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RESEARCH PAPER

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Theorizing the Multilevel Effects of Interruptions and the Role of Communication Technology

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Abstract

Our understanding of how interrupting the work of an individual affects group outcomes and the role of communication technologies (CT) in shaping these effects is limited. Drawing upon coordination theory and the literatures on computer-mediated communication and interruptions, this paper develops a multilevel theory of work interruptions. It suggests that interruptions that target individuals can also affect other group members through various ripple effects and a cross-level direct effect. We also discuss how the usage of five CT capabilities during interruption episodes can moderate the impact of interruptions at the individual and group levels. Our theoretical model draws attention to the importance of examining the individual-to-group processes to better understand the impact of interruptions in group environments. Additionally, by accounting for the role of the use of CT capabilities during interruption episodes, our work contributes to both the interruptions literature, which dedicates scant attention to the interrupting media, and to IS research on media use and media effects.

Keywords: Coordination, Team Behaviors, Theory Paper, Communication Technology, Interruptions, Ripple Effect, Group Performance, Multilevel Research

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1 Introduction

Interruptions at work and their effects on performance have been studied for a long time. Research shows that individuals are interrupted every ten minutes or less (Mark, Gudith, & Klocke, 2008; O'Conaill & Frohlich, 1995), that these interruptions have important effects on task performance (Addas & Pinsonneault, 2015; McFarlane, 2002; Monk, Trafton, & Boehm-Davis, 2008), and that more than a quarter of the interrupted tasks are not resumed (Dabbish, Mark, & González, 2011; O'Conaill & Frohlich, 1995). Increasingly, these work interruptions are triggered by communication technologies (CT), such as email, texting, instant messaging, video conferencing, and social media (Cameron & Webster, 2013; Galluch, Grover, & Thatcher, 2015; Gupta, Li, & Sharda, 2013). For example, CT-mediated work interruptions occur at an average rate of four interruptions per hour (Iqbal & Horvitz, 2007), with most of them being responded to almost immediately (Iqbal & Horvitz, 2007; Marulanda-Carter & Jackson, 2012).

Research on the impact of work interruptions has been conducted at the individual level and, to a lesser extent, at the group level. Individual-level studies report mostly negative effects of interruptions on cognitive workload, time pressure (e.g., Adamczyk & Bailey, 2004; Mark et al., 2008), time delays (e.g., McFarlane, 2002), and task-related errors (Basoglu, Fuller, & Sweeney, 2009; Gupta et al., 2013). Group-level studies show that interruptions affect group processes and outcomes, and especially group coordination and performance. That research stream links interruptions to high cognitive costs (Jessup & Connolly, 1993; Perlow, 1999), disruptions to group workflow and efficiency (Perlow, 1999; Zellmer-Bruhn, 2003), excessive coordination overhead (Hazlehurst, 2003), and coordination problems and breakdowns (Ren, Kiesler, & Fussell, 2008). There is also evidence suggesting that interruptions enable group members to communicate intensely and engage in group problem solving to resolve task-related issues (Jessup & Connolly, 1993; Zellmer-Bruhn, 2003).

While each research stream has provided significant insights, the two streams have developed relatively independently. As a result, we have gained knowledge of the consequences of individual interruptions on individual outcomes, and the consequences of group interruptions on group outcomes, but we have a limited understanding of *how* the effects of interruptions that originate at the individual level ripple out to groups and what the consequences are for such groups. This represents the first knowledge gap we address. During interruption episodes, the actions of an interrupted individual may have implications for other group members. For example, in 2011, a patient undergoing heart surgery died after her anesthesiologist had been constantly interrupted on his iPad. The anesthesiologist failed to detect and report the patient's low blood oxygen levels in time to the operating surgeon, who was unable to save the patient's life (Dossey, 2014).

Opening the individual-to-group black box and addressing this gap is therefore important. Examining the mechanisms through which individual-level interruptions affect groups advances our knowledge of how work interruptions ripple out in groups and allows us to understand the real and full impact of interruptions happening at the individual level. The present study can open an important stream of future research and provides strong theoretical foundations for such research. Our work also enables us to better guide managers on how to handle the processes by which the effects of interruptions ripple out, and to limit the detrimental impact on groups.

A second gap in both streams of literature is that the role of CT in shaping the effects of work interruptions is not well understood. While many of the interruptions examined in the extant literature have been mediated by CT, the role of CT is usually considered only insofar as it triggers the initial interruption (Cameron & Webster, 2013; Galluch et al., 2015; Gupta et al., 2013). However, CT can also play an important role *after* the interruption has been triggered, whether by CT or other media, and that role is largely overlooked. Specifically, individuals working in group contexts can use different capabilities of CT (e.g., email's capability to communicate in parallel) to respond to interruptions in at least three ways. First, one can use CT to address the interruptions' demands (e.g., for an interrupting email that requests information, one could send the requested information to all group members simultaneously). Second, one can also use CT capabilities to communicate one's reaction to the interruptions to others (e.g., expressing distress). Third, one can use such capabilities (e.g., parallel communication) to manage the consequences of interruptions (e.g., discussing with the others how to [re]organize the work that was interrupted). Usage of the CT capabilities to perform these multiple activities can have an impact at the individual level (e.g., increasing cognitive load), the individual-to-group processes (e.g., facilitating the spread of cognitive load to other members), and the group level (e.g., hindering information integration). Hence, examining the use of technology capabilities during interruption episodes can help explain the multilevel effects of work interruptions and can provide practitioners with insights on what media capabilities are the best or worst to use during such episodes. More broadly, our work contributes to understanding the multilevel relationships between technology use and organizational processes.

