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The role of attention for insight problem solving: effects of mindless and mindful incubation periods

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ABSTRACT
Incubation periods may be beneficial for insight problem solving either because they allow to mentally disengage from incorrect solution attempts or because they provide additional opportunities to rethink a problem. We investigated whether incubation periods either filled with an easy stimulus-response task, which does not require much attention, a more difficult stimulus-response task, or a mindfulness intervention, which should both require higher sustained-attention levels, differently affect problem solving. Results showed no difference in solution rates and frequencies of Aha! Experiences between the stimulus-response-task groups, which generally thought more, and the mindfulness group, which generally thought less about yet unsolved problems during the incubation period. Results did not change when individual differences in working-memory capacity and trait mind-wandering were controlled for. These findings suggest that short incubation periods may not be overly beneficial for insight problem solving, independent of whether they allow to periodically redirect attention to pending problems or not.

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Insight problem solving; attention; mind wandering; mindfulness; creative incubation; Aha! experience

When the solution to a difficult problem comes to mind suddenly and unexpectedly, rather than gradually and as a result of an intensive problem analysis, the problem solving process is often referred to as "insight." Danek (2018) argues that insight problem solving is a complex, non-linear transition process, which consists of an affective component, that is, a feeling of having an insight or Aha! Experience, and a cognitive component, that is, a sudden representational change or restructuring leading to a correct solution (see also Gick & Lockhart, 1995; Metcalfe & Wiebe, 1987). In line with this idea, it has been shown that correct solutions to creative problems are more often accompanied by Aha! Experiences than incorrect solutions (Danek et al., 2014b; Salvi et al., 2016; Threadgold et al., 2018; Webb et al., 2016) and that Aha! Experiences are more likely to occur when people experience a sudden rather than a gradual change in the problem representation (Danek et al., 2020; Kizilirmak et al., 2018). Furthermore, when finding a solution to an insight problem was associated with an Aha! Experience, this solution is more likely to be remembered than solutions that were not accompanied by such an experience (Danek et al., 2013; Kizilirmak et al., 2016), emphasising the strong impact of this affective component beyond the problem solving process. Given that both the Aha! Experience and the sudden change of the problem representation seem to be crucial components of the insight problem solving process, it is an important question from both a theoretical and an applied perspective under which conditions both components are most likely to occur.

According to classic ideas about creative thought, insight will often occur during incubation periods, that is, while taking a break from a yet unsolved problem (Wallas, 1926). Incubation periods are delay periods between the first exposure to a problem and its solution. Some researchers argue that a delay period will only allow for incubation when people had gotten stuck in their problem solving attempts before the delay. Others, however, do not consider such an

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impasse experience a necessary condition for incubation effects (Weisberg, 2006). For convenience, we will refer to the delay period as incubation period in this paper, but will return to the issue of impasse in the Discussion section.

Incubation periods are usually filled with more or less mundane activities that are not related to the pending problem. Recently, it has been shown that professional writers as well as physicists often generate creative solutions to unsolved problems (and are most likely to have an Aha! Experience) when they are not at work and currently not thinking about the problem at hand (Gable et al., 2019). From a theoretical standpoint, it is an open question, however, why insights should be especially likely to occur under such conditions. Segal (2004) identified three different possible explanations for this phenomenon. First, it may be that some external stimulus during incubation cues the solution or, at least, triggers the solution process. Second, it may be that the withdrawal of attention from the problem initiates a mental loosening of solution-irrelevant aspects of the problem, which, in turn, sets the stage for the discovery of a novel solution when the problem is approached again (cf. Simon, 1966). A third explanation may be that it is not the withdrawal of attention from but rather the periodical redirection of attention back to the problem during incubation periods that fosters insight. One reason for a beneficial effect of such attention redirection may be that the attentional focus is broadened in these situations because the problem itself is not solely in the focus of attention and an open attentional focus may be better suited to produce Aha! Experiences (Zedelius & Schooler, 2015).

Whereas it seems reasonable to assume that problem-related external information can foster new solution ideas, it is unlikely that this mechanism alone can account for creative incubation as not all incubation phases expose the problem solver to problem-relevant stimuli. Furthermore, only few stimuli will directly trigger insight. More often they will initiate a problem-related thought process finally leading to insight, a process not very different from the one assumed by the attention-redirection hypothesis. Therefore, in the present research, we aimed to put the remaining two explanations to the test. These two hypotheses make different predictions regarding the role of mental occupation with a pending problem during an incubation period. The attention-withdrawal hypothesis suggests that incubation periods work best when people do not engage in problem-related thoughts during this period whereas the attention-redirection hypothesis suggests that an intermitted mental return to the pending problem is key to gain insight into it.

