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Unexpected Interruptions, Idle Time, and Creativity: Evidence from a Natural Experiment

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Abstract. Interruptions are common in organizational life and last from seconds and minutes to hours and days. We rely on a quantitative abductive strategy to determine how extended work interruptions shape employees' creativity. We start by studying how surprising interruptions that cause idle time affect employees' creative performance. We do so by exploiting a natural experiment—a supply chain shortage that caused unexpected stops in production plants—to show that individuals exposed to such an interruption produce 58% more ideas than uninterrupted employees in the three weeks after the interruption. We corroborate this effect in a replication and extend it to idea quality. Investigating the effect's causes, we then show that we do not find the same effects for two other interruption types: for unexpected interruptions without idle time (i.e., intrusions), we find a negative effect on creative performance because employees forcefully disengage from their work and switch their attention to the interrupting task. For expected interruptions with idle time (i.e., planned breaks), we also find no positive effect on creative performance because employees discretionally disengage from work and focus on nonwork and leisure goals. We consider and evaluate three different theoretical explanations for our findings: attention residue, cognitive stimulation, and recovery. We end our abductive process by putting attention residue forward as the most likely explanation. Finally, we suggest three propositions based on our findings and discuss our contributions to the literature on interruptions and creativity in organizations.

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Keywords: interruptions • surprises • intrusions • breaks • idle time • slack • creativity • ideas • innovation • operations • manufacturing • idea management systems

Introduction

Interruptions to work are common in organizational life and take various forms: incoming calls, colleagues dropping in, vacation breaks, extreme weather, breakdowns of machinery, or supply shortages. More recently, scholars have investigated how interruptions in general affect creativity (e.g., Beeftink et al. 2008, Madjar and Shalley 2008, Sio and Ormerod 2009, Foroughi et al. 2014, Eliav and Miron-Spektor 2015, Madjar et al. 2019). Creativity—defined as coming up with novel and useful ideas (Amabile et al. 2005)—is crucial to organizational success because fresh ideas are the raw material for innovation and change. However, scholars in this field cannot agree on a verdict: whereas some studies find that interruptions fuel creativity (Beeftink et al. 2008, Madjar and Shalley 2008, Madjar et al. 2019), others find them to be harmful (Zellmer-Bruhn 2003, Foroughi et al. 2014).

Although these studies contribute to our understanding of interruptions and their effects on creativity, most of them concentrate on situations in which the primary tasks are suspended for only a very short time. Of course, short interruptions are only one part of organizational life and, thus, a small part of the overall picture. More prolonged interruptions may be rarer, but if they occur, they are much more disruptive (Christianson et al. 2009). Examples cited in existing studies include a supply chain disruption caused by an environmental disaster, in turn leading to the starving of downstream plants (operations stopping for weeks) (Dong et al. 2018); a preemptive ceasing of operations owing to extreme weather (operations stopping for days) (Dye et al. 2014); and machine breakdowns owing to equipment failures (operations stopping for hours) (Cai et al. 2017). Naturally, such extended interruptions are of particular concern for firms because of the high productivity loss. An underexplored area of research on interruptions is how prolonged interruptions affect creativity.

We seek to extend this research by focusing on how, when, and why interruptions that stop work operations for a long time affect creative performance in organizations. Extended interruptions may have a distinct impact on creative performance because they are associated with different cognitive processes than short interruptions. Extended interruptions potentially fuel creativity because time away from the task allows for time to think about the interrupted task (Sio and Ormerod 2009, Leroy et al. 2020), introduce novel stimuli (Dane 2010, Mochi and Madjar 2018), and lead to mental recovery (de Jonge et al. 2012). Then again, interruptions may be detrimental to creativity because of the disruption to work routines (Zellmer-Bruhn 2003, Borst et al. 2015, Feldman and Greenway 2020): employees may become detached from their tasks (de Jonge et al. 2012) and lose sight of work-related goals (Altmann and Trafton 2002). Surprisingly, there is little research on how extended interruptions affect creative performance and what mechanisms underlie their potential effects.

Given that extended interruptions and their effects on creativity is a poorly understood phenomenon, as is the complexity of the relationship between extended interruptions and creative performance, we follow an explorative approach (Bamberger and Ang 2016, Shepherd and Suddaby 2016, Behfar and Okhuysen 2018, Sætre and Van de Ven 2021). As in a number of recent studies (e.g., Hallen et al. 2020, Conti and Roche 2021, Sorenson et al. 2021), we rely on a quantitative abductive strategy, following four steps. First, we start by observing and establishing the existence and direction of a causal effect between extended interruptions and creative performance. To do so, we exploit a natural experiment—a supply chain shortage that caused unexpected stops at production plants that led to the interruption of work for some employees but not for others. We find that this extended interruption positively affected employees' creative performance in idea quantity. Second, we extend and corroborate the effect (Behfar and Okhuysen 2018): we replicate the effect in an alternative interruption event one year after the main event and extend the effect for idea quality as the outcome. Third, we move on to finding the causes for the effect (Gelman and Imbens 2013, Sætre and Van de Ven 2021): we ask whether the found effect is specific to the primary interruption types on which we are focusing (unexpected interruptions that create idle time: surprises). Specifically, we explore the effect of unexpected interruptions without idle time (i.e., intrusions) and expected interruptions with idle time (i.e., planned breaks) on creative performance. Our finding—that neither of these other interruption types affects creative performance positively—shows that creative performance is caused by what happens during an interruption. This insight leads us to the fourth step: to revisit our findings in light of which mechanisms could cause the pattern of different interruption types' effect on creativity. When considering three different theoretical explanations (Sætre and Van de Ven 2021)—attention residue, cognitive stimulation, and recovery—our abductive process leads us to put forward attention residue as the most likely explanation of our findings, suggesting that interruptions can cause creativity if there is a continued activation of related goals without the need to focus on other goals during the interruption. Finally, we develop tentative propositions to theorize from our findings (Behfar and Okhuysen 2018).

This study contributes to the research on interruptions and creativity in an organization (e.g., Jett and George 2003, Zellmer-Bruhn 2003, Mochi and Madjar 2018, Leroy et al. 2020). We explore how extended interruptions shape creative performance in firms and shed light on why some interruption types are particularly conducive to creativity. Interruptions' effects on creative performance are bound to what happens during the interruption time. Interruptions, during which individuals stop with the primary task but remain to some extent engaged with it, lead to attention residue and creative performance. In contrast, interruptions that engender disengagement from the primary task do not foster creativity.

Background

Interruption Types

Interruptions involve shifts in focus or suspension of behavior from ongoing work tasks (Jett and George 2003, Leroy et al. 2020, Puranik et al. 2020). This is a broad definition that can be applied to a multitude of interruptions across different dimensions. For instance, interruptions can be caused by both internal or external stimuli, be expected or unexpected, require different levels of attention, come with an accompanying interrupting task, and last from seconds and minutes to hours and days. Further, many different phenomena can constitute interruptions, such as intrusions, surprises, breaks, multitasking, or distractions (Jett and George 2003, Leroy et al. 2020).

This study focuses on longer interruptions that last for an extended time frame and have an objective start and end. Such types of interruption differ from multitasking (when many tasks run in parallel, and the interruption is not sequential) (Leroy et al. 2020) and distractions (when the performance of the task does not stop, but attention is pulled away) (Puranik et al. 2020).

Extended interruptions primarily take the form of intrusions, breaks, and surprises. Intrusions unexpectedly disrupt the current work for some time by forcing employees to focus on an interrupting task. Breaks are recesses from work that offer employees an opportunity for respite away from their primary task with their attention temporarily diverted to nonwork activities. Finally, surprises are interruptions when employees perceive the interrupting event as a deviation from an expected work pattern or schedule, which often diverts attention or focus as a response (Leroy et al. 2020).

We primarily study interruptions that equip employees with unexpected, extended idle time: involuntary downtime during which work tasks cannot be done (Brodsky and Amabile 2018). Thus, our main interruptions can be typologized as surprises because they represent a deviance from expected progress and lead to a pause in the completion of a task (Leroy et al. 2020). Importantly, not all surprises cause idle time, a point we return to in the discussion section.

Media reports are full of the interruption type we study. Production employees must wait hours if other employees upstream in the production line cause extended stops. Full city quarters (including many office buildings) are evacuated for days when old aircraft bombs are being dismantled. Employees are sent home to quarantine for days if a virus contaminates a firm. In this paper, we investigate the halting of a production line owing to missing supply parts that lasted four days. We then determine whether we would find the same effect if an interruption were either unexpected without idle time (i.e., an intrusion) or expected with idle time (i.e., a planned break).

Interruptions and Creativity

This paper explores the effects of extended interruptions on creative performance. The research on interruptions almost exclusively concentrates on investigating very short interruptions, typically lasting much less than 30 minutes. Laboratory studies show that interruptions are conducive to creative performance (Sio and Ormerod 2009), especially if one can interrupt work discretionarily (Beeftink et al. 2008, Madjar and Shalley 2008) or if the primary task is a divergent rather than a convergent thinking task (Eliav and Miron-Spektor 2015). Creative performance is also affected by the interrupting task: the later the subjects switched from the primary task to an interrupting task and the more similar the intervening task and the main task were, the higher the creative performance (Madjar et al. 2019).

However, the literature has not unequivocally found that interruptions typically increase creative performance (Mochi and Madjar 2018). For instance, Zellmer-Bruhn (2003) shows that unusually large interruption events impede the acquisition of new routines because individuals are busy coping with the interruption rather than focusing on consequent learning outcomes. Foroughi et al. (2014) show that interruptions lower creative performance in a laboratory task, especially during the execution phase.