To address these knowledge gaps, we develop a conceptual multilevel model of interruptions that considers the nature of the interruption content (i.e., two types of interruptions: congruent and incongruent), as well as the usage of five CT capabilities during interruption episodes (rehearsing, reprocessing, communicating in parallel, using rich symbol sets, and communicating rapidly).[1] Drawing on coordination theory (Crowston, 1997; Malone & Crowston, 1994) and the computer-mediated communication (CMC) literature, our model explains how interruptions targeted at individuals influence group coordination and outcomes through group members' actions during interruption episodes. To better capture the mechanisms through which individual-level interruptions affect groups, the present paper shifts the prevalent view of interruptions as one-time isolated events that affect a specific activity of individuals or groups to one that examines interruption episodes extending over time and during which group members interact and shape the effects of the interruptions. In sum, our work provides novel insights on a phenomenon that is important for theoretical and practical reasons (Weber, 2012).

[1] Rather than focusing on the physical attributes or capabilities of the media (i.e., the potential structures embedded in the technology), we focus on the actual usage of these capabilities. In Section 3, we conceptualize the use of five key CT capabilities.

In Section 2, we offer conceptual definitions and synthesize the literature on work interruptions. We indicate that interruptions create four individual-level constraints. We also identify the coordination problems and mechanisms elicited by interruptions in group settings and highlight gaps in our knowledge of how interruptions ripple out to groups and the role of CT in that process. In Section 3, we build a theoretical model of the multilevel effects of interruptions and theorize the role of CT capabilities used during interruption episodes. In Section 4, we discuss the model, its theoretical and practical implications, and areas for future research. Section 5 concludes the paper.

2 Work Interruptions in Individual and Group Settings

Before synthesizing the literature, we define the relevant concepts that we use (see Appendix A for a summary). Work interruptions are temporary suspensions of an individual's primary task activities in order to process information that is delivered by different media, including face-to-face (F2F), telephone, and communication technologies (CT) such as email, texting, instant messaging, video conferencing, and social media. Because we are interested in what happens *after* the onset of interruptions (i.e., their ripple effects and the use of CT to respond to interruptions), we do not differentiate between the media that initially interrupted the individual (F2F, telephone, or CT). Furthermore, in a group setting, the primary activities of an individual are the main tasks that he or she performs to contribute to a group's production function (McGrath, 1991).[2] Processing information consumes cognitive attention and typically includes viewing or listening to one or more messages or conversations, replying, and/or executing actions that were called for by the message(s) or conversation(s). Interruptions can originate from within or outside the group.

Rather than focusing on single interrupting events or messages, we focus on interruption episodes that individuals are exposed to over the course of their group work. During an interruption episode, individuals may process an interrupting message or conversation entirely or partially (e.g., by skimming it), process it multiple times (e.g., first by replying, then by executing actions called for in the message), or process several messages or conversations (including other messages that did not necessarily trigger the episode). We assume that during interruption episodes, an individual can use CT to respond to interruptions by engaging in three types of communication activities with other group members: (1) directly respond to the interruptions' demands, such as by replying or doing specific actions called for in the interrupting message(s) or conversation(s); (2) communicate one's reactions to the interruptions, such as by expressing emotional distress or alerting others that one is falling behind because of the interruptions; or (3) manage the consequences of the interruptions, such as by discussing with others how to continue or rearrange the work that was interrupted. Thus, interruption episodes include not only the immediate discrete interruption events but also their aftereffects.

We distinguish between two types of work interruptions based on the relevance of information contained in the interrupting messages or conversations (Addas & Pinsonneault, 2018; Cutrell, Czerwinski, & Horvitz, 2000; Mark et al., 2008). *Incongruent interruptions* (IINT) provide or request information or actions that are not relevant for primary activities. They may relate to secondary work activities (e.g., message from a coworker requesting help with a work-related issue) or activities that are unrelated to work (e.g., a message regarding a social event). While not relevant for primary tasks, IINT are not necessarily unimportant for work. For example, for a salesperson whose primary activities constitute new sales generation, an email requesting information to invoice a customer for a previously delivered service is an incongruent interruption. This interruption is not directly relevant for generating new sales and may disrupt the effective performance of these tasks, yet it might still be part of the work the salesperson is expected to do.