Preliminary empirical support for the attention-withdrawal hypothesis comes from a study by Ostafin and Kassman (2012) showing that insight problem solving (as assessed with a problem set collected by Schooler et al., 1993) was improved after an incubation period filled with a mindfulness intervention. As mindfulness interventions require participants to focus their attention fully on the here-and-now, they should leave little room for problem-related thoughts. However, other researchers interested in the beneficial effects of mind wandering, which describes the state when thoughts drift away from a current (incubation) task, found a pattern of results more in line with the attention-redirection idea. It has been shown, for example, that those people who solved insight problems after an incubation period reported more mind wandering during this period than non-solvers (Tan et al., 2015). Although it remains unclear whether mind wandering during incubation periods was causally related to insight problem solving in this quasi-experimental design, this finding hints towards a benefit from a mental return to the unsolved problem during incubation periods, at least if one assumes that the off-task thoughts were partly concerned with the problem. Using an experimental approach, Baird et al. (2012) asked participants to solve a standard creativity problem (i.e. the unusual uses task, Torrence, 1966). Two solution-attempt phases were separated by an incubation period that was filled with more or less attention-reliant activities. Results showed that during tasks, which require less attention, participants mind wandered more and further provided better solutions to the creativity problem afterwards. This pattern of results was also observed by other researchers using a slightly different creativity problem (Dijksterhuis & Meurs, 2006), but it did not always replicate (Smeekens & Kane, 2016).

In the present study, we built on this previous research using a novel set of insight problems developed by Danek et al. (2014b). We asked participants to watch magic effects performed by a magician and to discover the secret method behind it. While observing magic tricks, participants typically set up an initial view of the problem that is inadequate and requires a representational change to allow a solution, which is a crucial feature of insight problems (Danek, 2018). Further, strong Aha! Experiences are triggered upon solving (Danek et al., 2014a; Danek & Wiley, 2017), which is a second important criterion for tasks that are used to investigate insight. Others have recently adopted the magic trick paradigm, with similar results (Hedne et al., 2016).

All our participants were asked to find solutions to twelve previously presented magic tricks at two assessment points, which were separated by a 12-minute incubation period. To test conflicting predictions of the attention-withdrawal and the attention-redirection hypotheses regarding the cognitive mechanisms underlying incubation benefits for insight problem solving, we implemented three conditions with different incubation activities. In two conditions, the incubation period was filled with a stimulus-response task (a simple finger tapping task), which varied in its perceptual demands. In the low-demands condition we used the visual metronome response task (vMRT) that is not very attention-reliant as it has been shown to provide good opportunities to mind wander (Laflamme et al., 2018). In the high-demands condition, we made the target stimulus in the vMRT harder to detect in order to increase the perceptual load imposed by this task. This manipulation was inspired by previous research showing that perceptually demanding (visual-search) tasks bind attention and render mind wandering less likely (Forster & Lavie, 2009; Lavie, 2005). In a third condition, we asked participants to engage in a brief mindfulness body scan intervention, which was similar to the one shown to boost insight problem solving in previous research (Ostafin & Kassman, 2012). The resulting design allowed us to test for changes in problem-solving performance before and after the incubation period (i.e. problem-solving performance changes from the first to the second assessment) as well as for differential changes associated with the three kinds of incubation filler tasks. We assumed that participants engage in more problem-related (i.e. magic trick-related) and task-unrelated thoughts while performing the low-demands stimulus-response task than while performing the high-demands stimulus-response task and during the body scan intervention. As a manipulation check, we asked participants to report which percentage of the incubation time they were thinking about the currently ongoing task, about the magic tricks, and about other task-unrelated things. If this manipulation was successful, we would be able to test the competing hypothesis about the role of attention for insight problem solving. The attention-withdrawal hypothesis predicts that any kind of incubation period—and, if anything, particularly the high-demands and the body scan periods which leave little opportunities to think about the pending problem—improves insight problem solving. Contrary, the attention-redirection hypothesis predicts an (pronounced) incubation benefit in the low-demands condition that allows the mind to wander towards the unsolved problems from time to time.

To shed further light on the feelings associated with successful problem solving, we additionally asked participants to report on their experiences while attempting to find solutions to the magic tricks (Danek et al., 2013). In doing so, we aimed to test whether potential incubation-task-induced differences in insight problem solving performance are reflected by differences in the subjectively experienced Aha! Moment (affective component) as well as in the suddenness with which the solution comes to mind (cognitive component).

Finally, we assessed participants' working-memory capacity and trait mind-wandering tendencies as covariates. Individual differences in working-memory capacity have been shown to be associated with creative problem solving in general (Smeekens & Kane, 2016) and in particular with insight problem solving (Chuderski & Jastrzebski, 2018). One reason for the relationship between creative processing and working memory might be that people with higher working-memory capacity are better able to control their attention (Engle & Kane, 2004). Working-memory capacity thus seemed to be an important covariate to control for when pitting the attention-withdrawal and attention-redirection hypotheses against each other. Previous research also discovered positive correlations between trait mind-wandering and divergent thinking tasks (Preiss et al., 2016). Recently, Agnoli et al. (2018) found that tendencies to deliberately engage in mind wandering are positively related to creative performance whereas tendencies to spontaneously mind wander are negatively related to it. In the present study, we therefore also controlled for individual differences in deliberate and spontaneous mind wandering to isolate potential incubation-task-related effects.

Method

The study was conducted in accordance with national ethical guidelines and the Declaration of Helsinki (World Medical Association, 2013).