Even if it is not well-understood whether and, if so, how extended interruptions shape creative performance, the research agrees that interruptions can induce creativity by facilitating incubation (Sio and Ormerod 2009, Mochi and Madjar 2018, Madjar et al. 2019). Incubation happens when a task is set aside following some performance time, allowing the individual in question to come up with new ideas (Sio and Ormerod 2009). This period of incubation enables individuals to continue processing primary task–related information (e.g., Mochi and Madjar 2018) and approach the primary task with a new perspective (e.g., George 2007), overcoming any cognitive fixations (e.g., Beeftink et al. 2008) and recovering mentally when needed (e.g., Jett and George 2003).

Different mechanisms that can explain interruption-induced incubation include attention residue, cognitive stimulation, and recovery (Sio and Ormerod 2009, Mochi and Madjar 2018, Madjar et al. 2019, Puranik et al. 2020). First, unless employees disengage completely from an interrupted task after an interruption, significant attention may still be on the interrupted task; individuals experience attention residue (Leroy 2009, Leroy and Glomb 2018) defined as "thoughts about one task persist[ing] while performing another" (Leroy and Glomb 2018, p. 380). High attention residue may be conducive to creativity within the interrupted task's domain (Madjar et al. 2019): work-related thoughts remain active longer (Leroy 2009, Leroy and Glomb 2018), and these ruminations about work facilitate creativity (Cohen and Ferrari 2010, de Jonge et al. 2012). For instance, Madjar and Shalley (2008) show that individuals are more creative when interrupted if they focus on creativity goals for the interrupted task. And Vahle-Hinz et al. (2017) find that individuals pondering about work in their free time increases work-related creativity. However, if employees cognitively disengage—discretionally or not—from the interrupted task, attention residue decreases. With low attention residue, the goals associated with interrupted tasks begin to fade during the interruption (Altmann and Trafton 2002), and this decreasing amount of attention on work goals, in turn, lowers creative performance output (Mochi and Madjar 2018). For instance, interruption tasks reduce the quality of individuals' creative work if the activated goals associated with a creativity task deteriorate (Foroughi et al. 2014).

Second, interruptions can increase creative performance through cognitive stimulation. Interruptions can shift individuals' attention to new stimuli and, thus, update cognitive structures and induce creativity (Jett and George 2003, Dane 2010). In particular, unexpected interruptions can stimulate cognition because they go against expectations (Leroy et al. 2020). For instance, exposure to surprising interruptions can lead organizations to update and change their work processes and organizational routines (Bechky and Okhuysen 2011, Chen and Garg 2018). Similarly, forced experimentation typically leads individuals to try out and adopt new procedures (Larcom et al. 2017).

Third, interruptions may increase creative performance through recovery (Eliav and Miron-Spektor 2015) when employees cognitively disengage from their work during extended interruptions without intervening tasks. In turn, reduced stress and less cognitive exhaustion can fuel creativity (Eliav and Miron-Spektor 2015, Mochi and Madjar 2018).

The following sections explore the phenomenon of extended and unexpected interruptions with idle time, specifically whether and, if so, how such interruptions affect creative performance. Then, in the later section, we explore when and why extended interruptions shape creative performance in organizations. Table 1 provides an overview of our abductive research steps, the associated empirical tests, and their findings.

Establishing the Effect: Do Surprises with Idle Time Affect Creative Performance?

Context, Data, Variables, and Estimation Strategy

To test whether extended interruptions affect creativity, we investigated the creative outputs of employees based at the production plants of a European manufacturer of durable consumer goods in the mobility sector. The manufacturer employs more than 50,000 employees globally, runs more than 15 production facilities, and ships more than one million products each year. The production facilities manufacture various product types using dedicated, individual production lines. The production process is organized as serial production and includes manufacturing, assembly, and finishing.

We exploited a natural experiment to address the endogeneity issues involved in exploring the relationships between work interruptions and individuals' creative performance, namely, the stoppage of parts of production owing to adverse events at a supplier's site. This main event (hereafter referred to as plant A, supplier X fire) represents an incidence of our core phenomenon of surprise extended interruptions that lead to employees having idle time.

We also comparatively investigate other extended interruption events, such as another surprise extended interruption with idle time that occurred one year later at the same factory (hereafter plant A, supplier Y fire), an extended interruption in the form of an intrusion (hereafter plant B, flood), and extended interruptions in the form of planned breaks (hereafter plant A, extended weekends and school break).

Our primary output measure for creative performance was the number of suggested ideas, an indicator widely used to measure individual innovative output (Deichmann and van den Ende 2013). Specifically, we used data from the firm's idea submission system, to which employees submit ideas as individuals or as teams, and the organization selects some and rejects others. The idea submission system involves workers submitting a short description of an idea along with their names. They are kept informed of the progress of the idea submission and its evaluation process. Employees can submit ideas from anywhere in the organization (most coming from the production plants and involving process innovations), but notably, ideas cannot be submitted from home.

The ideas submitted to this idea management system can be seen as a form of creative performance because creativity is the production of novel and useful ideas or problem solutions (Amabile et al. 2005). Whether an idea is novel and valuable is decided by the receiving audience (Zhou et al. 2019); in our case study, the audience role was fulfilled by the organization, which decided the extent to which the ideas received were of any value. Nonnovel ideas provide no additional value because they are already known or already exist, and nonuseful ideas offer no additional value because the firm cannot capture value from them. To assess ideas' value, each idea is sent to one or more evaluators, who decide which ideas to implement and which to reject. The evaluators also assign an estimated monetary value to each chosen idea with the idea creators being rewarded with a share of the assessed value.

On average, the organization in question estimated it saved more than €100 million per year (more than $103,204,000) over the past three years thanks to the ideas sent to its idea management system. In these three years, employees submitted approximately 20,000 ideas each year, of which just more than half were implemented. Examples of the ideas submitted and implemented include the design for a new paint ordering system (saving roughly €280,000, ($288,800)), the suggestion to attach an air jet to a laser soldering head of a robot to reduce soldering residue (saving roughly €40,000 ($41,300)), and the proposal to use a special camera to facilitate identification of parts in the injection molding process (saving roughly €21,000 ($21,700)).

On average, each implemented idea submission had a value of roughly €8,500 ($8,800) and was rewarded with roughly €650 ($670). This high mean implementation rate and estimated value show that the idea submissions we studied are, on average, novel and useful. We can then conclude that the ideas we study represent employees' creative performance and a key pathway to creativity in this organization.

Our primary natural experiment (plant A, supplier X fire) focuses on a plant that produces three product models in various production lines (plant A). A midweek fire broke out at one of the firm's suppliers (for a timeline of events, see Figure 1) and caused substantial damage to the supplier's facilities as well as disrupted the supply chain. Consequently, parts needed downstream for manufacturing at plant A could not be produced and delivered. In response to the supply shortage, the firm halted manufacturing on the affected production lines the following Monday with operations resuming after four days.

The natural experiment relies on the fact that the firm produces several product lines and models in each plant. The production process covers many parts of the supply chain, including manufacturing and assembly for most product lines. Product lines are mirrored across

Table 1. Overview of the Research Strategy and the Empirical Tests

Section	Description of analysis	Event	Extended interruption type studied	Sample and analysis	Step in the abductive research process	Findings	Interruption effect
Establishing the effect: Do surprises with idle time affect creative performance?	Main analysis	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before/after the interruption CEM matched 1,985 individuals Individual FE and week FE Poisson specification	Establishing the effect	Interruptions increase idea quantity Submitting employees experiencing the interruption submit 58% more ideas per week	Positive
	Narrower time frame	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before and 2 weeks after the interruption CEM matched 1,812 individuals Individual FE and week FE Poisson specification	Establishing the effect	Interruptions increased the idea quantity Submitting employees who experienced the interruption submitted 60% more ideas per week	Positive
	Narrower time frame	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before and 1 week after the interruption CEM matched 1,650 individuals Individual FE and week FE Poisson specification	Establishing the effect	Interruptions increased the idea quantity Submitting employees who experienced the interruption submitted 76% more ideas per week	Positive
	Unmatched sample	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before/after the interruption Unmatched 3,248 individuals Individual FE and week FE Poisson specification	Establishing the effect	Interruptions increased the idea quantity Submitting employees who experienced the interruption submitted 39% more ideas per week	Positive
	Other plant as comparison group to check for spillover effects	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plants A and B 3 weeks before/after the interruption Comparison group uninterrupted employees in plant B CEM matched 1,625 individuals Individual FE and week FE Poisson specification	Establishing the effect	Interruptions increased the idea quantity Submitting employees who experienced the interruption submitted 52% more ideas per week Speaks against spillover effects of the interruption on uninterrupted employees	Positive

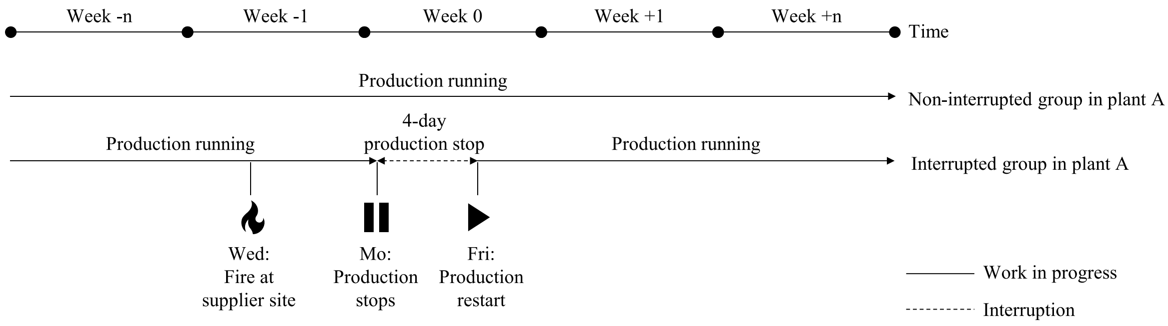
Table 1. (Continued)

