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Abstract

Recently, there has been a surge of interest in the measurement of mind wandering during ongoing tasks. The frequently used online thought-probing procedure (OTPP), in which individuals are probed on whether their thoughts are on-task or not while performing an ongoing task, has repeatedly been criticized, because variations in the frequency of thought probes and the order in which on-task and off-task thoughts are referred to have been shown to affect mind wandering rates. Hitherto, it is unclear whether this susceptibility to measurement variation only affects mean response rates in probe-caught mind wandering or poses an actual threat to the validity of the OTPP, endangering the replicability and generalizability of study results. Here we show in a sample of 177 students that variations of the frequency or framing of thought probes do not affect the validity of the OTPP. While we found that more frequent thought probing reduced the rate of probe-caught mind wandering, we did not replicate the effect that mind wandering is more likely to be reported when off-task thoughts are referred to first rather than second. Crucially, associations between probe-caught mind wandering and task performance, as well as associations between probe-caught mind wandering and covariates (trait mind wandering, reaction-time variability in the metronome-response task, working-memory capacity) did not change with variations of the probing procedure. Therefore, it seems unlikely that the great heterogeneity in the way the OTPP is implemented across different studies endangers the replicability and generalizability of study results. Data and analysis code are available at https://osf.io/7w8bm/.

Keywords: attention; mind wandering; thought probes; validity

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The body of literature on mind wandering has been continuously growing, which may not be surprising because mind wandering plays a critical role for performance in cognitive tasks and many applied domains. For instance, mind wandering during reading, during listening to lectures, and even during driving has been shown to be negatively associated with performance in the respective tasks (Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Smallwood & Schooler, 2015; Unsworth & McMillan, 2013; Yanko & Spalek, 2014).

But how can mind wandering be assessed during an ongoing task? A widely used method is the online thought-probing procedure (OTPP). In the OTPP, individuals are repeatedly probed on whether their thoughts had been on-task or not while performing an ongoing task. The OTPP has face validity and probe-caught mind wandering measured with the OTPP correlates with other mind wandering indicators, such as response-time (RT) variability (Seli, Cheyne, & Smilek, 2013), eye-movement patterns (Reichle, Reineberg, & Schooler, 2010), and questionnaire-based mind wandering self-reports (Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013). Additionally, individual differences in probe-caught mind wandering are associated with variations in working-memory capacity (WMC; e.g., Kane et al., 2017; Rummel & Boywitt, 2014; Unsworth & Robison, 2017). Finally, the addition of the OTPP to a cognitive task does not seem to alter the performance in this very task (Wiemers & Redick, 2018).

In general, the OTPP seems to be a valid assessment tool of mind wandering that is particularly useful for identifying cognitive and neural correlates of mind wandering. Because the OTPP measures mind wandering during experimental tasks, trial-specific self reports of mind wandering can be directly related to trial-specific measures of performance or neural activity (e.g., Allen et al., 2013; Hawkins, Mittner, Boekel, Heathcote, & Forstmann, 2015; Kam & Handy, 2013; Maillet & Rajah, 2016; Smallwood, Baracaia, Lowe, & Obonsawin, 2003). This allows the development and subsequent test of comprehensive theories on the neurocognitive mechanisms underlying mind wandering. Another benefit of the OTPP is that individuals do not have to actively monitor their state of mind during an experimental task to catch themselves mind wandering, as episodes of mind wandering are passively caught by regular interruptions of the task.

Challenges to the online thought-probing procedure

Although the OTPP seems to be a valid assessment tool, it poses a severe problem: Asking individuals about their mental states during experimental tasks may change the to-be-observed behavior by increasing individuals' meta-awareness about thought contents (Zedelius, Broadway, & Schooler, 2015). Indeed, when probes were presented more frequently, participants reported lower rates of mind wandering (Seli, Carriere, Levene, & Smilek, 2013). It remains unclear whether this decrease in probe-caught mind wandering reflects a continuous redirection of attention back to the ongoing task or more socially-desired responding (Rosenthal & Fode, 1963). That is, some participants who mind-wander often and are made aware of this by frequent thought probing may not be comfortable disclosing their perceived lack of compliance with the experimental task.

Furthermore, the order in which on-task and off-task thoughts are referred to in the OTPP (i.e., asking individuals whether they just had been engaged in "on- or off-task" versus "off- or on-task" thoughts; hereafter referred to as probe framing) affects probe-caught mind wandering (Weinstein, Lima, & van der Zee, 2018): Individuals reported higher mind wandering levels when off-task thoughts were referred to first rather than second. Findings that probe framing biases mind wandering reports may reflect insecurities about internal mental states that make self-reports bias prone. Such insecurities about personal mental states may be due to an ambiguous attentional state or due to a lack of meta-awareness about one's own attentional state.

Notably, method-induced differences in overall mind wandering primarily speak to the question of how probe-caught mind wandering is calibrated on the absolute level. The finding that probe framing changes the likelihood of a current mental state being considered task-related or -unrelated suggests, for example, that people are sometimes not certain about their attentional focus and self-reports are then bias prone (Seli, Jonker, Cheyne, Cortes, & Smilek, 2015). From a psychological-assessment perspective, method-related mean group differences do not necessarily impose a threat to the *validity* of the OTPP: If the rank order of individuals on the underlying mind wandering construct is not affected by these method factors, the validity of OTPP-assessed mind wandering will not be impaired. Method-imposed main effects will also not impose a validity threat if method factors are held constant across experimental conditions or controlled for (e.g., via counterbalancing), as long as none of the method factors causes ceiling or floor effects or interacts with the trait of interest. In sum, probe framing may induce a general response bias to report less or more mind wandering. If it does so for all individuals and/or experimental conditions to similar extents, probe framing would not affect the rank order of individuals and would therefore not pose a validity threat. Notably, although the interpretation of individual differences in mind wandering and their relation to other constructs would remain valid under these circumstances, any estimate regarding the frequency of mind wandering in the laboratory (or in real life) would need to be re-evaluated if arbitrary design aspects, such as probe framing, affected the frequency with which mind wandering is reported.