Participants

Hundred and fifty-four participants were recruited with the software *hroot* (Bock et al., 2014), an open-source software for managing participant pools. All participants received monetary incentives or course credit for their participation. Six participants who either did not follow task instructions, for whom the volume of the auditory mindfulness intervention had been accidentally set on mute, who did not follow the stimulus-response task instructions, or did not attempt to solve any insight problem were excluded. Insight problems for which participants indicated after the study that they had known their solution beforehand were also removed from the data set, but this did not result in the removal of complete data from any participant. The final sample size consisted of $N = 148$ participants ($M_{age} = 22.77$; $SD_{age} = 3.59$; 79% female).

Materials and procedure

To assess insight problem solving, we used twelve short video clips showing magic tricks performed by the professional magician Thomas Fraps (see https://www.youtube.com/watch?V=3B6ZxNROuNw, for an example clip). Each clip lasted between six and 43 s and participants were asked to generate possible solutions for each trick. Based on the performance data from Danek and Wiley (2017), we generated two trick sets (A and B) with six tricks each, which were comparable in difficulty and length. We only used tricks for which most participants from Danek and Wiley were not able to come up with a solution after a first presentation (mean solution time point $M = 2.31$; $SD = 0.25$, with 1 = after first presentation, 2 = after second presentation, and 3 = after third presentation). The number of tricks that were solved correctly after the second presentation, or for which plausible alternative solutions were generated, was used as an indicator of problem-solving performance.

Three different tasks were used as fillers during an incubation period. One task was the low-demands version of the visual metronome response task (vMRT) as introduced by Laflamme et al. (2018). For each trial of this task, a light-gray square (2.5×2.5 cm) is presented in the centre of a black screen for 150 ms followed by a blank black screen for 1150 ms. Participants are required to press the spacebar whenever the grey square appears on the screen. A second incubation task was very similar to the low-demands vMRT but perceptual processing of the target stimulus was more demanding in this task. That is, the grey square appeared at random and unpredictable screen positions and it was darker in colour as well as smaller in size (0.5×0.5 cm) as compared to in the low-demands version to make it harder to detect on the black screen. A third incubation task was a mindfulness intervention. For this task, participants engaged in an instructed body scan exercise, requiring them to focus their attention on different body parts one after the other. We used freely available German body-scan instructions (Doern, 2017) which were recorded by the second author.

To assess individual differences in mind wandering on a trait level, we applied a mind wandering questionnaire developed by Carriere et al. (2013). This questionnaire consists of two scales, a deliberate mind wandering (MW-D) and a spontaneous mind wandering (MW-S) scale with four items each that are to be responded to on a 7-point Likert scale. Mean ratings were used as indicators for trait mind wandering.

To assess individual differences in working-memory capacity we used the automated operation span task (Rummel et al., 2019; Unsworth et al., 2005). At each trial of this task, participants are presented with a series of three to seven letters. Between succeeding letters, participants are presented with simple math equations that need to be solved. At the end of each trial, participants are asked to recall the letters in the order they were presented in. The number of letters recalled at the correct position per participant was used as a working-memory capacity indicator.

The procedure is illustrated in Figure 1. Participants were randomly assigned to one of the three incubation-task conditions—that is, the low-demands vMRT, the high-demands vMRT, or the body scan condition—while ensuring approximately equal sample sizes for all three conditions. The experiment started with instructions for the respective incubation task participants were to perform during the incubation period alongside some practice trials. Then, all participants were

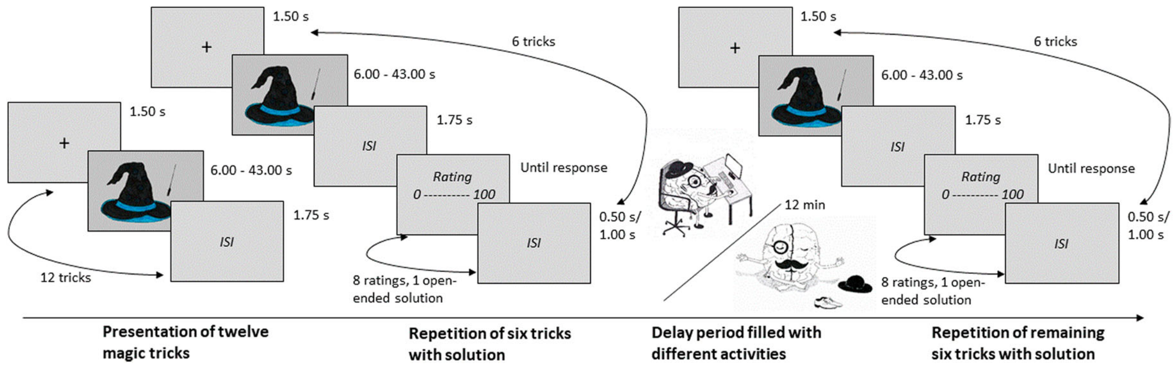

Figure 1. Illustration of the experimental procedure. *Note.* ISI = inter stimulus interval; ratings = ratings of the solution experience on scales from 0 to 100. Questions were "degree of Aha! experience," "pleasantness," "surprise," "suddenness with which solution came to mind," "relief by the solution," "impasse experience," provision of an open-ended solution, "confidence in the solution," "motivation to proceed," in this order). The ISI between ratings was always 0.50 s except after the open-ended response where the ISI was 1s.We thank Alina Zagel for creating the picture illustrations.