Section	Description of analysis	Event	Extended interruption type studied	Sample and analysis	Step in the abductive research process	Findings	Interruption effect
	Extended sample to check whether findings extend to all employees and not just to the idea submitters	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before/after the interruption Unmatched 43,000 individuals Week FE Pooled Poisson specification	Establishing the effect	Interruptions increased the idea quantity Employees who experienced the interruption submitted 58% more ideas per week Our findings extend to all employees and not just idea submitters	Positive
Extending and corroborating the effect: Do surprises with idle time affect creative performance? (plant A, supplier fires)	Different outcome: Idea quality	Fire at supplier X's site Production stopped for four days in some production lines in plant A	Surprising interruption with idle time	DV: Idea quality Plant A 3 weeks before/after the interruption 1,835 ideas Individual RE and week FE Tobit specification	Extending the effect to another dependent variable	Interruptions increased the idea quality Ideas submitted by employees who experienced the disruption were 3 points better on a scale of 0%–100%	Positive
	Replication in a second interruption event of the same type	Fire at supplier Y's site Production stopped for three shifts in some production lines in plant A	Surprising interruption with idle time	DV: Number of ideas Plant A 3 weeks before/after the interruption CEM matched 6 weeks 3,341 individuals Individual FE and week FE Poisson specification	Extending the effect to different sample	Interruptions increased the idea quantity Submitting employees who experienced the interruption submitted 34% more ideas per week	Positive
Expanding to other interruption types: How do intrusions affect creative performance?	Assessing whether we find the same effect if an interruption is unexpected but without idle time (i.e., an intrusion)	Flooding owing to a natural disaster Production stopped for up to one week in plant B, but not in plant A	Intrusion	DV: Number of ideas Plants A and B 3 weeks before/after the interruption CEM matched 6 weeks 2,770 individuals Individual FE and week FE Poisson specification	Evaluating the effect of other interruption types Finding causes and explanations for the effect	Individuals from the plant who experienced the intrusion submitted 19% fewer ideas than the uninterrupted group Intrusions negatively affected creative performance Unexpectedness alone without idle time did not lead to creative performance This insight speaks against cognitive stimulation as the primary explanation for our findings	Negative

Table 1. (Continued)

Section	Description of analysis	Event	Extended interruption type studied	Sample and analysis	Step in the abductive research process	Findings	Interruption effect
Expanding to other interruption types: How do planned breaks affect creative performance?	Assessing whether we find the same effect if an interruption is *expected* with idle time (i.e., a planned break)	Additional days off before or after weekends	Planned break	DV: Number of ideas 10 weeks before/after the interruption Plant A Extended weekends as a predictor for weekly idea submissions 21 weeks 6,795 individuals Individual FE Poisson specification	Evaluating the effect of other interruption types Finding causes and explanations for the effect	The number of consecutive days off before the start of a week did not significantly affect the number of ideas Planned breaks did not significantly affect the number of ideas in some specifications and negatively affected the number of ideas in others Scheduled free time off work did not increase creative performance This insight speaks against recovery or cognitive stimulation as the primary explanation for our findings	No effect
		School break in the state in which plant A is located Week off for some employees in plant A, but not in plant B	Planned break	DV: Number of ideas Plants A and B 3 weeks before/after the interruption CEM matched 6 weeks 4,418 individuals Individual FE and week FE Poisson specification	Evaluating the effect for other interruption types Finding causes and explanations for the effect	Submitting employees from plant A, whose state was on vacation, did not submit significantly more or less ideas after the vacation week than in plant B Planned breaks did not affect creative performance This insight speaks against recovery or cognitive stimulation as the primary explanation for our findings	No effect (partly negative effect)

Figure 1. Timeline of the Main Interruption Event (Plant A, Supplier X Fire)



plants. We exploited the fact that only some production lines were affected by the exogenous shock and not others. The employees working on the affected production lines received paid time off work for the four days that production halted. Importantly, the shock did not mean a loss of means of production at the manufacturer's site. After the supply of the relevant parts was reestablished, production in the affected production lines started again four days later. The data collection happened ex post via the idea management system and was unobtrusive to the employees.

Data. We constructed our sample around the interruption week. To start, we chose a large sampling frame ranging from 10 weeks before the event to 10 weeks after. As we mainly ran fixed effect models estimating within-individual effects, employees without outcome variation (mainly those who did not submit any ideas during this time frame) provided no information for our analysis and were not included.[1] We then aggregated idea submissions to the week level, which gave us a sample of 6,795 individuals observed over 21 weeks for focal plant A. Based on the exogenous interruption event, idea-submitting employees who worked on the production lines affected by the interruption represented the treatment group, and all others made up the control group.

Variables. Our dependent variable is an individual's number of ideas submitted per week. Unless stated otherwise, we excluded from our analysis the week in which the interruption occurred and tallied all ideas submitted in the interruption week and the subsequent week into a combined week. This procedure accommodated the fact that individuals in the interruption groups could not submit ideas during time off from work. Otherwise, we would run the risk of capturing pent-up ideas that may have accumulated over the days employees were off work. Our findings remained the same without this procedure, that is, if we just excluded the week without adding the ideas from the interruption week to the next week. We used two main factors and their interaction as independent variables. The first variable, $interruption_i$, measured whether individual i had experienced an interruption (one) or not (zero). The second variable, $after_t$, is an indicator equal to zero for the weeks before the interruption and one for the weeks after.

Matching. Even if our interruption represents an exogenous shock, the assignment to the interrupted group was not fully at random. For instance, employees in some functions were more likely to be affected by the interruption than others. To improve the balance between the interrupted and uninterrupted groups, we constructed a matched sample between the individuals exposed to the interruption and those who were not. This procedure sought to make the interrupted and uninterrupted groups more comparable concerning prior creative performance and other core variables. Specifically, we matched individuals based on gender, employee type, function, and prior innovative productivity, that is, the number of ideas submitted in the 10 weeks before the interruption.

We used coarsened exact matching (CEM) as the matching algorithm (Iacus et al. 2012) as it is often used for purposes similar to ours (e.g., Kolympiris et al. 2018, Teodoridis et al. 2019, Cornelius et al. 2020). For our study, CEM allowed us to address heterogeneity at the individual employee level and reduce model dependence and bias (Iacus et al. 2012). CEM coarsens each matching variable into discrete bins. Then, based on these coarsened data, units from the interrupted group were exactly matched with matches from the uninterrupted group.

Observations across groups are an exact match if they have the same configuration of coarsened data (i.e., they are in the same strata). Further, CEM prunes any unmatched units; in our study, it pruned 2,874 observations and reduced the sample size from 6,795 individuals (286 in the interrupted group) to 3,921 (286 in the interrupted group). CEM also creates weights to accommodate for any imbalance (Iacus et al. 2012); in our study, in some strata, there were more uninterrupted submitters per strata than interrupted ones. We used these weights in all our analyses that use CEM matching to adjust for different numbers of interrupted and uninterrupted idea submitters that appear in different strata.

To assess the success of our matching, we used the L1 statistic, which ranges from zero to one with smaller values representing more balanced and more successful matching (Iacus et al. 2012). The overall L1 statistic decreased from 0.493 in the unmatched sample to 0.145 in the matched sample. The univariate L1 statistic also reduced for all nominal variables (gender, from 0.008 to < 0.001; employee type, from 0.269 to < 0.001; function, from 0.457 to 0.074; as well as for prior innovative productivity, from 0.085 to 0.058). Based on this successful matching, we used the matched sample for most analyses unless stated otherwise.

Table 2 shows the descriptive data for the unmatched and matched samples. At the mean, submitters suggested 0.123 ideas per week in the unmatched sample (0.130 in the matched sample). Notably, the indicated sample sizes are smaller than the sample size indicated here and also vary in the difference-in-differences (DID) analyses to come. This variation was driven by the fact that our fixed-effects regressions dropped individuals without variance in their outcome. The number of observations depended on the different time frames we used in our study. More observations were dropped if we used a shorter time frame (and, thus, fewer individuals exhibited variation in their submission behaviors), and fewer observations were dropped if we used a longer time frame (and, thus, more individuals exhibited variation in their submission behaviors).

DID Design. To assess the interruptions' effects on subsequent ideation, we used the aforementioned DID estimation technique (Angrist and Pischke 2008), which is a quasi-experimental design that estimates a treatment's causal effect by obtaining a counterfactual (Cunningham 2020). The two-way fixed-effects difference-in-differences design we used is a standard design for causal inference in the context of natural experiments (e.g., Lee 2019, Teodoridis et al. 2019, Watson et al. 2022).

Specifically, we studied an interruption's causal effect by obtaining a counterfactual for the interrupted employees by comparing the preinterruption and postinterruption differences in the number of weekly ideas of interrupted and uninterrupted employees. Conceptually, the number of ideas submitted by the interrupted employees after the interruption needed to be adjusted for a time effect rooted in preinterruption and postinterruption differences; this effect is represented by the differences in the uninterrupted group before and after the interruption. It also needed to be adjusted by a group effect; this effect is represented by the difference between the interrupted and uninterrupted group before the interruption. To isolate our interest's effect, we subtracted the differences in the uninterrupted group before and after the interruption from the differences in the interrupted group before and after the interruption. This remaining difference is the difference-in-differences effect.

Whenever applicable, we used the canonical two-way fixed-effects design and included individual-level and week fixed effects (Angrist and Pischke 2008). A strength of two-way fixed-effect designs is that they remove individual- and time-specific effects. Individual-level fixed effects capture all individual heterogeneity, such as age, tenure, gender, function, personality characteristics, and other time-invariant covariates. Week fixed effects control for fluctuations in idea submission, for example, seasonal effects. However, a drawback of fixed-effects models is that individuals and weeks without outcome variance cannot be used for analysis. Thus, we replicated all conditional fixed-effects regressions with random effects and pooled clustered regressions. As a result, all our findings remained intact.