Probe frequency, however, may indirectly affect the validity of self-reported mind wandering in the OTPP by affecting its reliability. An increased probe frequency may, on the one hand, foster meta-awareness of mind wandering, causing variance compression by rendering mind wandering occurrences less likely. On the other hand, the OTPP's reliability should increase with more assessments. Because reliability is a prerequisite for validity (Lord & Novick, 1968), the number of probes may thus indirectly affect associations with external criteria. If increasing the frequency of thought probes reduces the occurrence of mind wandering or leads to socially desirable response behavior, there may be very delicate trade-offs between increasing reliability and decreasing between-subject variation. Moreover, frequent thought probing may affect individuals with higher mind wandering trait-scores differently than individuals with lower scores. Because individuals who are often unaware of their wandering mind should especially benefit from a probe-triggered increased meta-awareness, frequent probing could change the rank order of individuals on the mind wandering construct. First evidence suggests that more frequent thought probing may not affect attentional states at all, but may instead introduce a systematic response bias, as a higher probe frequency decreased mind wandering rates, but did not affect performance in the associated experimental task (Seli, Carriere, et al., 2013).

In a recent review of 102 studies, Weinstein (2018) identified 69 different ways the OTPP was implemented that varied from lab to lab and even from study to study. This heterogeneity might affect the replicability and generalizability of study results, if variations in the administration of the OTPP affected the validity of mind wandering reports. Although it has been shown that variations of probe frequency did not affect response variability, neither Seli, Carriere, et al. (2013) nor Weinstein et al. (2018) assessed how variations of the OTPP affected the correlation of probe-caught mind wandering with external criteria. Nevertheless, given the frequent use of the OTPP, a better understanding of which OTPP settings are optimal for a valid mind wandering assessment is warranted — not only to better evaluate previous findings and potential OTPP-induced differences in study results, but also to allow researchers to make more educated design decisions in future studies.

The Present Study

The present study aimed to assess the impact of variations of probe frequency and probe framing on the validity of the OTPP. For this purpose, we implemented the OTPP in the widely used sustained-attention-to-response task (SART; e.g., McVay & Kane, 2009; Smallwood, McSpadden, & Schooler, 2007). We manipulated probe framing (on-task first, off-task first) between and probe frequency (high, low) within participants. To evaluate the external validity of probe-caught mind wandering as a function of these conditions, participants completed three measures that have been shown to correlate with mind wandering: a trait mind wandering questionnaire, the metronome-response task, and a working-memory task.

In line with previous research, we expected off-task thoughts to occur less frequently in the on-task-first than the off-task-first framing condition, and less frequently in the high probe frequency than in the low probe frequency condition (Seli, Carriere, et al., 2013; Weinstein et al., 2018). In addition, we expected mind wandering to be negatively correlated with performance in the SART. Moreover, we expected probe frequency, but not probe framing to affect the validity of the mind wandering assessment. In particular, we suspected that a higher probing frequency would prevent individuals with higher mind wandering trait scores from mind wandering, resulting in smaller correlations of probe-caught mind wandering with SART performance and external criteria in the high probe-frequency than in the low probe-frequency condition.

Materials and Methods

Participants

We recruited a student sample of $N = 177$ participants (130 females, 46 males, one not reported) between 18 and 38 years ($M = 22.7$, $SD = 3.7$). All participants signed an informed consent and received 10 € or course credit as reward for their participation. Due to a coding error that led to unequal *n*s in the framing conditions with the preregistered sample size of 120 participants (91 females, 28 males, one not reported, $M_{age} = 22.9$, $SD_{age} = 3.8$), additional 57 participants (39 females, 18 males, $M_{age} = 22.4$, $SD_{age} = 3.7$) were recruited. The resulting sample size was in accordance with mixed-model guidelines that demand >50 observations within each Level-2 factor level (Paccagnella, 2011). Informed consent was obtained from all individual participants included in the study.

Materials

Sustained attention to response task (SART). Participants had to press the space bar when the word was a living object (go trials; 89 % of trials), and to withhold their response when the word was a non-living object (no-go trials; 11 % of trials). Words were high-frequency nouns denoting objects or animals which were presented for 0.3s and post-masked by a string of XXXXXXX for 1.5s. The task consisted of 10 practice trials without feedback (9 go trials/1 no-go trial) and 810 experimental trials that were divided into six blocks of 135 (120 go/ 15 no-go) trials.

During the SART, thought probes occurred repeatedly asking participants what they had been thinking immediately before the probe occurred. Participants responded to probes by pressing the arrow keys. Participants in the *on-task-first condition* were given the options ←) about the task, or →) about other things, and participants in the *off-task-first condition* were given the options ←) about other things, or →) about the task. This allocation of response mapping was chosen to increase framing effects by aligning the congruency between the visuospatial orientation on screen and the spatial orientation of the response options. Thought-probe frequency changed from the first to the second half of the SART. In the *high frequency condition*, participants were probed approximately every 30s (eight probes/block), while in the *low frequency condition*, they were probed approximately every 60s (four probes/block). Half of the participants were probed frequently first, the others infrequently first. Thought probes were equally distributed between go and no-go trials. Mean probe-caught mind wandering rates are shown in Figure 1 and internal consistencies are shown in Table 1.