given instructions on how to solve the magic tricks and solved an easy practice trick. Participants were informed that they would first have to simply watch several magic tricks and then would have to provide solutions for some of the tricks, namely the ones that would be repeated for a second time after the first round of presentations. Afterwards, participants were presented with 12 magic tricks in random order. Each presentation started with a 1500-ms fixation cross, which was followed by a 500-ms blank screen. Presentation trials were separated by a 1750-ms inter-trial-interval. Six tricks (i.e. those of Sets A or B, counterbalanced across participants within each condition) were then repeated in random order. Directly after the second presentation of each of these six tricks, participants were first asked to rate to which extent they had had an Aha! Experience when coming up with a solution using a visual analogue scale with the end points "no" and "yes" (internally the scale was scaled from 0 to 100 but with no numbers displayed). Participants were further asked to indicate on the visual analogue scale how pleasurable the moment of solution felt ("unpleasant" vs. "pleasant"), how surprised they felt ("not surprised" vs. "very surprised"), the suddenness with which the solution came to mind ("gradually" vs. "suddenly"), and how relieved they were upon finding the solution ("tense" vs. "relieved"). Questions were presented with a 500-ms inter-stimulus interval. Then, after a 1000-ms blank screen, participants were asked to write down the solution they came up with for the respective trick. Instructions encouraged participants to respond quickly to this question, but solution times were not limited in order not to disadvantage those who typed slowly. For each repeated trick, participants had to either provide a solution or to type in "no idea" before the next trick was presented. Once a solution was provided participants could not change their submitted solution anymore. Finally, participants had to rate how certain they were that their solution was correct ("very uncertain" vs. "very certain"), and how motivated they were to solve the next trick ("not at all" vs. "a lot"). All these insight problem solving rating scales were derived from a previous study (Danek & Wiley, 2017) and translated into German.

Next, participants were exposed to an incubation phase filled with one of three tasks depending on the incubation condition. The low-demands and high-demands vMRT participants performed 525 trials of the respective task (the first five trials served as buffer trials), which took them approximately 12 min. In the mindfulness-intervention condition, participants followed the body scan instructions (see above) for approximately 12 min. To reduce the likelihood that participants in the high-demands and body scan conditions still mind-wandered about the unsolved magic tricks, we told participants of these two conditions that they would not have to solve the remaining tricks. The low-demands vMRT participants were correctly informed that they would have to generate solutions for the remaining six tricks after the incubation period.

After the incubation period, all participants were asked how they felt at this particular moment ("exhausted" vs. "fit"; on a scale ranging from 0 to 100). To examine participants' thought contents during incubation, participants were further asked to indicate which percentage of the total time during their respective incubation task they (1) had been focusing on the task, (2) had been thinking about the previously presented tricks, and (3) had been thinking about other things not related to the task or the tricks. Subsequently, the six tricks from the remaining set (either Set A or B, depending on the counter-balance condition) that had only been shown once at the beginning of the experiment were presented for a second time and participants had to generate solutions for each trick and answer the same questions about the solution process as for the first set.

After the experiment, participants were presented with short descriptions of all twelve magic tricks and were asked whether they had known the solution of any of the tricks before they took part in the present study. Participants finally provided some basic demographic information, performed the operation span task, and completed the mind-wandering trait questionnaire before they were debriefed and dismissed.

Results

We conducted Bayesian analyses of variance (BANOVAs) with the software *JASP* (Love et al., 2019) and Bayesian hierarchical mixed models with the *brms* R-package (Bürkner, 2017). Model parameters for the latter were estimated using the brms default settings for the number of Markov Chain Monte Carlo (MCMC) chains, burn-in samples, additional samples and thinning parameters. For regression weights, we used default priors which were non-informative for population-level effects and weakly informative for group-level effects. To the best of our knowledge, no previous study used comparable perceptual-demand/mindfulness manipulations to investigate incubation-period effects within a similar insight problem task. Consequently, we set uniform priors for all analyses and report Bayes factors (*BF*s) in favour of the alternative hypothesis (conventionally indicated as BF_{10}) or the Null hypothesis (conventionally indicated as BF_{01}) depending on which of the two were more likely. To evaluate statistical significance, we used the conventions outlined by Lee and Wagenmakers (2014). That is, we considered $1 < BF \leq 3$ as only anecdotal evidence, $3 < BF \leq 10$ as moderate evidence, $10 < BF \leq 30$ as strong evidence, and $BF > 30$ as very strong evidence in favour of the respective hypothesis. All data and code of analyses is available at the Open Science Framework (OSF) under the doi: 10.17605/OSF.IO/P5BQG.