By contrast, *congruent interruptions* (CINT) provide task-pertinent information, reveal discrepancies in task processes or outcomes, or request actions that are relevant to performing primary task activities. These interruptions often motivate behavioral changes and adjustments (Addas & Pinsonneault, 2018; Jett & George, 2003). Of note, our conceptualization excludes messages or conversations that are relevant

[2] Our conceptualization of primary activities differs from prior research in two ways. First, past studies have primarily treated interruptions as discrete events that disrupt an individual's focal task (i.e., whatever he or she was working on at the moment of interruption). In contrast, we study interruption episodes that extend over time and span multiple activities. Hence, we do not focus on an immediate task being interrupted but rather, on how individuals are exposed to interruption episodes over the course of conducting their work (i.e., their set of primary activities). Second, unlike past research at the individual-level, primary activities for us include the activities of an individual only insofar as they feed into the group's tasks (i.e., they exclude the job activities of that individual that are unrelated to the group's objectives).

to primary tasks but have no bearing on performing those tasks (e.g., an email that confirms a meeting regarding task-related issues). In other words, we focus on interruptions for which task-related problems might be solved (e.g., clarifying user requirements in a software development project) or decisions made (e.g., prioritizing user requirements). CINT may not be consistent with the specific task an individual is doing at the moment of interruption, yet they are relevant or complementary to primary task activities in general, and, by extension—if the focus is on group settings—relevant to the group's production function.

2.1 Work Interruptions and Individuals

Our literature review includes studies conducted at both the individual and the group levels. We searched two major databases (ABI/Proquest; Web of Science), Google Scholar (which searches the full text of articles), and a specialized database on interruptions (http://interruptions.net/literature.htm). We used the following keywords for the search: ("information technology" OR "communication technology" OR work) AND (interruptions) AND (group OR team)[3] AND (performance OR impact). Following the initial search, we scrutinized the abstract and/or the content of each article to confirm that the presence of the keywords was not cursory and that the main research objectives involved examining the effects of work interruptions in the appropriate context (individual or group). We also found additional studies that cited or were cited by the identified articles.

Our final set comprises studies with a diverse range of interruption media including F2F, telephone, CT, and interruptions triggered by pop-up messages appearing on computer screens. We did not find qualitatively different effects of interruptions generated through different media, although the magnitude of the effects sometimes differed. For example, Nees and Fortna (2015) find that compared to F2F interruptions, computer-generated interruptions have longer interruption lags and resumption lags. Below, we first synthesize the findings from the individual-level studies and then follow up with a discussion of the group-level studies.

The literature on work interruptions in individual settings considers IINT and CINT (albeit most studies focus on one or the other and do not explicitly examine the effect of interruption type) and various interruption media and information flows. Most studies examine unidirectional information flows, such as pop-up messages appearing on computer screens that impose unrelated tasks (i.e., IINT) (Adamczyk & Bailey, 2004; McFarlane, 2002). Others examine unidirectional messages that provide task-relevant information (i.e., CINT), such as feedback, to individuals (e.g., Addas & Pinsonneault, 2018; Ang, Cummings, Straub, & Earley, 1993; Szalma, Hancock, Dember, & Warm, 2006). Another set of studies focuses on interruptions providing bidirectional information flows, both synchronous (F2F: Baethge & Rigotto, 2013; instant messaging: Gupta et al., 2013) and asynchronous (email: Addas & Pinsonneault, 2018; Iqbal & Horvitz, 2007).

Work interruptions (both IINT and CINT) have been found to create cognitive stress constraints (time pressure and cognitive workload) and performance-based constraints (time delays and output errors) on individuals. The first constraint is *time pressure,* which is defined as an individual's perception that there is a scarcity of time available to complete one or more tasks relative to the demands of the task(s) at hand (e.g., Baethge & Rigotti, 2013; Mark et al., 2008). The evidence indicates that time pressure increases with greater exposure to interruptions (Mark et al., 2008) and one study quantifies this increase at 55% (Adamczyk & Bailey, 2004). Time pressure increases because interruptions create additional work that needs to be performed within a given time period and incur switching costs and delays in resuming primary activities (e.g., Iqbal & Horvitz, 2007; Marulanda-Carter & Jackson, 2012). Studies also show that individuals who suspend their primary tasks to handle interruptions continue to think about their unfinished activities (i.e., attention residue) (cf. Leroy, 2009) and thus feel increasing pressures to finalize these activities in time.

A second constraint created by work interruptions is *cognitive workload* (Baethge & Rigotti, 2013; Basoglu et al., 2009; Galluch et al., 2015; Gupta et al., 2013). While IINT may have a stronger effect, given that they require juggling attention between different cognitive spheres (Galluch et al., 2015), the evidence shows that CINT also increase cognitive workload (Addas & Pinsonneault, 2018; Mark et al., 2008; Szalma, Hancock, Dember, & Warm, 2006). This effect has been attributed to the fact that interruptions require allocating and sharing attentional resources between primary activities and interruption activities, creating situations in which attentional demands exceed capacity (Bowers, Braun, & Morgan, 1997). Resources are also exhausted because interruptions impinge on the original demands of the primary activities, which require constant activation, suppression, and reactivation of cues in one's working memory (Iqbal & Horvitz, 2007).