Our two-way fixed-effects difference-in-differences approach was modeled after the following baseline

Table 2. Descriptives and Correlations for the Unmatched and Matched Samples of the Main Interruption Event (Plant A, Supplier X Fire)

	Variable	*N*	Mean	Standard deviation	Minimum	Maximum	1.	2.	3.
Unmatched sample									
1.	Cumulative ideas submitted 10 weeks before the interruption	6,795	1.430	2.212	0.000	38.000			
2.	Female	6,795	0.111	0.314	0.000	1.000	−0.060		
3.	Interrupted	6,795	0.042	0.201	0.000	1.000	0.005	0.005	
4.	Mean weekly ideas	6,795	0.123	0.155	0.048	2.238	0.833	−0.059	0.026
Matched sample									
1.	Cumulative ideas submitted 10 weeks before the interruption	3,921	1.509	2.140	0.000	22.000			
2.	Female	3,921	0.062	0.241	0.000	1.000	−0.033		
3.	Interrupted	3,921	0.073	0.260	0.000	1.000	−0.004	0.067	
4.	Mean weekly ideas	3,921	0.130	0.149	0.048	1.190	0.821	−0.041	0.023

regression, using worker weeks as the analysis unit:

$$DV_{i,t} = f(\beta * interruption_i * after_t + I_i + \omega_t + \varepsilon_{i,t}),$$

where $DV_{i,t}$ is the number of ideas submitted by submitting employees i in week t. The fixed effects for individuals (I_i) and weeks (ω_t) absorbed the direct effects of individuals and weeks, which is why $interruption_i$ and $after_t$ were not included in the equation as direct effects. β is the coefficient of interest for testing whether there is a significant differential in idea output between submitting employees who have been exposed to the interruption and those who have not. Our primary dependent variable—the number of ideas submitted—is a count variable. Thus, if not stated otherwise, we used Poisson models with clustered errors at the individual level in our analyses. Our findings remain intact under a linear model specification.

Causal inference based on difference-in-differences designs relies on the core assumption that the difference between the treatment and control groups would have been constant over time without the treatment (the parallel trends assumption) (Angrist and Pischke 2008, Cunningham 2020). In our case, the parallel trends assumption means that, prior to the interruption, the number of weekly ideas should be similar for interrupted and uninterrupted submitting employees. To support the parallel trends assumption, we conducted three tests.

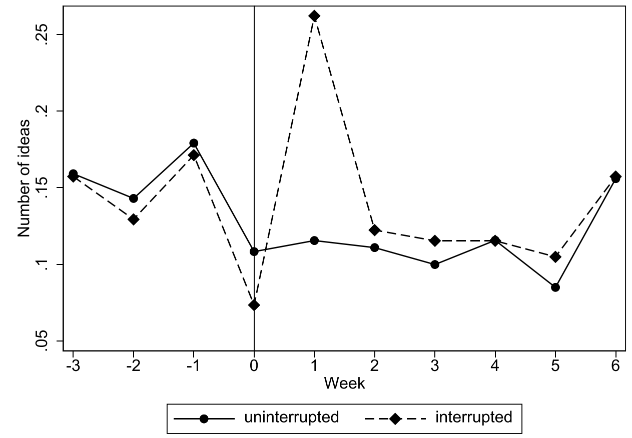
First, by visually inspecting the weekly idea suggestions of submitting employees across all weeks, including the submission week, we saw that the submission numbers by interrupted and uninterrupted submitting employees followed parallel trends before the interruption (see Figure 2).

Second, we show that the time trends are not significantly different for the interrupted and uninterrupted groups before the interruption by investigating the interactions between time and both groups. Significant interaction effects indicate a violation of the parallel trends assumption. However, we did not find any significant differences across both groups in their effect on weekly idea submissions in both a continuous and a dummy specification (baseline: interruption week) of the three weeks before the interruption ($p > 0.10$).

Third, we used a linear event study design to check the pretreatment balance between the interrupted and uninterrupted employees (Cunningham 2020). We compared the interrupted group to the uninterrupted group three weeks before the interruption and six weeks after, using the interruption week as a baseline. The overlapping confidence intervals in Figure 3 indicate that interrupted and uninterrupted employees followed similar paths concerning weekly submissions before the interruption but not afterward.

We also checked our findings' validity using placebo checks (Cunningham 2020) to find out whether our

Figure 2. Model-Free Evidence: The Number of Ideas Submitted per Week (Plant A, Supplier X Fire)

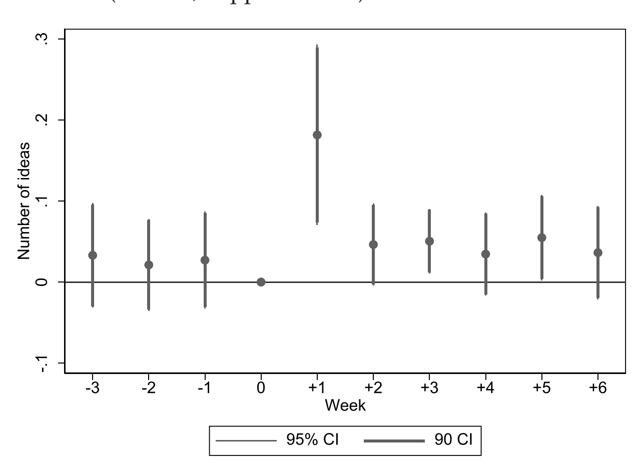


difference-in-differences findings were driven by omitted variables or by the research design. We checked whether we could replicate our results from the next section when being in the interrupted or uninterrupted group was randomly assigned rather than using the actual categorization. We found no significant differences between the two groups in any of the tests we conducted in the next section ($p > 0.10$). Reassuringly, the interruption effect does not exist when it should not exist.

Main Findings (Plant A, Supplier X Fire)

Before presenting the main difference-in-differences analyses, we begin by presenting model-free and explorative evidence on the interruption's effect on idea submissions, including the interruption week and all submitting employees in location A. Figure 2 compares the average weekly idea suggestions of submitting employees across all weeks, including the submission week (i.e., we did not collapse the interruption week and the

Figure 3. Event Study Plot for Surprising Interruption with Idle Time (Plant A, Supplier X Fire)



following week into one). We chose three weeks before the interruption and six weeks after as a time frame for our data exploration. A visual inspection shows that the interrupted group submitted more ideas overall than the uninterrupted group after experiencing the interruption. In the week of the interruption, the interrupted group submitted fewer ideas because they spent less time at work. In the three weeks after the interruption, the interrupted group submitted more ideas than the uninterrupted group. This finding reflects the temporary effect of the interruption, which lasted some three weeks and faded over time.

We now turn to our main analyses to establish whether and how extended unexpected interruptions with idle time affect creative performance. Our findings can be found in Table 3. First, we compared the interrupted group to the uninterrupted group for the six weeks after the interruption, using three weeks before the interruption as a baseline. We estimated whether the interrupted group submitted significantly more ideas for each week after the interruption than the uninterrupted group. We found that the effect was most pronounced and significant in week 1 after the interruption (incidence rate ratio (IRR) = 1.757, $p < 0.01$). In week 2, it became nonsignificant (IRR = 1.274, $p > 0.1$) but reverted to being significant in week 3 (IRR = 1.503, $p < 0.1$). The effect became nonsignificant again after week 3 and remained nonsignificant in the weeks thereafter. These findings align with the explorative analysis and support the interpretation that the interruption's effect lasts no longer than three weeks. We restricted our sample to three weeks before and after the interruption for most of the following analyses to reflect this insight.

Using this time frame, we found that submitting employees who experienced the interruption had 58% more idea output than uninterrupted submitting employees (IRR = 1.576, $p < 0.01$). This is our main finding: extended unexpected interruptions associated with idle time led to higher creative performance in terms of the weekly number of ideas in the three weeks after the interruption. The effect remained stable when we restricted the time after the interruption to two weeks (IRR = 1.595, $p < 0.01$) or one week (IRR = 1.757, $p < 0.01$). We also checked whether our findings hold when we do not rely on our matching approach. We replicated our main findings in the unmatched sample and found that individuals in the interruption group submitted 39% more ideas than those in the uninterrupted group (IRR = 1.386, $p < 0.05$).

In the main analysis, we relied on a within-plant comparison (plant A) to compare interrupted to uninterrupted individuals. However, the interruption could have had unpredictable consequences for employees whose work had not been interrupted, for instance, an increased workload. To determine whether there were any spillover effects of the interruption in plant A, we investigated whether we found the same effect when comparing the submitting individuals who experienced the interruption (plant A) with submitting uninterrupted individuals from plant B. Because no employees in plant B were affected by the interruption, they were all in the comparison group. We relied on the same matching procedures as earlier (prior ideas submitted, gender, and employee type) but left out matching functions because these were not uniform across plants and, therefore, not comparable. Using the same specification from the main analysis, we could replicate our findings: individuals in the interrupted group submitted 52% more ideas per week than those in the uninterrupted group (IRR = 1.517, $p < 0.05$). This insight shows there was no spillover effect of the interruption on employees whose work was not interrupted.

Next, we focus on whether the findings extend to all employees of plant A and not just idea submitters. Owing to our research design in the previous analyses, we focused on submitting employees who were active in the idea management system and excluded employees who submitted no ideas during the periods of interest. This approach is valid for our main analyses because nonsubmitters showed no variance in the outcome and did not supply information for the fixed-effects analyses we used. Nevertheless, it remains relevant to question whether our findings apply to all employees from plant A. Thus, we created a full sample of all employees from plant A, including the information on whether they had experienced an interruption. Because the previous variables we used for matching were unavailable in this data set, we ran our analysis on an unmatched sample of 43,000 employees, of which 8,500 were exposed to the interruption and 34,450 were not. We used the same specification as in the main analysis but dropped the individual fixed effects to retain individuals without variation in the outcome in the analysis (with fixed effects, our results are the same as in the main specification). We kept the clustering at the individual level for pooled Poisson regressions. As expected, our findings remained intact: interrupted employees submitted 39% more ideas than uninterrupted ones (IRR = 1.386, $p < 0.05$).