Manipulation check and solution experiences

Condition means for all assessed variables are shown in Table 1. We first tested whether the self-reported amount of task-unrelated thoughts, excluding problem-related thoughts, during the incubation phase varied between the three incubation-task conditions. A BANOVA indicated very strong evidence for group differences, $BF_{10} = 168705.32$. Follow-up simple comparisons further indicated that task-unrelated thought rates were lower in the body scan condition than in the low-demands vMRT, $BF_{10} = 1999270.17$, and the high-demands vMRT, $BF_{10} = 4089.90$, conditions. The two vMRT conditions, however, did not differ, $BF_{01} = 4.76$. A similar pattern was observed for problem-related thoughts. There was moderate evidence for group differences, $BF_{10} = 8.88$, and follow-up tests showed lower rates in the body scan than in the low-demands vMRT, $BF_{10} = 5.42$, and the high-demands vMRT, $BF_{10} = 50.38$, conditions. The two vMRT conditions, again, did not differ, $BF_{01} = 3.92$.

We next tested whether participants' subjective solution experience varied with the factors incubation-task conditions and/or assessment point (i.e. regarding the degree to which they had an Aha! Experience, the suddenness with which a solution came to mind, the pleasantness associated with the solution, the level of surprise, the confidence with the generated solution, the degree to which a dead end was reached prior to the solution, and the relief after generating a solution). The Aha!-Experience degree generally increased from the first to the second assessment, $BF_{10} = 8.59$, and so did confidence, $BF_{10} = 5.25$. There was no evidence that any of the other variables varied systematically between incubation groups or assessment points and, most importantly, there was no evidence for any interaction effect between the two factors, all $BF_{10} < 3$. Self-reported motivation to carry on with the task decreased from the first to the second assessment, $BF_{10} = 3456*10^6$.

We also tested whether total solution times for correct solutions differed between incubation conditions and/or assessment points. Solution

Table 1. Mean (standard deviation) for the solution experience, solution frequency, and thought reports.

	Low-Demands vMRT		High-Demands vMRT		Body Scan	
Problem-Related Thoughts	6.90 (9.06)		8.08 (8.84)		2.83 (4.93)	
Task-Unrelated Thoughts	58.57 (23.28)		58.68 (16.45)		37.40 (19.04)	
	Before Incubation	*After Incubation*	*Before Incubation*	*After Incubation*	*Before Incubation*	*After Incubation*
Aha! experience	41.52 (13.05)	46.92 (19.71)	41.93 (16.82)	45.50 (16.40)	44.66 (17.13)	49.56 (19.71)
Pleasure	48.85 (10.92)	49.11 (12.36)	48.85 (10.81)	50.52 (11.48)	51.88 (11.57)	53.69 (11.22)
Surprise	46.92 (10.94)	50.26 (14.15)	46.37 (11.49)	46.05 (12.95)	45.35 (12.13)	47.96 (9.69)
Suddenness	50.37 (13.48)	48.48 (15.19)	48.30 (8.66)	50.64 (11.13)	46.18 (11.92)	48.84 (11.89)
Relief	48.26 (10.00)	48.75 (13.21)	48.46 (10.19)	49.87 (10.84)	49.73 (11.84)	53.68 (10.81)
Certainty	38.01 (17.55)	43.69 (19.95)	38.06 (17.44)	41.64 (17.90)	36.58 (16.26)	39.33 (19.79)
Motivation	74.18 (22.73)	65.53 (27.78)	74.10 (20.66)	55.65 (28.77)	77.27 (18.80)	67.05 (27.70)
Solution Times	56.94 (28.86)	51.72 (29.51)	55.96 (37.72)	45.32 (29.60)	50.14 (29.60)	41.60 (23.50)
Solution Probability	38.30 (22.80)	40.40 (22.70)	39.10 (22.20)	41.10 (28.10)	39.70 (29.50)	45.80 (25.70)

times generally decreased from the first to the second assessment, $BF_{10} = 4.51$, suggesting that participants became faster in generating correct solutions. There was moderate evidence against a general incubation condition effect, $BF_{01} = 4.58$, as well as against an interaction effect, $BF_{01} = 9.89$.

Creative problem solving performance

To achieve a creativity measure, the freely reported solutions were coded by two independent raters as correct or incorrect using a coding manual that had been developed with the help of the magician. A third independent rater solved inter-rater conflicts. Solutions were coded as correct when they properly described how the magician achieved the magic effect or a plausible alternative solution. Solutions that were not plausible or impossible given the conditions in the video were coded as errors. Correct solutions were assigned a value of 1 and incorrect solutions as well as no solutions a value of 0. The inter-rater reliability was good, Cohen's kappa = .85. Mean solution rates per condition are displayed in the last row of Table 1.