IINT also create *time delays*. These interruptions introduce secondary tasks that divert time and attention from primary activities (Iqbal & Horvitz, 2007) and they also incur switching costs (i.e., the time it takes to orient oneself back to the interrupted

[3] We omitted this phrase when we searched for studies in individual settings.

tasks upon resumption). Such reorientation time has varied between one minute (Marulanda-Carter & Jackson, 2012) and 16 minutes (Iqbal & Horvitz, 2007) per interruption, which adds up over the course of the work. Interrupting messages also trigger a "chain of diversions," where individuals do not just process the interrupting message but also other messages or tasks before resuming their primary activities (Iqbal & Horvitz, 2007). Repeated exposure to IINT also increases task completion time, another measure of task performance efficiency that reflects the time it takes to complete primary activities once they are resumed (e.g., Gupta et al., 2013; McFarlane, 2002). On the contrary, CINT have limited effects on resumption time (Cutrell et al., 2000) and no effects on task performance efficiency (Szalma et al., 2006).

Finally, IINT increase the *output errors* in primary tasks, both in terms of final outcomes (e.g., wrong decisions) and intermediate outputs (e.g., erroneous information; inaccurate reports). IINT are linked to increases in error rates (e.g., Basoglu et al., 2009; Gupta et al., 2013; McFarlane, 2002) and decreases in decision accuracy (e.g., Arroyo & Selker, 2003). Studies suggest that errors increase because individuals often react to IINT by economizing cognitive effort in their primary activities, such as by skipping steps or taking shortcuts (Mark et al., 2008). Further, individuals suppress cues held in memory that are relevant to their primary tasks. Retrieving such cues to resume the tasks is difficult and prone to errors caused by memory limitations (Monk et al., 2008). Additionally, IINT consume attention resources, and this can deplete the resources available for monitoring and correcting behaviors relevant to the primary tasks. By contrast, CINT are not linked to output errors (Ang et al., 1993), because the process losses that they might incur are countered by informational gains. In one study, CINT are found to improve sensitivity to error (Szalma et al., 2006).

In sum, the individual-level literature suggests that work interruptions (both IINT and CINT) create two cognitive stress constraints (time pressure and cognitive workload) and that IINT create two performance-based constraints (time delays and output errors). While many of the interruptions studied are mediated by CT, no study has looked at the capabilities of CT and how they might influence the effects of interruptions.

2.2 Work Interruptions and Groups

Because the literature on interruptions in group settings focuses on group coordination and group performance as the main outcomes, we organize the results around two key themes from coordination theory—coordination problems and mechanisms (Malone & Crowston, 1994)—as well as the final group outcomes (see Table 1). *Coordination problems* occur because interdependencies in a system (e.g., a group) constrain the functioning of some parts of the system and therefore need to be effectively managed or coordinated. These constraints can come from three types of dependencies: sharing dependencies (when multiple activities use the same resource), fit dependencies (when multiple activities together produce a single resource), and flow dependencies (when one activity produces a resource that is used by another activity) (Malone & Crowston, 1994).

Coordination mechanisms are the additional activities that are performed to overcome constraints and effectively manage the dependencies (i.e., to coordinate) among activities (Malone & Crowston, 1994). Following coordination literature, we focus on two broad types of explicit coordination mechanisms. The first, task organization, implements practices designed to manipulate tasks and the resources employed therein, such as role switching, temporal coordination, and others. These practices are designed or codified into programs of action (Gittell, 2002), either in a predefined way or in response to coordination problems (Crowston, 1997; Malone & Crowston, 1994).

The second coordination mechanism, group problem solving, is an organic process of intense communication between group members to resolve problems (Gittell, 2002; Okhuysen & Eisenhardt, 2002). While coordinating by task organization can also involve communication, its primary goal is to reduce the need for continuous communication (Grant, 1996). By contrast, communication in groups using group problem-solving coordination is more intense, more personal, less standardized, and deliberately sought as a means of resolving problems (Grant, 1996).

The studies in Table 1 are summarized in two categories. Set 1 includes studies that examine the consequences of interruptions targeting all members of groups. Set 2 includes studies on the group impact of interruptions that target individual group members. We classified the studies in each set by whether they examine IINT or CINT. Many studies do not explicitly characterize the interruptions as either type, nor do they examine their content relevance. In such cases, we classified the interruptions by examining how they are described in the study. Table 1 also includes interruptions that we could not classify because not enough information is provided. We also report on the technology capabilities identified (if any), as well as the elements of coordination theory (coordination problems and mechanisms) and group outcomes.