For the SART analyses, hit-rates and mean RTs on go trials as well as false-alarm rates on no-go trials were calculated. The first five trials of each block and three trials after a thought probe as well as trials with RTs faster than 100ms, slower than 3000ms, or with logarithmized reaction times exceeding ±3 SDs of an individual participant's RT distribution were discarded. These decisions regarding discarded trials were made a priori to exclude prepotent responses and extremely slow outliers that may bias inferences regarding cognitive processes of interest and may reduce statistical power (Ratcliff, 1993), but were not explicitly specified in the preregistration. Three participants with more than 15% misses and two participants with mean RTs $<$ 250ms on go trials showed low compliance with task instructions and were excluded from further analyses.

Table 1

Internal consistencies of probe-caught mind wandering as a function of trial type (go vs. no-go) and probing-related manipulations (probe frequency, probe framing).

	Framing	Frequency	Cronbach's alpha
Go	off-task first	low	0.57
		high	0.73
	on-task first	low	0.62
		high	0.66
No-Go	off-task first	low	0.62
		high	0.75
	on-task first	low	0.58
		high	0.60

Mean go-trial RT was 453.57ms (SD = 76.65ms), and mean no-go false-alarm rate was 0.46 (SD = 0.20). Mean go-trial RTs and no-go false-alarm rates showed good reliabilities, $\alpha_{goRT} = .93$, $\alpha_{no-goFA} = .92$.

Covariates.

Spontaneous and deliberate mind wandering questionnaire (Trait-MW). Participants completed a 13-item questionnaire on daily mind wandering. The questionnaire contained items from the MWQ (Mrazek et al., 2013) and the spontaneous and deliberate mind wandering scales MW-S and MW-D (Carriere, Seli, & Smilek, 2013) that were rated on a 7-point Likert scale. Participants had a mean deliberate mind wandering score of $M = 4.31$ ($SD = 1.21$) and a mean spontaneous mind wandering score of $M = 4.24$ ($SD = 0.85$). The 9-item spontaneous mind wandering scale consisting of the MWQ and the MW-S showed acceptable reliability estimates, $\alpha = .76$, $\omega = .65$, while reliability estimates were lower for the 4-item deliberate mind wandering scale, $\alpha = .58, \omega = .65$.

Metronome response task (MRT). Participants were presented a constant series of 75 ms long 60 dB tones at the rate of one tone per 1.3 seconds and were instructed to press the space bar in synchrony with the onset of each tone (Seli, Cheyne, & Smilek, 2013). They completed 18 practice trials and 900 experimental trials. Intra-individual standard deviations of the difference between the onset of the tone and their corresponding key press were calculated as a measure of behavioral variability across all trials. Any trials with omission errors or more than one key press per tone were excluded from this analysis. Participants had a mean reaction time variability of $M = 86.12$ ms ($SD = 29.54$ ms). The reliability of this reaction variability measure estimated based on an odd-/even-split of trials was good, $r = .99$.

Operation span task (OSpan). WMC was assessed with partial scores in the OSpan task (Rummel, Steindorf, Marevic, & Danner, 2017), in which participants were shown letter series that were interleaved by to-be-solved equations. After three to seven letters, participants had to recall the letters in the presented order. Data from four non-compliant participants ($< 85\%$ of correctly solved equations, OSpan score ≤ 15) were removed. Participants had an average operation span of $M = 63.50$ ($SD = 9.43$). The OSpan score had an acceptable reliability, $\alpha = .79$.

Procedure

After giving consent, participants completed the Ospan task, the MRT, the SART, and finally the trait mind wandering questionnaire and a demographic questionnaire in this order.

Data analysis

We used Bayesian generalized mixed-models assuming a Bernoulli distribution with a logit link function to accommodate for distributional properties of probe-caught mind wandering, time-on-task effects, and the interaction of between- and within-subject factors. Moreover, the mixed-model approach allowed for directly estimating the effect of probing-related manipulations on the association between probe-caught mind wandering and its covariates.

Self-reported thought states (0 = on-task, 1 = off-task) were the primary dependent variable for all models. We estimated three separate models: In the first two models, we assessed how probing-related manipulations affected the relationship between probe-caught mind wandering and SART performance. To evaluate the effects regarding performance (i.e., RTs/false alarms) in the go/no-go trials of the SART, we included time-on-task, single trials RTs/false alarms and and probe frequency (low vs. high) as Level 1-predictors. On Level 2, we included probe framing (task-related first vs. task-unrelated first) and mean RTs/false alarm rates as between-subject predictors. Moreover, we included random slopes for probe frequency, time-on-task, and single trial performance effects. To identify the configuration of probing conditions yielding the greatest association between self-reported thought states and task performance, we included three-way-interactions between probe frequency, probe framing, and performance indicators as predictors of self-reported mind wandering. These two models considered different performance indicators for go and no-go trials (i.e., go-trial RTs, and no-go false-alarms).

In the third model, we evaluated how probing-related manipulations affected the relationship between probe-caught mind wandering and its external covariates. For this purpose, we included time-on-task, trial type (go vs. no-go), and probe frequency (low vs. high) as Level 1-predictors. Covariates (OSpan score, reaction time variability in the MRT, and Trait-MW score) and probe framing (task-related first vs. task-unrelated first) were included as Level 2-predictors. In addition, we included random slopes for probe frequency and time-on-task in the model.