Extending and Corroborating the Effect: Do Surprises with Idle Time Affect Creative Performance? (Plant A, Supplier Fires)

So far, we have shown that unexpected interruptions associated with idle time lead to the generation of more ideas. We now corroborate and extend this finding by employing idea quality as a different measure of creative performance and replicating our results in a separate sample (cf. Behfar and Okhuysen 2018). These findings are shown in Tables 4 and 5.

First, we checked whether interruptions with idle time in our main event (plant A, supplier X fire) also shaped creative performance concerning idea quality, not just quantity. To this end, we exploited the fact that

Table 3. Establishing the Interruption Effect on Weekly (Plant A, Supplier X Fire)

	Week-by-week specification		Main specification (+3 weeks after interruption)		Narrower time frame (+2 weeks after interruption)		Narrower time frame (+1 week after interruption)		Unmatched specification		Comparison with uninterrupted plant B		All employees	
Interruption event	Plant A, supplier X fire		Plant A, supplier X fire		Plant A, supplier X fire		Plant A, supplier X fire		Plant A, supplier X fire		Plant A, supplier X fire		Plant A, supplier X fire	
Sample	Submitting employees from plant A		Submitting employees from plant A		Submitting employees from plant A		Submitting employees from plant A		Submitting employees from plant A		Submitting employees from plant A and plant B		All employees from plant A	
Interrupted group	Interrupted submitting employees from plant A		Interrupted submitting employees from plant A		Interrupted submitting employees from plant A		Interrupted submitting employees from plant A		Interrupted submitting employees from plant A		Interrupted submitting employees from plant A		Interrupted employees from plant A	
Comparison group	Uninterrupted submitting employees from plant A		Uninterrupted submitting employees from plant A		Uninterrupted submitting employees from plant A		Uninterrupted submitting employees from plant A		Uninterrupted submitting employees from plant A		Uninterrupted submitting employees from plant B		Uninterrupted employees from plant A	
Dependent variable	Number of ideas		Number of ideas		Number of ideas		Number of ideas		Number of ideas		Number of ideas		Number of ideas	
	Coefficient	IRR	Coefficient	IRR	Coefficient	IRR	Coefficient	IRR	Coefficient	IRR	Coefficient	IRR	Coefficient	IRR
+1 week × interrupted	0.563**	1.757**												
		(0.366)												
+2 weeks × interrupted	0.242	1.274												
		(0.307)												
+3 weeks × interrupted	0.407+	1.503+												
		(0.319)												
+4 weeks × interrupted	−0.028	0.972												
		(0.224)												
+5 weeks × interrupted	0.282	1.326												
		(0.338)												
+6 weeks × interrupted	0.112	1.118												
		(0.240)												
After × interrupted			0.449**	1.576**	0.466**	1.595**	0.564**	1.757**	0.326*	1.386*	0.416*	1.517*	0.326*	1.386*
				(0.260)		(0.285)		(0.366)		(0.228)		(0.247)		(0.228)
Number of observations		22,644		11,910		9,060		6,600		19,488		9,750		258,000
Number of individuals		2,516		1,985		1,812		1,650		3,248		1,625		43,000
Number of weeks		9		6		5		4		6		6		6
Chi-square		343,123		252,648		118,414		38,761		269,482		915,611		24,782
p-value		0.000		0.000		0.000		0.000		0.000		0.000		0.000
Log-likelihood		−10,341,225		−6,065,984		−4,978,493		−3,834,515		−9,304,865		−6,853,180		−24,715
Week effects		Fixed		Fixed		Fixed		Fixed		Fixed		Fixed		Fixed
Individual effects		Fixed		Fixed		Fixed		Fixed		Fixed		Fixed		Clustered errors
Matched sample		Yes		Yes		Yes		Yes		No		Yes		No

Note. Clustered standard errors appear in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

organizational evaluators assessed all submitted ideas and assigned a monetary value to each. Thus, we used the ideas' monetary value (normalized by maximum idea value) as a proxy for idea quality with a range from 0 (the idea was rejected) to 100 (the highest monetary value in the sample).

We then analyzed the idea-level quality using the same matching and difference-in-differences approach as earlier. We employed tobit as an estimation technique because the dependent variable has a censored solution at zero. Ideas with a value lower than zero were rejected and, thus, not assessed; that is, the negative value was unobservable to us. The lowest value for selected ideas was zero, which provided the lower bound for the tobit analysis. We used random-effects models with clustered errors for employees because fixed-effects estimates are inconsistent with the tobit model (Greene 2004). To absorb heterogeneity on the individual level, we controlled for the variables used for matching (prior number of ideas submitted, gender, and function). We found that ideas submitted by interrupted workers were significantly more valuable than those submitted by uninterrupted employees ($\beta = 3.006$, $p < 0.05$). That means that everything else being equal, ideas submitted by the interrupted group are three points more valuable on our idea value scale. In short, interrupted individuals submitted not only more ideas but also better quality ones.

Second, we replicated our study on another occasion (plant A, supplier Y fire) to increase our findings' reliability. The goal of such internal replication in the abduction process is to determine whether inferences from one sample may also be drawn when applied to another sample (Bamberger 2019). One year after the events in our main analyses occurred, plant A was again affected by an interruption in the supply chain (see Figure 4 for a timeline of events): a fire at another supplier's site that led to a production stoppage at the plant, which meant that three working shifts were canceled. Again, we argue that this is an exogenous variation that helps us control the endogenous relationship between an interruption and idea production. We relied on the same empirical strategy as our main event concerning sampling frame, data analysis, and matching. This replication showed that interrupted individuals submitted 34% more ideas than the uninterrupted group (IRR = 1.343, $p < 0.05$) in the three weeks after the interruption.

In sum, these analyses show that our findings hold across different measures and contexts, extending and corroborating our findings (Behfar and Okhuysen 2018, Bamberger 2019).

Table 4. Corroborating and Extending the Effect to Different DV (Plant A, Supplier X Fire)

	Extension to other DV: Idea quality
Interruption event	Plant A, supplier X fire
Sample	Submitting employees' ideas from plant A
Interrupted group	Interrupted submitting employees' ideas from plant A
Comparison group	Uninterrupted submitting employees' ideas from plant A
Dependent variable	Idea quality
	Coefficient
After × interrupted	3.006* (1.492)
Number of observations	3,445
Number of individuals	1,835
Number of weeks	6
Chi-square	23,952
p-value	0.0129
Log-likelihood	−2,065,893
Week effects	Fixed
Individual effects	Random
Additional control variables	Yes (coeffficients not shown)
Matched sample	Yes

Note. Clustered standard errors are in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 5. Corroborating and Extending the Effect to Different Sample (Plant A, Supplier Y Fire)

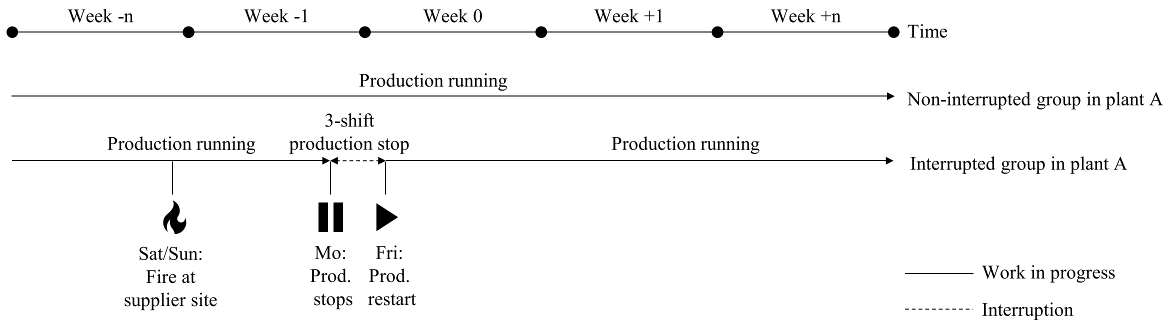
	Extension with alternative interruption event	
Interruption event	Plant A, supplier Y fire	
Sample	Submitting employees' ideas from plant A	
Interrupted group	Interrupted submitting employees from plant A	
Comparison group	Uninterrupted submitting employees from plant A	
Dependent variable	Number of ideas	
	Coefficient	IRR
After × interrupted	0.295*	1.343* (0.198)
Number of observations		20,046
Number of individuals		3,341
Number of weeks		6
Chi-square		910,133
p-value		0.000
Log-likelihood		−11,076,262
Week effects		Fixed
Individual effects		Fixed
Additional control variables		No
Matched sample		Yes

Note. Clustered standard errors are in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Expanding to Other Interruption Types: How Do Intrusions and Planned Breaks Affect Creative Performance?

So far, we have presented evidence that some extended interruptions lead to higher creative performance. We studied particular types of extended interruptions: unexpected interruptions that give employees extended idle time. Conceptually, the types of interruption analyzed

Figure 4. Timeline of the Replication of the Surprising Interruption with Idle Time (Plant A, Supplier Y Fire)



are surprises that represent a deviance from expected progress that causes a pause (Leroy et al. 2020). Very little research has been carried out on surprises with workers' idle time, making it hard to predict the existence and direction of its effect on creative performance. Now that we have found the effect, it is important to establish its cause (Gelman and Imbens 2013, Behfar and Okhuysen 2018, Sætre and Van de Ven 2021). To achieve this, we expanded our abductive inquiry and used additional data to develop a more comprehensive explanation of the phenomenon in scope (Behfar and Okhuysen 2018). Specifically, we compared the extended interruption type studied to date—surprising interruptions with idle time—with intrusions and planned breaks to determine whether we would find the same effect if an interruption is either unexpected without idle time (i.e., an intrusion) or expected with idle time (i.e., a planned break).