The evidence summarized in Table 1 suggests that both IINT and CINT impose constraints on groups similar to those imposed on individuals. For instance, interruptions increase groups' time pressures (Jessup & Connolly, 1993; Perlow, 1999), reduce their concentration (Jessup &

Connolly, 1993), and increase their workload (Perlow, 1999; Ren et al., 2008).

Additionally, IINT and CINT create coordination problems for groups, such as workflow disruptions (Perlow, 1999; Zellmer-Bruhn, 2003), increases in coordination overhead (Hazlehurst, 2003), dysfunctional work time cycles (Perlow, 1999), and coordination breakdowns (Ren et al., 2008). The evidence shows that groups implement structural coordination mechanisms to mitigate the coordination problems induced by interruptions. For example, an aircraft crew facing interruptions through the air traffic control system used a *formal checklist* that provided a mutual sense of the state of the aircraft to crewmembers (Hazlehurst, 2003). The crew relied on the checklist and on one another to resume their interrupted tasks. *Role switching* (applying redundant people resources to the task) is another mitigating mechanism (Chong & Siino, 2006; Ren et al., 2008). A study of pair programmers sharing a task finds that role switching compensates for interruptions by enabling programmers to alternate between tasks and interruptions (Chong & Siino, 2006). *Temporal coordination* is an alternative coordination mechanism, which is observed in a study of a group of software engineers who constantly interrupted one another (Perlow, 1999). In response to the disruptions, the company scheduled "quiet time" for the engineers to work uninterrupted.

Finally, the research shown in Table 1 suggests that CINT enable group problem-solving coordination and have positive effects on group outcomes. Groups use CINT to switch to mindful modes of processing and to engage in collective discussions on how to improve their work (Jessup & Connolly, 1993; Okhuysen & Eisenhardt, 2002; Zellmer-Bruhn, 2003). In turn, this leads to positive outcomes, such as parallel execution (Hazlehurst, 2003), enhanced knowledge integration (Okhuysen & Eisenhardt, 2002), and new knowledge acquisition (Zellmer-Bruhn, 2003).

Table 1. Empirical Literature on Work Interruptions in Group Settings

Set 1: Group-level interruptions and group outcomes						
Author(s)	**Type of interruptions (IINT/ CINT)[a]**	**Interrupting medium**	**Technology capabilities**	**Coordination problems**	**Coordination mechanisms**	**Group outcomes**
Chong and Siino (2006)	IINT and CINT (not differentiated)	Face-to-face (F2F); cell phone	N/a	Few problems because pair programmers share the same task and could rely on one another to continue the task	Role switching	Paired programmers initiate interruptions that are more functional and of shorter duration, respond faster to interruptions, possess situational awareness to determine importance of interruptions, monitor each other's work during interruptions, are more flexible in ending interruptions, rely on one another to remember details of interrupted tasks, and use resource sharing to recover more quickly from interruptions.

Table 1. Empirical Literature on Work Interruptions in Group Settings

Hazlehurst (2003)	CINT	Air traffic control system	N/a (use of manual checklist)	Increases in coordination overhead from interruptions	Executing a preflight checklist by the crew Mechanisms for mutual understanding of crew roles/ responsibilities Shared awareness of aircraft state (implicit mechanism)	Aircraft crewmember interruptions help identify discrepancies, which improve the group's coordination and performance outcomes. Interrupt-driven processing is critical for pointing out discrepancies beyond the immediate routine task, which enables group flexibility, parallel execution, and error detection.
Okhuysen and Eisenhardt (2002)	CINT	Written instructions	N/a	Attention switches	Group problem solving	Formal interventions trigger windows of opportunity in which group members engage in discussions that result in improving their processes and better integrating their knowledge.
Zellmer-Bruhn (2003)	CINT (and other group-level structural events)	Not specified	N/a	Disruption of existing routine flow	Group problem solving (increased search and acquisition of new routines)	Interruptions trigger mindful processing, which increases groups' knowledge transfer efforts and acquisition of new knowledge beyond the existing routines. Interruptions rated as disruptive reduce knowledge acquisition.
Set 2: Individual-level interruptions and group outcomes						
Author(s)	**Type of interruptions (IINT/ CINT)[a]**	**Interrupting medium**	**Technology capabilities**	**Coordination problems**	**Coordination mechanisms**	**Group outcomes**
Perlow (1999)	Not specified	Not specified	N/a	Disruptions to workflow; increases in time pressures; work overload; vicious work-time cycles	Temporal coordination ("quiet time") strategy is implemented to mitigate effects of interruptions	Interruptions lead to vicious work-time cycles: while interruptions are aimed at solving disruptions to work, they themselves create further work disruptions. "Quiet time" strategy increases individual productivity in the short term. Interruptions that are relevant are seen as "interactive activities" that have some positive effects.