We used a hierarchical mixed-model approach to analyse problem-solving performance. Parameter estimates for all models are displayed in Table 2. This approach allowed us to account for the dichotomous nature of this dependent variable by using a logit-link function. We first specified a baseline crossed-random intercept model allowing intercepts to vary with subjects and tricks. To test our hypothesis that magic-trick solution probability changes from the first to the second assessment and differently so for the three experimental conditions, we specified additional models that included incubation condition and assessment point (both effect-coded) separately and tested for main effects by comparing them to the baseline model. In doing so, we found strong evidence for the absence of an incubation condition effect, $BF_{01} = 10.44$. Furthermore, we found (weak) evidence against an assessment point effect, $BF_{01} = 2.15$, which would be considered anecdotal according to the conventions we applied. We next specified a main-effects-only model that included both factors simultaneously and tested for a significant interaction between factors by comparing a model that contained the interaction as an additional predictor against the main-effects-only

Table 2. Results of the mixed-model analyses for condition effects.

	Estimate	Est. Error	Lower-Bound 95%-BCI	Upper-Bound 95%-BCI
Baseline				
Group-Level Effects				
Subject	0.51	0.10	0.33	0.70
Trick	1.01	0.27	0.63	1.67
Bayesian R^2	0.16	0.02		
Incubation-Condition-Only				
Group-Level Effects				
Subject	0.53	0.10	0.33	0.72
Trick	1.02	0.26	0.63	1.65
Population-Level Effects				
Intercept	−0.97	0.31	−1.61	−0.36
LD-vs-HD	0.04	0.10	−0.16	0.24
LD-vs-MF	−0.02	0.10	−0.22	0.18
Bayesian R^2	0.16	0.02		
Assessment-Point-Only				
Group-Level Effects				
Subject	0.53	0.10	0.33	0.73
Trick	1.02	0.27	0.63	1.64
Population-Level Effects				
Intercept	−0.97	0.31	−1.61	−0.36
AS	−0.01	0.05	−0.12	0.09
Bayesian R^2	0.16	0.02		
Main-Effects-Only				
Group-Level Effects				
Subject	0.53	0.10	0.34	0.72
Trick	1.02	0.27	0.63	1.67
Population-Level Effects				
Intercept	−0.96	0.31	−1.59	−0.35
LD-vs-HD	0.04	0.10	−0.16	0.24
LD-vs-MF	−0.01	0.10	−0.21	0.18
AS	−0.01	0.06	−0.13	0.10
Bayesian R^2	0.17	0.02		
Main-Effects-and-Interaction				
Group-Level Effects				
Subject	0.53	0.10	0.33	0.73
Trick	1.02	0.27	0.63	1.67
Population-Level Effects				
Intercept	−0.99	0.33	−1.64	−0.36
LD-vs-HD	0.04	0.10	−0.17	0.24
LD-vs-MF	−0.01	0.10	−0.21	0.19
AS	−0.01	0.06	−0.12	0.09
LD-vs-HD: AS	−0.09	0.08	−0.24	0.07
LD-vs-MF: AS	0.08	0.08	−0.08	0.23
Bayesian R^2	0.17	0.02		

Note. LD = low demands condition; HD = high demands condition; MF = mindfulness condition; AS = assessment point. At the group level, all effects are random intercept only effects; at the population level, all effects are fixed effects. All experimental comparisons are effect-coded. Bayesian versions of the R^2 statistics for each model are calculated using the approach proposed by Gelman et al. (2019).

model. This analysis provided strong evidence against an interaction effect, $BF_{01} = 19.36$.[1]

As the experimental manipulations did not affect trick solution rates, we next tested whether differences in Aha! Experience, working memory capacity, thinking about the magic tricks during incubation, state mind-wandering during incubation, or trait mind-wandering were associated with trick solution probability without considering the experimental factors any further (see Table 3 for parameter estimates).

Comparing a model with the predictor self-reported Aha! Experience with the baseline model provided very strong evidence that those tricks that were accompanied by stronger Aha! Experiences were more likely to be solved correctly, $BF_{10} > 366*10^{10}$. Similarly, comparing a model with the predictor self-reported suddenness with which solutions came to mind with the baseline model provided at least moderate evidence that those tricks to which solutions occurred more suddenly, were more likely to be solved correctly, $BF_{10} = 3.26$. Correct solutions felt more pleasurable, $BF_{10} = 1108247*10^6$, and more relieving, $BF_{10} = 13258935$, than incorrect ones but not more surprising, $BF_{01} = 7.90$. Participants were more certain about the correctness of factually correct than factually incorrect solutions, $BF_{10} = 4632966*10^{17}$. Working memory capacity was not related to solution probability, $BF_{01} = 3.86$, and there was strong evidence that none of the state or trait mind-wandering variables were associated with solution probability, all $BF_{01} \geq 28.13$. Importantly, controlling for all or any subset of these covariates would not have changed the finding that the experimental manipulations of incubation activities and assessment points had no effect on problem solving performance.

Discussion

In the present study, we investigated whether incubation periods filled with activities that allow to periodically think about yet unsolved insight problems are more likely to foster problem solving through insight than incubation periods that are filled with activities that were designed to largely

[1]To gain a complete picture regarding how our experimental manipulations affect problem solving performance, we also tested whether incorrect solution rates would vary with experimental conditions. To this end, we coded incorrect solutions as 1 and correct as well as non-solutions as 0 and repeated the solution performance analyses with this new criterion variable. Results showed no main effect of incubation condition, $BF_{01} = 18.84$, and no interaction, $BF_{01} = 21.37$, but a decrease of incorrect solutions from the first to the second assessment, $BF_{10} = 7.76$. As we did not observe an increase in correct solutions from the first to the second assessment, this decrease suggests that participants were more likely to provide no solution rather than an incorrect one during the second as compared to the first assessment.