Intrusions (Plant B, Flood)

First, we investigated an intrusion's effect on employees' creative performance.

Existing research propounds that an intrusion's effect on employees' creative performance can go two ways (Mochi and Madjar 2018): intrusions can lead to creativity by providing cognitive stimulation in the form of new perspectives on the interrupted task (Dane 2010), but intrusions also have the potential to diminish creativity as incoming demands force individuals to disengage from the primary task (Leroy et al. 2020). This highlights that, whereas intrusions share the element of unexpectedness with surprises, they contrastingly force a worker's full engagement with an interrupting task (Leroy et al. 2020).

To explore intrusions' effects on employees' creative performance, we exploited the occurrence of a natural experiment that interrupted production at one of two manufacturing plants when the downtime after the interruption was filled by an engaging task. This interruption event helped us to study whether intrusions that do not introduce idle time also positively affect employees' creative performance.

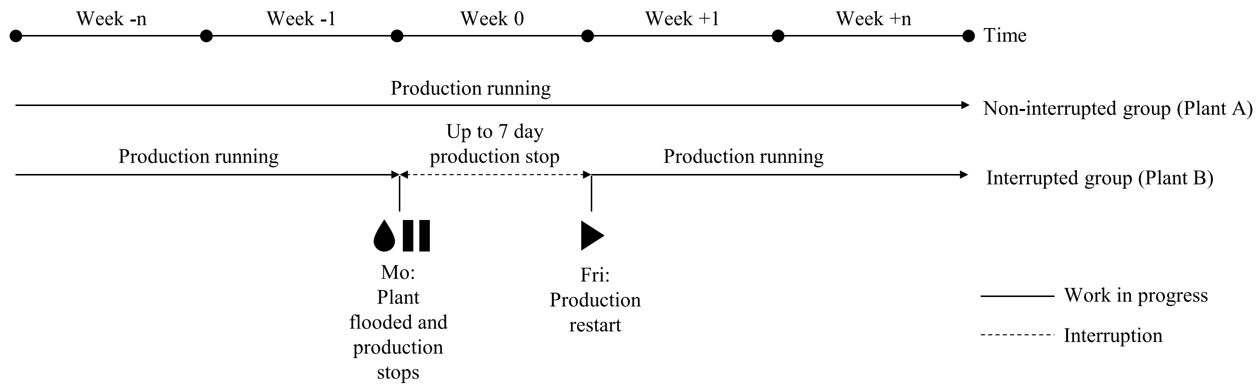
One year before the investigated events in our main analyses, plant B was severely affected by environmental flooding. Heavy rains in the night from Sunday into Monday led to fatalities in the region and many households being swamped by water. Almost all areas of plant B were affected by the flood, and thus, operations ground to a sudden halt. These operational interruptions lasted from a few days to an entire week, depending on the extent of the damage to machinery or building infrastructure, with almost all operations resuming on the Monday of the following week. In the aftermath of this disaster, most employees were either diverted to cleaning up and repairing the facilities or granted paid leave to repair their flooded homes or assist in their community (see Figure 5 for a timeline of events).

Our analysis relied on the same empirical strategy as our main event: investigating the difference-in-differences three weeks before and after the interruption week. As we could not trace which employees had been sent home and which had their work diverted to cleaning and repairing the plant facilities, we decided to compare the entire plant B to the unaffected plant A. We used the same matching procedure as the between-plant comparison from the main findings. We found a significant relationship (see Table 6 for our findings): the workers from the flooded plant B who experienced a major interruption submitted 19% fewer ideas than the uninterrupted group from plant A (matched sample: IRR = 0.810, $p < 0.05$, unmatched sample: IRR = 0.801, $p < 0.05$). Thus, in contrast to surprising interruptions with idle time, extended intrusions negatively affect employees' creative performance.

Planned Breaks (Plant A, Extended Weekends and School Break)

Second, we investigated planned breaks' effects on employees' creative performance. Planned breaks share a similarity with surprise interruptions in that they both introduce nonwork idle time into an employee's daily life—the difference being in the nature of the idle time with planned breaks offering intentional rather than

Figure 5. Timeline of the Intrusion (Plant B, Flood)



unexpected pauses (Leroy et al. 2020). As a means of comparison, we investigated how planned breaks (specifically long weekends and school breaks) affected creative performance to gauge whether this type of interruption, as with surprises with idle time, also positively affected employees' creative performance.

As with intrusions, very little research exists on how planned breaks affect creative performance in interrupted domains. The few laboratory studies that have been conducted show that discretionary breaks can foster creativity (Beeftink et al. 2008), especially if goals related to the interrupted task remain activated (Madjar and Shalley 2008). These studies suggest that planned breaks can induce incubation via receiving new cognitive stimuli during an interruption (Jett and George 2003). Further, planned breaks may also lead to higher creative performance because employees can recover during their free time on planned breaks (Eliav and Miron-Spektor 2015), thereby facilitating creativity (Mochi and Madjar 2018). On the other hand, planned breaks could also reduce creative performance as employees deliberately disengage from work goals (Leroy et al. 2020) and experience less attention residue and less work-related rumination to enable creative performance to take place (de Jonge et al. 2012). For our study, we used two checks to explore the association between planned breaks and employees' creative performance. First, we took our total sample across 21 weeks and exploited the fact that some weeks had extended breaks before they started (e.g., during the Easter break and other holidays). Our sample included long weekends because these additional days were mainly Mondays or Fridays. We then checked each week in the sample for how many consecutive days were free before the week started (weekend days plus Mondays and/or Fridays off), representing the primary independent variable of our mechanism check. We also checked how many working days each week had (regular weekdays minus holiday days) because shorter working weeks, in theory, lead to fewer idea submissions. We then used robust conditional fixed-effects Poisson regression at the week level to check whether consecutive days off before the week affected the number of ideas submitted by the employees (see Table 7). We used the full unmatched sample across all 21 weeks for this estimation. Our results show that the number of consecutive days off before the beginning of each week did not significantly affect the number of ideas submitted (IRR = 1.044, $p > 0.10$), going against the notion of extended planned breaks positively affecting creative performance.

Second, to explore the effects of planned breaks on employees' creative performance, we exploited the fact that, during one week in the academic year, the schools in plant A's region have a holiday but not the schools in the region where plant B is situated. Thus, during this week, plant A's employees are more likely to be on vacation and spending time with their children than those in plant B (for a timeline of events, see Figure 6). We relied on the same empirical strategy as our main

Table 6. Extended Intrusions and Creative Performance (Plant B, Flood)

Interruption event	Plant B, flood	
Sample	Submitting employees from plant A and B	
Interrupted group	Interrupted submitting employees from plant B	
Comparison group	Uninterrupted submitting employees from plant A	
Dependent variable	Number of ideas	
	Coefficient	IRR
After × interrupted	−0.211*	0.810* (0.087)
Number of observations		16,440
Number of individuals		2,740
Number of weeks		6
Chi-square		208.049
p-value		0.000
Log-likelihood		−8,614.276
Week effects		Fixed
Individual effects		Fixed
Matched sample		Yes

Note. Clustered standard errors are in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 7. Extended Planned Breaks and Creative Performance (Plant A, Extended Weekends)

Interruption event	Plant A, extended weekends	
Sample	Submitting employees from plant A	
Dependent variable	Number of ideas	
	Coefficient	IRR
Additional days off per week	−0.439***	0.645*** (−0.028)
Consecutive days off before week	0.043	1.044 (−0.035)
Number of observations		142,695
Number of individuals		6,795
Number of weeks		21
Chi-square		211.607
p-value		0.000
Log-likelihood		−42,523.690
Individual fixed effects		Yes
Matched sample		No

Note. Clustered standard errors are in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

event, investigating the difference-in-differences three weeks before and after the vacation week. Because we could not trace which employees took a vacation and which did not, we compared plant A to plant B, using the same matching procedure as the between-plant comparison in the previous section.

As the findings in Table 8 show, our analysis did not flag any significant positive relationship between extended planned breaks and creativity. The off-work employees from plant A did not submit significantly more ideas after their vacation week than those in plant B, where no school vacations were scheduled. Instead, the effect is significant and negative in the matched sample (IRR = 0.885, $p < 0.1$) but not significant in the unmatched sample (IRR = 0.980, $p > 0.1$). To summarize this section, our results show that, as opposed to surprising interruptions with idle time, extended planned breaks do not increase creative performance and can potentially even be viewed as being detrimental to the creative process.

Deriving Plausible Explanations and Propositions: Surprises with Idle Time, Intrusions, and Planned Breaks

So far, we have established that extended interruptions in the form of surprises with idle time are likely to increase creative performance, whereas intrusions and planned breaks are not. This section explores the underlying mechanisms of each type of interruption to explain why some extended interruptions facilitate creative performance and others do not. As mentioned in previous sections, the mechanisms of cognitive stimulation, recovery, and attention residue are key considerations when offering theoretical explanations for our findings (Sætre and Van de Ven 2021). We now revisit and evaluate these three different mechanisms that could underlie interruption-induced incubation and creative performance in the light of our findings. We then develop tentative propositions to theorize from our findings (Behfar and Okhuysen 2018).

The first postulation to consider is that, during interruptions, a worker's attention shifts to new stimuli, which then leads to updated cognitive structures and new knowledge, thereby fostering creativity (Jett and George 2003, Dane 2010, Mochi and Madjar 2018). If cognitive stimulation is the main pathway to creative performance, we should see a positive effect following all interruptions, including intrusions and planned breaks. After all, both surprises with idle time and intrusions enable employees to receive unexpected cognitive stimulation to trigger creativity. Similarly, expected interruptions, such as planned breaks, should also be associated with cognitive stimulation and positive creative performance because planned time off work may introduce new perspectives and information (Jett and George 2003, Mochi and Madjar 2018). However, our findings show a significant negative relationship between intrusions and creative performance and no significant positive relationship between planned breaks and creative performance. These insights, then, speak against cognitive stimulation as the primary explanation for our findings.