Table 1. Empirical Literature on Work Interruptions in Group Settings

Ren et al. (2008)	IINT and CINT (not differentiated)	F2F; phone	N/a	Increases in workload, stress, and coordination breakdowns as a result of higher-profile groups (e.g., surgeons) interrupting lower-profile groups (e.g., nurses)	Constant communication; joint problem solving; role switching	Interruptions create group conflicts and organizational losses (financial losses and delays). Three factors are critical for coping with interruptions and promoting coordination: trajectory awareness, IS integration, information pooling, and organizational learning.
Jessup and Connolly (1993)	CINT	Electronic brain-storming system	N/a	High cognitive costs (feeling interrupted, less able to concentrate, and more time pressured).	Group problem solving and piggybacking on each other's ideas	Groups frequently interrupted with ideas can better coordinate their ideas, which leads them to outperform infrequently interrupted groups and nominal groups. But this comes at a cognitive cost (feeling interrupted, less able to concentrate, and more time pressured).
Weisband et al. (2007)	CINT	Electronic messaging	Modality of interruption (silent delivery to messaging board vs. on-screen pop-up)	N/a	Subjects coordinate the master schedule through joint interaction on the system	Interruption modality (silent delivery to messaging board rather than screen pop-up) increases task switching, which in turn improves group performance (measured as effective coordination of surgeries) in response to CINT (information relevant to surgery).

[a]In many studies, the type of interruptions was implicitly present; that is, the studies did not explicitly characterize interruptions as incongruent or congruent, nor did they measure variations in the interruption's relevance to the primary task. In such cases, we classified the interruptions as incongruent or congruent by examining how these interruptions were described in the study.

IINT = incongruent interruptions; CINT = congruent interruptions

Our review of the group literature highlights two research gaps. First, little is known about how the effects of interruptions that occur at the individual level might ripple out to groups. The studies on individual interruptions and group outcomes (set 2) do not open this black box. Second, like the individual-level studies, the group literature does not examine what role the usage of different capabilities of CT might have during interruption episodes. A single study examines a technology capability (interruption modality), but that capability was not controlled by users and occurred before—not during—interruption episodes (Weisband, Fadel, & Mattarelli, 2007).

Closing these two gaps is important for theoretical purposes, namely to explain both how the effects of interrupting an individual are not localized and can have more serious consequences by spreading to others, and how the use of technology can influence these effects. Additionally, closing these gaps helps to provide practical guidelines on how to control the ripple effects of work interruptions before they affect the entire group and what media capabilities are best or worst to use during interruption episodes.

In summary, the individual-level literature on work interruptions identifies four constraints imposed by these interruptions: time pressure, cognitive workload, time delays, and output errors. Further, the group-level literature suggests that interruptions create coordination problems. It identifies coordination mechanisms that groups apply to mitigate the negative effects of interruptions. Additionally, it highlights the positive role of CINT in that they enable group problem-solving coordination, which improves group outcomes.

In Section 3, we draw on these literatures and on coordination theory (Malone & Crowston, 1994) to develop our multilevel theoretical model of interruptions. The model theorizes how interruptions that influence individuals can affect the group as a whole through ripple effects and a cross-level direct effect. Drawing on the CMC literature, we also examine the role of the usage of different CT capabilities during interruption episodes.

3 Theoretical Model

Before theorizing the multilevel effects of work interruptions, we present the key assumptions and boundaries of our model (Weber, 2012). Our model looks at what happens after an individual is exposed to work interruptions and experiences one or more of the four individual constraints we described in the literature review (i.e., time pressure, cognitive workload, time delays, and/or output errors). The model focuses on the actions and interactions that are instigated by such an individual as well as his or her use of CT capabilities during interruption episodes, which have several consequences at the individual and group levels.

Our model assumes that an individual exposed to interruptions can use different CT capabilities to communicate with other group members in three ways: (1) address the interruptions' demands (e.g., provide some requested information); (2) communicate one's reaction to the interruptions (e.g., express distress or concerns); or (3) coordinate with others how to manage the interruptions' consequences (e.g., discuss how to adapt and reorient the work). Using the CT capabilities to perform these actions has effects at the individual and group levels, as well as on the individual-to-group processes (see Figure 1). While we acknowledge that individuals could also perform these communicative actions using other media (e.g., F2F discussions with group members), the scope of our theory covers only the usage of CT capabilities. Because CT have become a major means of communication and collaboration, both in distributed (Caya, Mortensen, & Pinsonneault, 2013) and collocated groups (Birnholtz, Dixon, & Hancock, 2012), we argue that our scope covers a large portion of the phenomenon. Additionally, responding to interruptions—whether these were triggered by CT or otherwise—using CT is a highly efficient way of transmitting information (e.g., individuals can send information to a large number of others with a click of a button).