We used the brms R package (Bürkner, 2017, 2018) to estimate parameters for the Bayesian models that were fitted with three Markov Chain Monte Carlo (MCMC) chains. Each chain contained 1,000 burn-in samples and 5,000 additional samples with a thinning parameter of 10, resulting in 1,000 posterior samples per chain that were combined to one posterior sample consisting of 3,000 samples for each model parameter. Regression weights had non-informative normally distributed priors, $b_{i>0} \sim N(0, 5)$, intercepts had Student's t distributed priors, $b_0 \sim t(3, 0, 10)$, standard deviations of random effects had Cauchy distributed priors, $\sigma \sim Cauchy(0, 2)$, and the covariance matrices had LKJ Cholesky hyperpriors with $\eta = 1$. Model convergence was evaluated based on the Gelman-Rubin convergence statistic $\hat{\mathrm{R}}$ (Gelman & Rubin, 1992), with $\hat{\mathrm{R}}$ values close to 1 indicating negligible differences between within- and between-chain variances. We report the mean and 95% credible interval (CI) as an equally-tailed interval to describe the posterior distributions of sampled regression weights. Model fit was evaluated by comparing samples from the posterior predictive distribution to observed probe-caught mind wandering and based on Bayesian R^2.

Data and analysis code are available at https://osf.io/7w8bm/. The study was preregistered prior to conducting the research on January 15th, 2018, at https://osf.io/sv38t/. We deviated from the preregistration in four points: First, we recruited 57 additional participants to account for a coding error that led to unequal *n*s in the framing conditions. Second, we conducted all analyses in a Bayesian and not a frequentist framework to account for the fact that our delayed collection of 57 samples resulted in a sequential sampling plan that would have resulted in a greater Type I error probability in frequentist analyses. Either way, generalized mixed-models allow to model any distributional properties of variables. We modeled dichotomous responses to thought probes as Bernoulli distributed with a logit link function, which was not explicitly specified in the preregistration but adequate given the dichotomous nature of responses to thought probes. Third, we estimated separate models to evaluate the validity of the OTPP in the prediction of performance on go trials (RTs) and no-go trials (false alarms), which was not explicitly outlined in the preregistration, but necessary given the different performance measures in the two SART conditions. Fourth, we included random slopes for probe frequency and time-on-task in the model. For those readers unfamiliar with generalized mixed-models, we would like to state that these deviations in the analytic procedure (Bayesian vs. frequentist, inclusion of random slopes) are minor and were not motivated by a lack of significant findings for the preregistered analyses. Although we believe that the analyses included in the present study are more appropriate than the preregistered ones, we uploaded analysis code and results associated with the preregistered analyses in the online repository. Parameter estimates resulting from frequentist analyses were comparable to parameter estimates from Bayesian analyses reported in the results section and only one effect differed in significance between the preregistered and reported analyses (see Results section). Most importantly, any conclusion we drew from the present analyses would not have differed if we had relied on the preregistered plan of analysis.

Results

First, we explored how probing-related manipulations affected the relationship between probe-caught mind wandering and SART performance (see Table 2). All chains converged for the two models below, as indicated by $\hat{R}$ values equal to 1, and the models explained about 25 % of variance in probe-caught mind wandering, $R^2_{go} = .22, R^2_{no-go} = .27$ (see Figure 3A and 3B for a comparison of predicted with observed mind wandering rates). During the course of the task, participants became more likely to report task-unrelated thoughts, as reflected by a positive logarithmic association between block and probe-caught mind wandering on both go and no-go trials, b_{go} = 0.80, 95%-CI = [0.58; 1.03], b_{no-go} = 0.61, 95%-CI = [0.42; 0.81]. In addition, we found that participants were more likely to engage in mind wandering when probes were presented less frequently, b_{go} = -0.29, 95%-CI = [-0.40; -0.17], b_{no-go} = -0.25, 95%-CI = [-0.40; -0.10], whereas we found no effect of probe framing on mind wandering, b_{go} = -0.14, CI = [-0.32; 0.04], b_{no-go} = -0.11, 95%-CI = [-0.33; 0.12], and no interaction between probe frequency and probe framing, b_{go} = 0.10, 95%-CI = [-0.02; 0.22], b_{no-go} = -0.09, 95%-CI = [-0.24; 0.07]. See Figure 1 for an overview of the probing-related effects on probe-caught mind wandering.

We found no association between go-trial RTs and probe-caught mind wandering on the between-subject level, $b_{between}$ = -0.10, 95%-CI = [-0.31; 0.09], but participants tended to react faster when mind wandering as indicated by the small association between go-trial RTs and mind wandering on the within-subject level, b_{within} = -0.10, 95%-CI = [-0.19; -0.00]. There was no interaction between these associations and any