Table 3. Results of the mixed-model analyses for covariates.

	Estimate	Est. Error	Lower-Bound 95%-BCI	Upper-Bound 95%-BCI
Baseline				
Group-Level Effects				
Subject	0.51	0.10	0.33	0.70
Trick	1.01	0.27	0.63	1.67
Bayesian R^2	0.16	0.02		
Aha! Experience				
Group-Level Effects				
Subject	0.72	0.10	0.53	0.93
Trick	1.08	0.29	0.66	1.80
Population-Level Effects				
Intercept	−2.23	0.35	−2.91	−1.55
Covariate	0.03	< 0.01	0.03	0.04
Bayesian R^2	0.29	0.02		
Solution Suddenness				
Group-Level Effects				
Subject	0.54	0.10	0.33	0.72
Trick	1.02	0.28	0.63	1.71
Population-Level Effects				
Intercept	−2.23	0.35	−2.91	−1.55
Covariate	0.01	< 0.01	0.00	0.02
Bayesian R^2	0.17	0.02		
Solution Pleasantness				
Group-Level Effects				
Subject	0.66	0.10	0.48	0.86
Trick	1.00	0.26	0.62	1.64
Population-Level Effects				
Intercept	−2.92	0.36	−3.65	−2.22
Covariate	0.04	< 0.01	0.03	0.04
Bayesian R^2	0.25	0.02		
Solution Surprise				
Group-Level Effects				
Subject	0.53	0.10	0.34	0.72
Trick	1.00	0.26	0.64	1.66
Population-Level Effects				
Intercept	−0.70	0.34	−1.36	−0.02
Covariate	−0.01	< 0.01	−0.01	0.00
Bayesian R^2	0.17	0.02		
Solution Relief				
Group-Level Effects				
Subject	0.64	0.10	0.45	0.83
Trick	0.99	0.26	0.62	1.61
Population-Level Effects				
Intercept	−2.64	0.36	−3.35	−1.92
Covariate	0.03	< 0.01	0.03	0.04
Bayesian R^2	0.22	0.02		
Solution Certainty				
Group-Level Effects				
Subject	0.70	0.10	0.53	0.90
Trick	1.01	0.27	0.63	1.70
Population-Level Effects				
Intercept	−2.08	0.33	−2.76	−1.44
Covariate	0.03	< 0.01	0.02	0.03
Bayesian R^2	0.25	0.02		
Working Memory Capacity				
Group-Level Effects				
Subject	0.72	0.53	0.93	0.72
Trick	1.08	0.29	0.66	1.80
Population-Level Effects				
Intercept	−1.46	0.35	−2.17	−1.55
Covariate	0.01	< 0.01	0.00	0.02
Bayesian R^2	0.17	0.02		
State Mind Wandering (trick-related)				
Group-Level Effects				
Subject	0.52	0.10	0.33	0.71
Trick	1.01	0.27	0.62	1.64
Population-Level Effects				
Intercept	−0.99	0.31	−1.61	−0.36
Covariate	0.00	0.01	−0.01	0.02
Bayesian R^2	0.16	0.02		

(*Continued*)

Table 3. Continued.

	Estimate	Est. Error	Lower-Bound 95%-BCI	Upper-Bound 95%-BCI
State Mind Wandering (not trick-related)				
Group-Level Effects				
Subject	0.52	0.10	0.33	0.71
Trick	1.01	0.26	0.63	1.64
Population-Level Effects				
Intercept	−0.93	0.34	−1.60	−0.27
Covariate	0.00	0.00	−0.01	0.02
Bayesian R^2	0.16	0.02		
Trait Mind Wandering				
Group-Level Effects				
Subject	0.52	0.10	0.34	0.71
Trick	1.01	0.28	0.63	1.69
Population-Level Effects				
Intercept	−0.80	0.51	−1.83	0.17
Deliberate	0.01	0.06	−0.11	0.13
Spontaneous	−0.05	0.06	−0.17	0.07
Bayesian R^2	0.16	0.02		

Note. At the group level, all effects are random intercept only effects; at the population level, all effects are fixed effects. Bayesian versions of the R^2 statistics for each model are calculated using the approach proposed by Gelman et al. (2019).

prevent thoughts about the pending problems. In doing so, we aimed to test the conflicting hypotheses of whether attention withdrawal from or attention redirection to a pending insight problem during incubation periods is beneficial for insight problem solving.