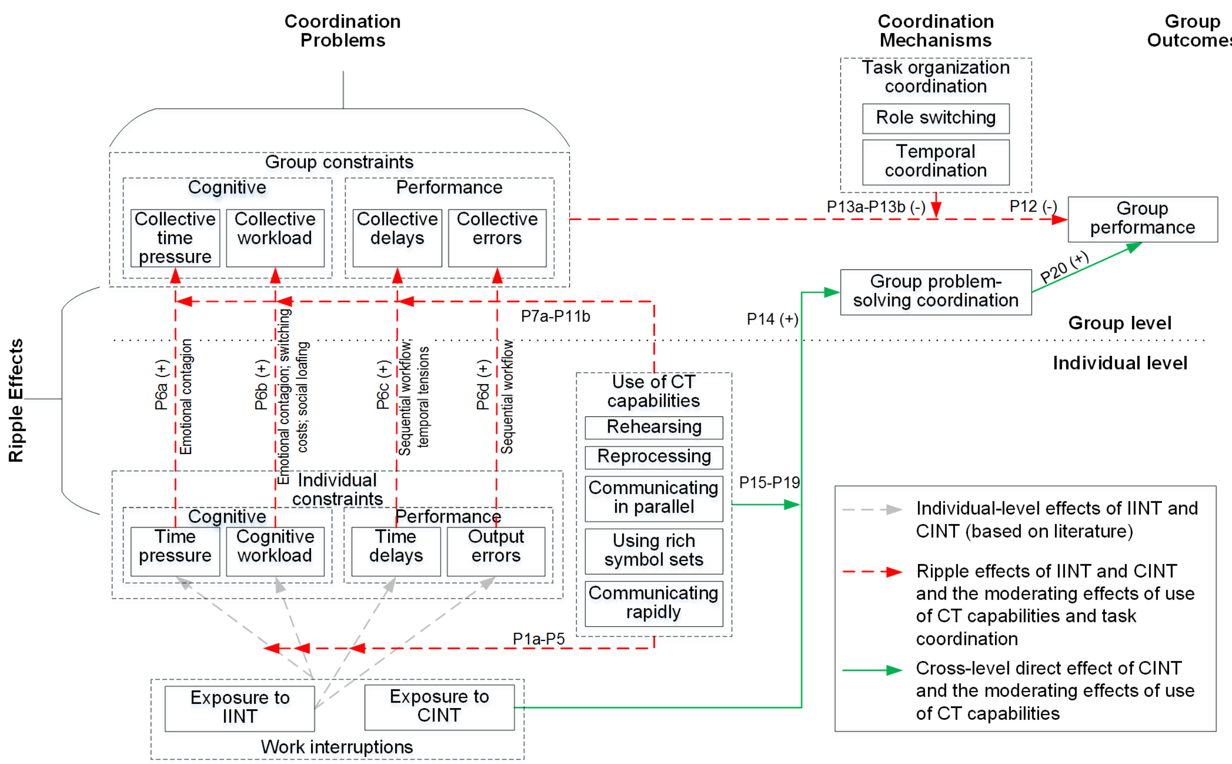


Figure 1. Theoretical Model

Our model is mostly applicable to groups having the following five attributes. First, it applies to groups working on specific intellectual (i.e., knowledge) tasks and projects. Second, we assume that these tasks or projects are time-bounded and have defined beginnings and ends. Individual-level interruptions are likely to have stronger group-level effects in groups that are under time pressures and for which delays can have important consequences. Our model thus excludes groups that are not time bounded (e.g., top management groups, permanent work groups). Third, we focus on groups that rely on CT to facilitate and coordinate their work, which excludes groups performing live events, such as firefighters, music orchestra groups, and sports teams. Fourth, the model is particularly suited for groups with high levels of task interdependence (i.e., where the primary tasks are tightly linked to one another), which is a fundamental basis through which the ripple effects occur. Hence, advisory teams that meet periodically and have activities that are far and in between are not included. Fifth, the model assumes that the tasks of a group require explicit coordination (e.g., because its members have specialized expertise). Teams with high temporal stability (e.g., top management groups, permanent work groups) are less suited because they rely more on implicit—rather than explicit—coordination (Hollenbeck, Beersma, & Schouten, 2012).

Given these attributes, our model is most applicable to project groups. These groups typically work on defined, specialized, and time-limited projects. They also perform highly interdependent knowledge tasks and include members with cross-functional expertise that requires explicit coordination efforts.

The multilevel model shown in Figure 1 suggests that exposure to incongruent interruptions (IINT) and congruent interruptions (CINT) influence group performance through two paths. The first path, illustrated with red dotted lines, includes the ripple effects of IINT and CINT, the consequences of these ripple effects on group performance, the moderating effects of usage of CT capabilities on the individual constraints as well as on the ripple effects, and the moderating effect of task coordination.[4] Essentially, the ripple effects describe the processes by which the individual-level effects of interruptions (i.e., the four individual constraints) influence other group members (i.e., ripple out) through task interdependencies and the actions and interactions instigated by the interrupted individual during interruption episodes.

The first path constitutes what is known in multilevel theory as a unit-level model with shared and global (i.e., mixed) constructs (Kozlowski & Klein, 2000). The main predictors, group constraints, are shared unit constructs (i.e., they come to be shared by group members owing to the rippling out of individual constraints) and the outcome, group performance, is a global unit construct. Both predictor and outcome are at the same higher level of theoretical interest, namely the group level.