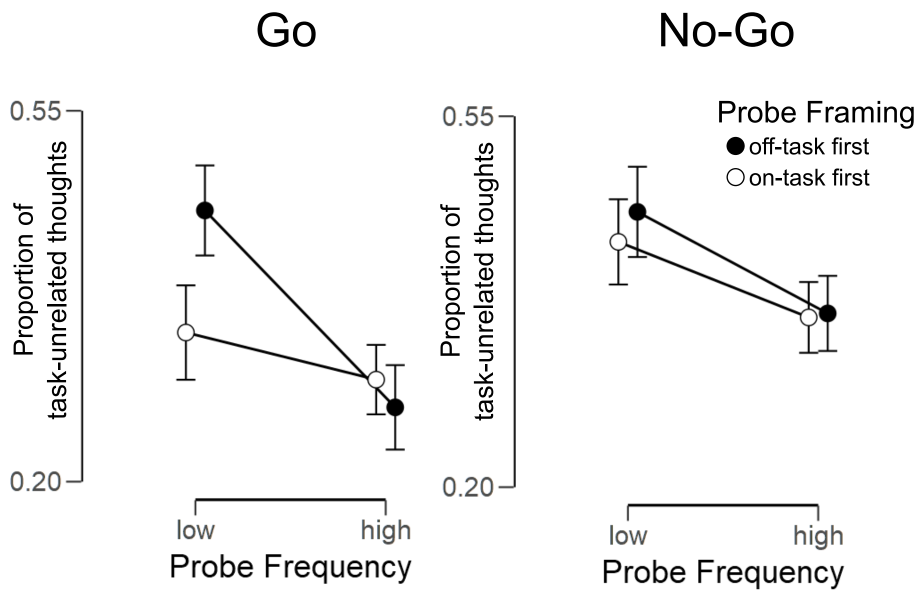

Figure 1. Probe-caught mind wandering rates as a function of trial type (go vs. no-go), probe frequency (low vs. high), and probe framing (off-task first vs. on-task first). Error bars indicate 95% credibility intervals.

probing-related factor, all $|b_s| \leq .04$. After giving a false response on no-go trials, participants were more likely to report having been off-task, as indicated by a significant Level-1 effect of no-go false-alarms on mind wandering, $b = -1.39$, 95%-CI = [-1.66; -1.14]. Participants with higher mean false-alarm rates were, however, not more likely to be-off task, $b = -0.02$, 95%-CI = [-0.21; 0.18]. Again, these effects were not moderated by the probing-related manipulations, all $|b_s| \leq .08$.

Associations between mind wandering and covariates

To explore whether the probing manipulations affected the associations between mind wandering and its covariates, we considered mind wandering probed after both go and no-go trials simultaneously in one model and entered mind wandering trait-questionnaire scores, MRT RT-variabilities, and OSpan scores as additional Level-2 predictors (see Table 3). All chains converged, as indicated by $\hat{R}$ values equal to 1, and the model explained 21% of the variance in probe-caught mind wandering (see Figure 3C for a comparison of predicted with observed mind wandering rates). We

Table 2

Parameter estimates for the effect of probing-related manipulations on the relationship between mind wandering and SART performance

	Go trials (performance measure: RTs)		No-go trials (performance measure: false alarms)	
	b	*SD*	*b*	*SD*
Intercept	-1.76 [-2.08; -1.45]	1.11 [0.75; 1.49]	-0.46 [-0.76; -0.16]	1.29 [0.92; 1.71]
Time-on-task	0.80 [0.58; 1.03]	0.64 [0.24; 0.97]	0.61 [0.42; 0.81]	0.44 [0.03; 0.83]
Frequency	-0.29 [-0.40; -0.17]	0.25 [0.02; 0.48]	-0.25 [-0.40; -0.10]	0.21 [0.01; 0.44]
Framing	-0.14 [-0.32; 0.04]		-0.11 [-0.33; 0.12]	
Single trial performance	-0.10 [-0.19; -0.00]	0.09 [0.00; 0.26]	-1.39 [-1.66; -1.14]	0.90 [0.57; 1.21]
Mean performance	-0.10 [-0.31; 0.09]		-0.02 [-0.21; 0.18]	
Frequency x framing	0.10 [-0.02; 0.22]		-0.09 [-0.24; 0.07]	
Frequency x single trial performance	-0.03 [-0.13; 0.07]		0.01 [-0.20; 0.22]	
Framing x single trial performance	0.04 [-0.06; 0.13]		0.06 [-0.20; 0.31]	
Frequency x mean performance	0.03 [-0.09; 0.15]		0.08 [-0.04; 0.20]	
Framing x mean performance	0.00 [-0.20; 0.19]		-0.05 [-0.24; 0.14]	
Frequency x framing x single trial performance	-0.04 [-0.13; 0.05]		0.03 [-0.18; 0.24]	
Frequency x framing x mean performance	0.02 [-0.10; 0.14]		0.01 [-0.10; 0.13]	

Note. Squared brackets show 95% *CIs; b = regression weight; SD = standard deviation of random effect*

found main effects of block, $b = 0.70$, 95%-CI = [0.54; 0.86], trial type, $b = -0.20$, 95%-CI = [-0.26; -0.13], and probe frequency, $b = -0.25$, 95%-CI = [-0.33; -0.17], but not probe framing, $b = -0.11$, 95%-CI = [-0.28; 0.06], on probe-caught mind wandering. Specifically, participants were more likely to report being off-task in later rather than earlier stages of the SART, on no-go rather than go trials, and when being probed less rather than more frequently. In addition, there was a three-way-interaction between trial type, probe frequency, and probe framing, $b = 0.08$, 95%-CI = [0.02; 0.14], which suggested that off-task probe framing biased responses only when participants were probed on go-trials with a low probing frequency.