In line with previous research, insight problem solving in our study was positively related to Aha! Experiences (Danek et al., 2014b; Salvi et al., 2016; Threadgold et al., 2018; Webb et al., 2016) and correct solutions came more suddenly to mind than incorrect solutions (Danek & Wiley, 2017). That is, the present research further supports the two-component idea of insight problem solving (Danek, 2018; Gick & Lockhart, 1995; Metcalfe & Wiebe, 1987). In line with our hypothesis, people who performed an easy stimulus-response task during incubation engaged in more task-unrelated as well as problem-related thoughts than people who engaged in a mindfulness exercise during incubation. Other than expected, however, the amount of task- and problem-related thoughts was not reduced when the stimulus-response task was perceptually more taxing. Importantly, our results provided no evidence that an incubation period of twelve minutes fostered insight problem solving, independent of the kind of activity people engaged in during incubation. In particular, we did not find any evidence that mind wandering (neither about the problem nor about other things) during incubation was related to insight problem solving, as for instance argued by Tan et al. (2015). In fact, the Bayesian analyses provide strong evidence against an interaction of assessment point and incubation task, implying that the kind of activity performed during incubation does not matter much. The Bayesian analyses did not provide clear support for or against a general incubation effect, as the evidence against an improvement from the first to the second assessment remained anecdotal. The absence of a clear incubation benefit in the present study may be nevertheless interesting, as it contradicts the general notion that incubation always benefits insight problem solving, but supports the idea that various moderating variables can influence whether incubation positively affects insight problem solving or not (Sio & Ormerod, 2009, 2015). Further research is certainly necessary to better understand incubation benefits and their boundaries.

It is noteworthy that some theorists argue that incubation benefits can only be expected when participants reached an impasse during initial solution attempts prior to an incubation phase (Ohlsson, 1992). In the present study, we did not control for impasse experiences because previous research has shown that impasse is not a necessary condition for an Aha! Experience to occur in the insight problem task we used (Danek et al., 2014a), although it can be experimentally induced (Petervari & Danek, 2019). It could also be argued that the nature of magic tricks is such that they lead observers directly into a state of impasse, before any problem solving attempts, as reflected in the strong sense of wonder and astonishment triggered by a seemingly impossible event for which no explanation is readily available. In light of the fact that solution performance was generally far from perfect during both assessment points and that we observed a general increase in Aha! Experiences from the first to the second assessment, we believe that our task setting was generally suitable to allow for incubation benefits. Nevertheless, it would be certainly interesting to use other insight problem tasks and control for impasse experiences in future studies.

Some limitations of the present findings should also be considered when evaluating the absence of an incubation benefit in the presented study. For instance, the reduced motivation to generate a solution, which we observed from the first to the second assessment, may have cancelled out incubation effects. This seems not very plausible, however, because, despite this motivational drop, the degree of Aha! Experiences increased from the first to the second assessment whereas solution times for correct solutions decreased. The latter may reflect a general practice effect rather than an incubation benefit but both findings speak against a decline in the motivation to provide solutions. Similarly, participants may have felt exhausted after providing solutions for the first six tricks and thus did not work as hard during the second assessment. Again, the faster solution times for correct solutions during the second assessment speak against this point. Additionally, it has been shown that brief mindfulness interventions such as the one we used in the present study can prevent mental fatigue effects (Friese et al., 2012). In light of these findings, we find it unlikely—and particularly so for participants in the mindfulness condition—that mental fatigue effects have cancelled out incubation effects in our study. However, we cannot completely rule out this alternative interpretation for the absence of problem-solving improvements from the first to the second assessment. One may further argue that an incubation period of twelve minutes was simply too short for fostering insight or that the magic tricks are not typical insight problems when it comes to incubation benefits. However, others have found that even a full night sleep does not benefit insight problem solving neither when the task is to solve magic tricks nor with more classic insight problem scenarios (Schönauer et al., 2018; but see Sanders et al., 2019). Finally, we also would like to acknowledge that there are different types of creative problems that are assumed to profit from insight and it is an open question for future research whether the present findings observed with knowledge-lean visual magic-trick problems would translate to verbal and more knowledge-rich problems.

As previous research has shown that trait tendencies to engage in deliberate mind wandering are positively related to creative problem solving but tendencies to spontaneously mind wander are negatively related to it (Agnoli et al., 2018), we controlled for individual differences in trait mind wandering (as well as state mind wandering) and also tested their relation to insight problem-solving performance. The results of the experimental manipulation were independent of mind wandering states and our results further provided strong evidence that neither deliberate nor spontaneous mind-wandering tendencies were related to insight problem solving. Our results were less clear with regard to whether working- memory capacity was positively related to insight problem solving or not. The Bayesian analyses provided some—but only moderate—evidence against the existence of such a relationship. Therefore, future research is necessary to clarify the role of working-memory capacity for insight problem solving.

To conclude, the results of the present study imply that incubation periods are not always beneficial for insight problem solving, independent of whether they allow for rethinking a problem or encourage mental disengagement from a problem. Furthermore, the observed Null relations between problem solving and state and trait mind wandering challenge theoretical claims that insight problem solving benefits from mind-wandering opportunities (Tan et al., 2015). Recently, some scholars argued that different types of creative problems profit from different mental states (Lippelt et al., 2014; Zedelius & Schooler, 2015). Future research is therefore needed to further clarify the role of attention and mind wandering for solving different types of creative and complex problems.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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