Second, we consider if our findings can be explained by recovery as employees arguably recover mentally and

Figure 6. Timeline of the Planned Break (Plant A, School Break)

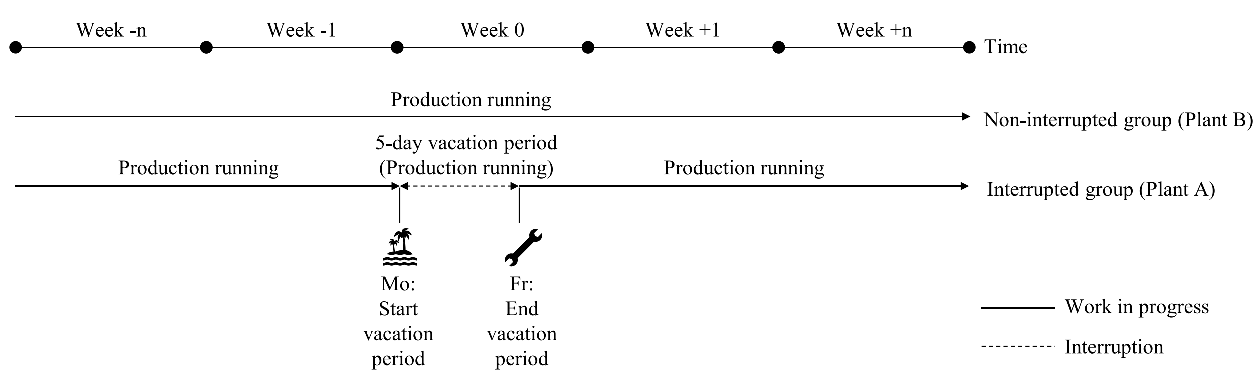


Table 8. Extended Planned Breaks and Creative Performance (Plant A, School Break)

Interruption event	Plant A, school break	
Sample	Submitting employees from plant A and plant B	
Interrupted group	Interrupted submitting employees from plant A	
Comparison group	Uninterrupted submitting employees from plant B	
Dependent variable	Number of ideas	
	Coefficient	IRR
After × interrupted	-0.121^{+}	0.885^{+}
		(0.070)
Number of observations		26,448
Number of individuals		4,408
Number of weeks		6
Chi-square		128.05
p-value		0.000
Log-likelihood		−11,827.057
Week effects		Fixed
Individual effects		Fixed
Matched sample		Yes

Note. Clustered standard errors are in parentheses.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

physically to some extent during an interruption because they have temporarily ceased work (Eliav and Miron-Spektor 2015, Mochi and Madjar 2018). If recovery is the main pathway to creative performance, we should then also see a positive effect of expected extended interruptions, such as planned breaks, which, as with surprise interruptions, are paid time off from a usual work routine. However, as seen in our findings, there is no significant positive relationship uncovered between planned breaks and creative performance. Thus, the concept of recovery is also not a suitable primary explanation for our findings.

Finally, our findings could be explained by attention residue that employees experience during an interruption, that is, thoughts around work that persist during the interruption (Leroy 2009, Leroy and Glomb 2018). We see that surprises with idle time interrupt work but do not lead individuals to disengage from work goals because this type of extended interruption does not introduce additional cognitive demand. Instead, surprise interruptions with idle time allow for continued activation of related goals without the need to focus on other goals, creating the right conditions for idea incubation and creativity. Our main findings align with this theory: when operations stop and interrupt employees, they experience unscheduled idle time that allows their attention to remain on work, inducing idea incubation and creative performance.

If attention residue is the main pathway to creative performance, we should see a negative effect of intrusions on creative performance. Workers experiencing intrusions switch their attention to the goals of the incoming task and, thus, are forced to disengage from the primary task. Cognitive disengagement lowers attention residue during intrusions (Leroy 2009, Leroy and Glomb 2018, Leroy et al. 2020), which then negatively affects a worker's creative performance. As can be seen from our natural experiment on intrusions, the attention residue explanation aligns with our findings: the intrusion caused by flooding forced workers to disengage from their primary task and focus entirely on rebuilding facilities at work or carrying out repair work at home or within their local community. As a consequence, this sudden and extreme shift of focus reduced employees' attention residue on the primary task and, thus, on work-related creative performance. We can apply the same argument to planned breaks: if attention residue is the main pathway to creative performance, planned breaks should also have a negative effect because of the amount of respite they grant employees (Leroy et al. 2020). A planned break is an act of intentional cognitive disengagement from work with the focus shifting entirely to nonwork tasks. This mental (as well as physical) break from the workplace lowers attention residue (Leroy 2009, Leroy and Glomb 2018, Leroy et al. 2020), which, in turn, results in decreased work-related creative performance. Again, our findings on planned breaks agree with this line of argument: workers on vacation were shown to be disengaged from the primary task in order to focus on leisure activities, reducing their attention residue on the work and negatively (or at least not positively) affecting their work-related creative performance.[2]

To summarize, our results show that interruptions affect creative performance differently depending on what happens during an interruption: Higher attention residue during an interruption leads to higher creative performance. This insight abductively yields theoretical predictions of when and why extended interruptions create creative performance, relying on attention residue as a plausible explanation.

First, surprises with idle time create attention residue among workers during the period of interruption. This type of interruption evidently allows for a persistence of cognitive activity about work as well as the continued activation of work goals, which, in turn, enables idea incubation and creative performance. Therefore, our baseline proposition is the following.

Proposition 1. *Extended surprises with idle time increase employees' creative performance, allowing for attention residue during the interruption.*

In contrast, our studies reveal that attention residue and interruption-induced creativity are lower for intrusions as this type of interruption compels workers to focus on the incoming task and related goals. Therefore, our second proposition is the following.

Proposition 2. *Extended intrusions decrease employees' creative performance, in contrast to extended surprises with idle time, because employees' attention switches to the interrupting task and reduces attention residue during the interruption.*

Finally, individuals readily disengage from work during planned breaks and focus on nonwork goals during this type of interruption; this negatively affects attention residue and interruption-induced incubation regarding work-related creativity. Therefore, our third proposition is the following.

Proposition 3. *Extended planned breaks decrease employees' creative performance, in contrast to extended surprises with idle time, because work disengagement reduces attention residue during the interruption.*

Discussion and Conclusions

Interruptions are common in organizational life and range in duration from seconds to hours, days, or weeks. We have investigated how extended interruptions affect employees' creative performance. We set out by focusing on unexpected interruptions that provide employees with idle time (i.e., surprises) and exploring their effects on creative performance. We exploited a natural experiment in which a fire at a supplier's site interrupted the firm's work processes and caused some employees to stop work for a few days. We found the same picture across all our analyses: employees who had time off because of an unexpected interruption submitted significantly more ideas than the uninterrupted group—the former group submitting 58% more ideas than the latter group in the three weeks after the interruption.

We then analyzed whether we also encounter this result for other interruption types: unexpected interruptions without idle time (i.e., intrusions) or expected interruptions with idle time (i.e., planned breaks). We found that these interruption types had an adverse effect on creative performance: there was a negative effect for intrusions and no effect for planned breaks (specifically, the planned breaks' effect was negative in some specifications and not significant in others).

After considering and evaluating different theoretical explanations, we can abduct attention residue as the most likely explanation for our findings. Therefore, we propose that extended surprises with idle time increase employees' creative performance because these types of interruptions allow for attention residue during the interruption. Compared with extended surprises with idle time, the creative performance effect resulting from planned breaks and intrusions was not positive because both interruption types led to a reduction of attention residue. This is because planned breaks enable employees to discretionarily disengage from work to focus on nonwork and leisure goals. During intrusions, employees are compelled to disengage from their work, switch their attention to the interrupting task, and focus on other work goals.

Theoretical Implications

Our paper contributes to the literature on interruptions and creativity for the primary reason that we are able to abduct that surprise interruptions with idle time positively affect employees' creative performance. There is very little research into the relationships between surprising interruptions with idle time and creative performance, in part because such events are rare (Christianson et al. 2009). Yet, if such interruptions happen, they are greatly concerning to firms because the risk of major productivity loss is high. However, we are able to offer empirical evidence to show that these surprise interruptions with idle time have an upside in the form of more and better ideas, contributing to the notion of the "bright side of interruptions" (Puranik et al. 2020).

Further, our insights align with research into how surprise interruptions foster idea incubation and creativity (Mochi and Madjar 2018, Leroy et al. 2020). Interestingly, our findings suggest that it is not the state of alertness following the unexpectedness of the interruption that causes the creativity because we did not find a creativity-enhancing effect for unexpected intrusions. Instead, we suggest that creative performance during an interruption is a consequence of attention residue: employees remain engaged with the work task and associated goals, which leads to information processing and ruminations about work.

It should be noted that our study focuses on a specific type of surprise interruption: one that introduces idle time for employees owing to an adverse event in the supply chain. Whereas not within the scope of this paper, this insight raises the question of whether we would find the same effect for surprises that do not result in down time for workers. Interruptions always break expectations but are not necessarily based on negative events that cause pauses (Leroy et al. 2020). Considering the positives of surprise interruptions, this type of interruption could also represent a positive deviance from expectations that leads to accelerated work processes. For instance, a sudden demand shock results in an unexpected increase in orders and consequently requires production to speed up significantly. When work is interrupted by this type of sudden break in expectations, workers are starved of time rather than granted idle time, and thus, we would not expect an increase in creative performance (Baer and Oldham 2006, Elsbach and Hargadon 2006, Baird et al. 2012, Mochi and Madjar 2018). In such cases, idea incubation is blocked because workers need to continue to tend to the primary task instead of setting it aside.