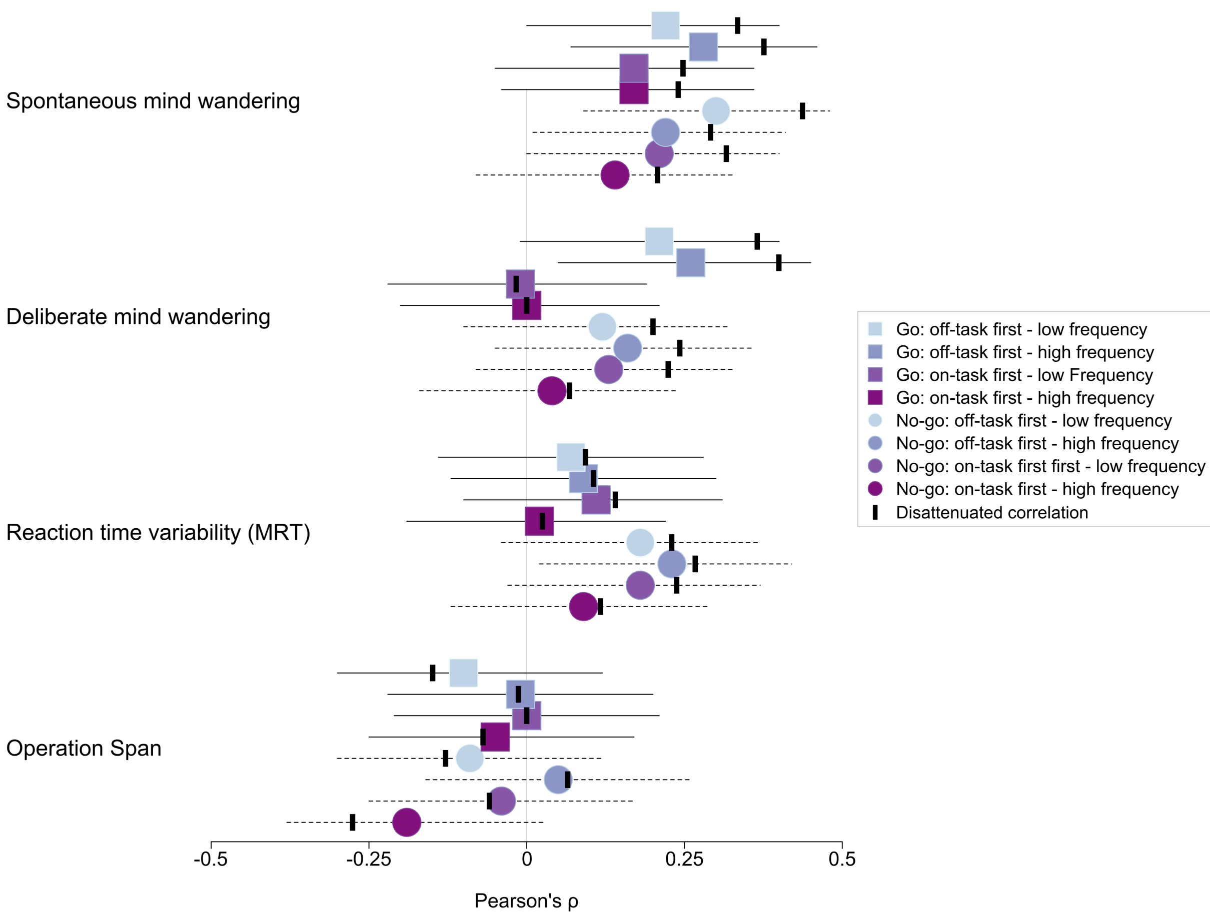

Figure 2. Associations between the probe-caught mind wandering and covariates (spontaneous trait mind wandering, deliberate trait mind wandering, MRT RT-variability, Ospan score) as a function of trial type (go vs. no-go), probe frequency (low vs. high), and probe framing (on-task first. vs off-task first. Error bars indicate 95% credibility intervals. Vertical bars indicate correlations disattenuated for unreliability.

Participants with higher spontaneous mind wandering traits also reported more probe-caught mind wandering, $b = 0.29$, 95%-CI = [0.11; 0.48]. This association was not moderated by the probing-related manipulations, all $|b_s| \leq .03$ (see upper part of Figure 2). We observed no association between deliberate mind wandering trait scores and overall probe-caught mind wandering, $b = 0.12$, 95%-CI = [-0.04; 0.29], but a three-way interaction between deliberate mind wandering, probe frequency, and probe framing, $b = -0.09$, 95%-CI = [-0.17; -0.00]. This three-way interaction can be

Table 3

Parameter estimates for the effect of probing-related manipulations on the relationship between mind wandering and covariates

	b	*SD*		*b*
Intercept	-1.42 [-1.65; -1.20]	1.09 [0.85; 1.35]	Frequency x MW-S	-0.03 [-0.11; 0.06]
Trial type	-0.20 [-0.26; -0.13]	0.12 [0.01; 0.25]	Frequency x MW-D	-0.07 [-0.15; 0.01]
Time-on-task	0.70 [0.54; 0.86]	0.63 [0.45; 0.82]	Frequency x MRT	-0.01 [-0.09; 0.08]
Frequency	-0.25 [-0.33; -0.17]	0.12 [0.00; 0.29]	Frequency x OSpan	0.00 [-0.08; 0.09]
Framing	-0.11 [-0.28; 0.06]		Framing x MW-S	-0.03 [-0.21; 0.15]
MW-S	0.29 [0.11; 0.48]		Framing x MW-D	-0.05 [-0.22; 0.11]
MW-D	0.12 [-0.04; 0.29]		Framing x MRT	0.01 [-0.16; 0.19]
MRT	0.16 [-0.03; 0.32]		Framing x OSpan	-0.03 [-0.21; 0.13]
OSpan	-0.08 [-0.25; 0.09]		Trial type x MW-S	0.03 [-0.04; 0.10]
Trial type x frequency	-0.04 [-0.10; 0.02]		Trial type x MW-D	0.01 [-0.05; 0.07]
Trial type x framing	-0.03 [-0.10; 0.03]		Trial type x MRT	-0.08 [-0.15; -0.02]
Frequency x framing	0.01 [-0.07; 0.09]		Trial type x OSpan	0.00 [-0.07; 0.07]
Trial type x frequency x framing	0.08 [0.02; 0.14]		Frequency x framing x MW-S	-0.03 [-0.12; 0.06]
			Frequency x framing x MW-D	-0.09 [-0.17; -0.00]
			Frequency x framing x MRT	-0.05 [-0.14; 0.03]
			Frequency x framing x OSpan	-0.08 [-0.16; 0.01]

Note. Squared brackets show 95% *CIs; b = regression weight; SD = standard deviation of random effect; MW-S = Spontaneous mind wandering scale; MW-D: Deliberate mind wandering scale; MRT = Reaction time variability in the MRT; OSpan = Operation span*

decomposed by inspecting the correlation coefficients in the upper part of Figure 2: When off-task thoughts were referred to first in the probes, participants with higher deliberate mind wandering traits reported more probe-caught mind wandering. However, when on-task thoughts were referred to first, there was no association between deliberate mind wandering trait scores and probe-caught mind wandering except when probes were presented infrequently following no-go trials.

MRT RT-variabilities predicted mind wandering on no-go, but not go trials, as indicated by a significant interaction with trial type, $b = -0.08$, 95%-CI = [-0.15; -0.02], and a non-significant main effect of RT variabilities, $b = 0.16$, 95%-CI = [-0.03; 0.32]. This association was not moderated by the probing-related manipulations, all $|b_s| \leq .05$ (see middle part of Figure 2).

We observed no overall association between probe-caught mind wandering and OSpan scores, $b = -0.08$, 95%-CI = [-0.25; 0.09], and no interactions between OSpan scores and probing-related manipulations, all $|b_s| \leq .08$ (see lower part of Figure 2).[1]

Discussion

We investigated whether the frequency and framing of thought probes affects the validity of online thought-probing of mind wandering. Consistent with previous studies (Seli, Carriere, et al., 2013), we found that when thoughts were probed more frequently, participants were less likely to report off-task thoughts. Specifically, more frequent probing decreased the occurrence of probe-caught mind wandering by 10 percent. Apart from one specific condition, we did not find systematic effects of the order in which on- and off-task thoughts were referred to on probe-caught mind wandering. Hence, mind wandering was not more likely to be reported when off-task thoughts were referred to first rather than second (Weinstein et al., 2018). This 'conceptual replication failure' could be due to any methodological difference between the present study and the study by Weinstein et al. (2018), which investigated probe-framing effects in the context of a reading task using a different framing manipulation and different response mapping. However, if anything, the visuospatial alignment of response options and response keys used in the present study should have augmented and not diminished any effect of probe framing. All in all, our results question the generalizability rather than the

[1]The single difference between results of the preregistered analyses and the analyses reported in this manuscript concerned the three-way interaction between OSpan score, probe framing, and probe frequency, that was significant in the preregistered frequentist without random slopes ($b = -0.07, p = .037$), but not in the Bayesian model with random slopes ($b = -0.08$, 95%-CI = [-0.16; 0.01]). An inspection of the effect size of this effect, however, indicated that it was negligible ($\omega^2_{\text{partial}} = .00$) and would not have been significant if we had adjusted α-levels to account for the sequential sampling. Hence, any conclusion we drew from the present analyses would not have differed if we had relied on the preregistered plan of analysis.