Second, we have empirical evidence to show that extended interruptions in the form of surprises with idle time increase creative performance, whereas intrusions and planned breaks do not. The contribution to the literature here lies in investigating the differential effects of interruptions. Our findings are consistent with the view that not all interruptions affect creative performance in the same way (Mochi and Madjar 2018, Leroy et al. 2020). They allow us to speak to the conditions under which interruptions are conducive to creative performance or not (Leroy et al. 2020, Puranik et al. 2020): interruptions' creative performance benefits are conditional on employees' attention residue retained on an interrupted task. Thus, the type of interruption that enables a worker to remain engaged with a disrupted primary task leads to attention residue and, in turn, a positive creative performance. In contrast, interruptions that engender disengagement from a primary task are detrimental to thinking creatively. Regarding intrusions, workers are compelled to disengage from the task to attend to the more pressing interrupting task, which introduces different work goals and, thus, reduces creativity. This insight aligns with research that describes interruption tasks as being too cognitively engaging (Elsbach and Hargadon 2006, Sio and Ormerod 2009) and, therefore, having a detrimental effect or no impact at all on workers' creative performance. For planned breaks, a worker's disengagement from the task happens discretionarily owing to nonwork goals becoming active, which, as our results show, does not foster idea incubation in the work domain. This insight aligns with studies showing that interruptions filled with activities too remote from the interrupted task's domain (Madjar et al. 2019) can negatively affect or have no effect on creative performance. At first sight, our findings might be at odds with the notion that interruptions are most conducive to creativity if they incorporate a low-demand task instead of no task (Sio and Ormerod 2009, Baird et al. 2012): we present empirical evidence to show that time off work only results in creativity if it is genuinely idle—as with unexpected interruptions—but not if it is anticipated leisure time filled with prescheduled activities. However, most existing studies are laboratory studies, in which resting means "to sit quietly during the incubation interval" (Baird et al. 2012, p. 1118). We show what happens in a real-life situation; employees exposed to idle time after a surprise are not sitting quietly. Instead, they leave work and engage in a leisure activity. Thus, surprising interruptions with idle time likely involve stopping the primary task and engaging in some undemanding leisure activity as thoughts continue to process work-related information—an optimal condition for idea incubation to happen (Sio and Ormerod 2009, Mochi and Madjar 2018).

Third, we contribute to the literature by putting forward attention residue as the likely source of positive effects on creative performance. Attention residue—"thoughts about one task persist[ing] while performing another" (Leroy and Glomb 2018, p. 380)—is linked mainly to negative outcomes in noncreative tasks owing to its cognitive costs (Leroy 2009, Leroy and Glomb 2018, Leroy et al. 2020). It causes lower performance on an interrupting task because individuals do not fully transition their attention from the interrupted task (Leroy and Glomb 2018). Attention residue also negatively affects the interrupted task upon transitioning back from the interrupting task (Leroy 2009). We contribute to the literature on attention residue by considering the flipside: the positive function of attention residue on creativity regarding the interrupted task. Our findings suggest that attention residue is a process that likely underlies incubation-induced creativity during the period following the interruption. When workers (forcefully or discretionarily) disengage from the primary task, they experience lower attention residue, focusing most of their attention on other work-related or nonwork goals. Those who do not disengage from the interrupted task experience higher attention residue because their attention remains on the interrupted task, thoughts about work content persist, and work-related goals remain activated, facilitating creativity. Therefore, the cognitive cost of having persisting thoughts about the interrupted task after being interrupted can be seen as beneficial concerning creativity.

As an aside, we also contribute to research that links time with individual innovative performance. Studies show that additional availability of time affects individuals' performance in the implementation stage of the innovation process by reducing the opportunity cost of time (Agrawal et al. 2018): with extra time, contingent on having an idea, individuals pursue projects with a lower initial idea value and put more effort into these. We show that the unexpected provision of unscheduled idle time affects individuals' creative performance at the idea-generation stage of the innovation process because the disrupted task remains active in their cognition. Therefore, increased time availability has different implications for different stages of the innovation process, leading to more and better ideas in the early stages and greater implementation effort in the later stages.

Finally, our work represents an example of the growing amount of exploratory quantitative work that uses an abductive lens to find the causes of an observed effect (e.g., Hallen et al. 2020, Conti and Roche 2021, Sorenson et al. 2021). This type of research differs from traditional hypothetico-deductive quantitative research, which starts with theory-driven hypotheses and tests them, producing validated knowledge claims about the effects of causes (Mantere and Ketokivi 2013, Behfar and Okhuysen 2018, Sætre and Van de Ven 2021). In contrast, exploratory quantitative research begins with an empirical puzzle or poorly understood phenomenon and moves on to generating hunches about possible explanations underlying a phenomenon. These different explanations are evaluated and tested by researchers until they converge on a plausible theoretical explanation.

In our paper, we followed the abductive process to establish the positive effect of extended surprise interruptions on creative performance, putting forward hunches as a means of explanation: specifically, attention residue, cognitive stimulation, and recovery. We then evaluated the three potential mechanisms within the context of different extended interruptions with the patterns we discovered pointing to attention residue as the most plausible explanation for the underlying phenomenon. Note that, next to the type of exploratory quantitative work leading up to theoretical propositions presented in this paper, abductive work can also take other forms, such as taxonomy development, measurement design, replication studies, or meta-analyses (Bamberger and Ang 2016).

The benefits of exploratory quantitative work for organizational scholars are rooted in relying on abduction as a mode of reasoning. Abductive reasoning moves from data to a theory that would make the observed phenomenon plausible and "assigns primacy to the empirical world, but in the service of theorizing" (Van Maanen et al. 2007, p. 1149). Relying on abductive reasoning can lead organizational researchers to garner useful and valuable insights that cannot be obtained with induction or deduction methods. By putting empirical data first, abduction lets organizational researchers explore novel discoveries and establish them as phenomena (van de Ven et al. 2015, Bamberger and Ang 2016). Further, by enabling the development and evaluation of explanations for observed phenomena, abduction is the mode of reasoning by which we can develop a new theory about emerging phenomena (Mantere and Ketokivi 2013, van de Ven et al. 2015). Finally, as the abductive research process starts with an anomaly or unexplained issue, it helps to engage with and solve meaningful problems and challenges (Van Maanen et al. 2007, Kistruck and Slade Shantz 2022).

On the downside, quantitative exploratory work using an abductive lens produces narrower and weaker knowledge claims than work relying on induction and deduction as reasoning modes (Sætre and Van de Ven 2021). First, the explanations based on abductive reasoning are not universally valid theories (Behfar and Okhuysen 2018), but rather provide explanations for the context in which the phenomenon is observed (Ketokivi and Mantere 2010). Second, abduction relies on the researcher and not on pure logic to infer the explanation of a phenomenon (Ketokivi and Mantere 2010, Mantere and Ketokivi 2013). Abductively generated theory should, thus, be interpreted as tentative or conjectural knowledge claims that must be subjected to further testing and scrutiny (Mantere and Ketokivi 2013). Instead of validity, plausibility becomes the criterion to judge the theory emerging from abductive research (Behfar and Okhuysen 2018, Sætre and Van de Ven 2021). These disclaimers of how to understand the results that come from exploratory quantitative work that uses an abductive lens also apply to our findings.

Managerial Implications

It should be evident from our findings that our ideas have important implications for managers. When workflows are interrupted, much managerial attention naturally goes into removing the interruption sources and getting operations up and running again as quickly as possible. Our study shows that, in addition, managers should pay attention to the fact that ideas and creativity are especially likely to flow in times of interruption. Firms could harness this insight by increasing incentives for ideas during interruptions to encourage employees to use their free time to think about improving work processes.

Further, managers should ensure that employees can easily access idea management systems from their homes or should convene employees for creativity workshops after an interruption has ended. There is, then, a more radical strategy in place to harness the power of surprise interruptions, for example, giving employees impromptu days off (Cutter 2020, Sandler 2021). Even if the primary purpose of this method is to prevent staff burnout, our findings suggest that such measures are also beneficial to creativity.

Limitations and Future Research

Despite the value of our study to the current literature on interruptions and creative performance, we should acknowledge that it has limitations. First, even if we abduct attention residue as the tentative explanation for our findings, we are unable to ultimately show that the proposed mechanism is the one through which interruptions affect creative productivity. Future research could investigate which process links interruptions and innovations by using experimental designs (Shin and Grant 2021).

Second, as noted in the discussion, we primarily studied one specific type of surprising interruption: one that equips employees with idle time. Future research could test whether findings differ for surprise interruptions that speed up work processes instead.

Third, we focus on whether interruptions lead to creativity in the domain of the interrupted task as we measure creative performance in the work setting. We did not investigate the outcomes for the interrupting domain; for instance, the fact that attention residue keeps employee cognition focused on work may harm creativity in the leisure domain (Agrawal et al. 2018) or lead to a work–home conflict (Harrison and Wagner 2016). Future research could investigate such outcomes.

Fourth, our comparison does not allow us to directly test the effects of surprising interruptions versus planned breaks versus intrusions because we only compared each interruption type's effect against uninterrupted work. Whereas designs similar to ours are common in interruption research (Pendem et al. 2022), future research could address this point.

To conclude, this paper shows that surprise interruptions leading to employee idle time have a large and significant positive effect on employees' creative performance because they allow for attention residue during the interruption period. In contrast, planned breaks and intrusions do not facilitate and may even hinder creative performance.

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Endnotes

[1] We check whether our findings are robust to including all employees in our sample later in this paper.

[2] We find a significant negative effect in some specifications and a nonsignificant effect in others.

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