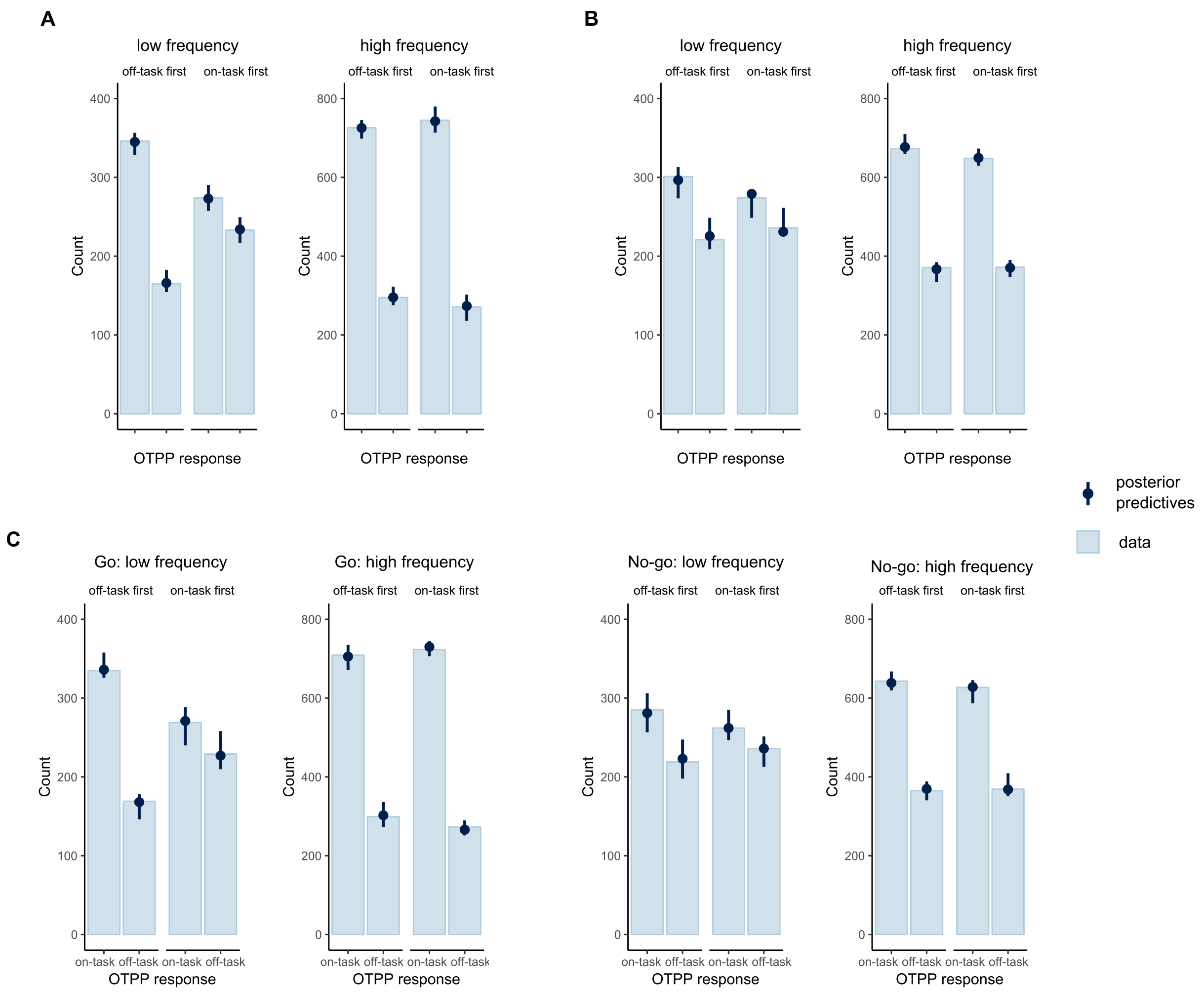

Figure 3. Comparison of observed to predicted thought-probed mind wandering rates across all participants for each of the three models. A: Thought-probed mind wandering in go-trials as a function of probe frequency and probe framing (first model). B: Thought-probed mind wandering in no-go-trials as a function of probe frequency and probe framing (second model). C: Thought-probed mind wandering as a function of trial type, probe frequency, and probe framing (third model). Dark blue circles and error bars represent estimated rates of thought-probe mind wandering and their 95% highest density intervals; light blue bars represent observed rates of thought-probe mind wandering.

reliability of the probe-framing effect.

More importantly, we found little evidence that probe-frequency and probe-framing manipulations affected the validity of the OTPP: The association of probe-caught mind wandering with SART performance and with mind wandering covariates did not vary systematically between probing conditions. The moderate reliability estimates of probe-caught mind wandering suggested that it may be advisable to use latent variable models or at least correct for attenuation when using the OTPP in individual differences research. In addition, we suggest a frequent rather than an infrequent presentation of thought probes when researchers are interested in individual differences in mind wandering and employ the SART or similar simple cognitive tasks. In such tasks, a more frequent probing will increase the reliability of the probe-caught mind wandering measure. As of yet, we do not know if this recommendation also holds for more dynamic contexts such as reading or creative generation tasks, as frequent thought probing might disrupt participants' train of thoughts and impair reading comprehension or the incubation and generation of creative ideas. Because this is an open question, more research on the psychometric properties of the OTPP in different contexts is needed.

One exception to this result was the association between the deliberate mind wandering trait and probe-caught mind wandering, which was only observed when off-task thoughts were referred to first. The redirection of awareness towards off-task thoughts may have reduced the occurrence of mind wandering in all but those individuals who deliberately engaged in mind wandering to escape the monotonous task, resulting in a positive association between trait deliberate mind wandering and probe-caught mind wandering in the SART. Future research using an OTPP variant that differentiates between unintentional and intentional mind wandering (Seli, Carriere, & Smilek, 2015) could speak to this issue. The unpredicted observed association between the deliberate mind wandering trait and probe-caught mind wandering when infrequently presented probes referring to on-task thoughts first followed no-go trials, may be a fluke in the data that warrants replication.

Participants with greater WMC were not more or less likely to let their minds wandering during the SART. Others have reported substantial correlations between WMC and probe-caught mind wandering, but on a latent level (e.g., Kane et al., 2017), which might explain why we did not find such a correlation with the (manifest) mixed-model approach. Moreover, the range of WMC scores may have been somewhat restricted in our student sample, resulting in an underestimation of the true correlation.

Irrespective of our probing-related manipulations, we found a strong association between false-alarm rates in the SART and probe-caught mind wandering on no-go trials. This result may either imply that thought reports are good predictors of SART-performance on the trial level or that participants use their own performance (which is arguably experienced quite saliently in the case of a false-alarm in the SART) as a cue for judging whether they had been on- or off-task at a certain moment. Future studies could use other tasks in which performance is less saliently experienced or in which (bogus) performance feedback can be manipulated to decide between these two alternatives. Until then, researchers using the SART with the OTPP should be cautious to not capitalize on performance-feedback effects on mind wandering.

Limitations

Because the participant sample consisted largely of students, there was likely some variance restriction in cognitive measures. In particular, reduced variance in the operation span task may have led to an underestimation of the true association between working memory capacity and probe-caught mind wandering and may thus have prohibited us from finding any moderation of this association by experimental manipulations of the OTPP.

In addition, we only investigated the effects of probe frequency and framing on the validity of the OTPP in a single task. While the SART is probably the most widely used experimental task in research on mind wandering (e.g., McVay & Kane, 2009; Smallwood et al., 2007), it is unclear if these results can be generalized to other cognitive tasks such as *n*-back tasks (e.g., Rummel & Boywitt, 2014), visual-search tasks (e.g., Forster & Lavie, 2009) or to reading tasks (e.g., Unsworth & McMillan, 2013).

Conclusion

We found little evidence that the frequency or the framing of thought probes affected the validity of the OTPP in the sustained-attention-to-response task. If these results can be generalized to other tasks, it seems unlikely that the great heterogeneity in probe frequency and framing of the OTPP across different studies endangers the replicability and generalizability of study results.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All participants gave their informed consent prior to participating in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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