The second path, illustrated with green solid lines, depicts a positive effect of CINT on group problem-solving coordination and ultimately on group performance and the moderating effect of usage of CT capabilities. Because the predictor (exposure to CINT) and the outcomes (group problem-solving coordination and group performance) are at different levels of analysis, this path represents a cross-level direct effect (Kozlowski & Klein, 2000).

3.1 The Ripple Effects and the Use of CT Capabilities

The literature review suggests that work interruptions create four distinct constraints for individuals (i.e., time pressure, cognitive workload, time delays, output errors). Our model extends the literature by theorizing how these individual-level constraints ripple out to the group and what role CT plays in this process. First, the use of different CT capabilities to communicate with other group members during interruption episodes moderates the individual-level effects before they ripple out to the group (P1a–P5). Second, the ripple effects extend these individual constraints of interruptions to the group level, leading to coordination problems for the group (P6a–P6b). Third, the CT capabilities used also moderate these individual-to-group processes (P7a–P11b). Fourth, the coordination problems created by the ripple effects ultimately decrease group performance (P12). Finally, groups can employ two task coordination mechanisms—role switching and temporal coordination—to mitigate the negative effects of the group's coordination problems on group performance (P13a–P13b).

3.1.1 Impact of Use of CT Capabilities on Individual-Level Effects

An individual exposed to IINT or CINT—whether triggered by CT or otherwise—can use different CT capabilities to perform the three communicative actions we described (address the interruptions' demands, communicate one's reactions, and/or manage the consequences of interruptions with the other members). The CMC literature identifies different CT capabilities that influence how groups communicate and coordinate their work, which are summarized by Dennis, Fuller, and Valacich (2008) in their work on media synchronicity theory. Drawing upon these insights but adapting them to a user-centric perspective (focusing on user actions), we propose five CT capabilities used during interruption episodes: rehearsing, reprocessing, communicating in parallel, communicating rapidly, and using rich symbol sets.[5] Rehearsing is the extent to which

[4] A ripple effect describes how changes made in one part of a system influence other parts of the system (Stevens, Myers, & Constantine, 1974). This term is used in group literature to describe how stress and emotions ripple out to groups (Barsade, 2002).

[5] We adapt Dennis et al.'s (2008) terms that focus on the physical capabilities of the media (rehearsability,

individuals review or fine-tune their messages before sending them. Reprocessing is the extent to which individuals reexamine or process prior messages again (own or received from others). Communicating in parallel is the extent to which individuals engage in multiple conversations simultaneously (i.e., within a given interruption episode). This capability captures two facets: simultaneity (sending messages to multiple recipients or receiving messages from multiple senders) and sequentiality (lack of sequential adjacency such that a message and its reply may be separated by other messages). The fourth capability used is communicating rapidly, which refers to the speed with which individuals engage in conversations and receive feedback. Finally, using rich symbol sets refers to the number of ways in which individuals communicate their messages using various types of symbols (e.g., visual, video, or verbal cues or emoticons).

Usage of four CT capabilities (rehearsing; reprocessing; communicating in parallel; communicating rapidly) will positively moderate the effects of IINT and CINT on three individual-level constraints (time pressure; cognitive workload; time delays), and use of one capability (using rich symbol sets) will have a negative moderation effect (see Appendix B). Rehearsing messages during interruption episodes consumes substantial cognitive and time resources in order to plan, edit, and review the intended messages and tailor them to the specific audience within the group (Tang, Wang, & Norman, 2013). These resources consumed add to the burdens of being interrupted. Accordingly,

P1: Rehearsing strengthens the effects of IINT and CINT on individual time pressure (P1a) and on individual cognitive workload (P1b), and it strengthens the effect of IINT on individual time delays (P1c).

Similarly, reprocessing messages during interruption episodes—whether interrupting messages or messages created in the context of the three communication acts we identified—incurs cognitive and temporal costs that add to the costs of interruptions. This is because reprocessing involves reading and rereading messages (Tang et al., 2013), and occurs during interruption episodes where resources are already stretched. Reprocessing requires storing and retrieving messages and their contexts in one's mind and remembering the details while relying on limited contextual cues (Giordano, Stoner, DiGangi, & Lewis, 2010). Reprocessing can also lead to processing more information around the messages, such as by accessing web links or documents attached to the messages (Robert & Dennis, 2005). Hence:

P2: Reprocessing strengthens the effects of IINT and CINT on individual time pressure (P2a) and on individual cognitive workload (P2b), and it strengthens the effect of IINT on individual time delays (P2c).

Furthermore, communicating in parallel during interruption episodes enables an individual exposed to interruptions to exchange messages concerning the interruptions simultaneously with multiple others. Consequently, messages between group members become interleaved (i.e., a message and its reply become separated in time by other messages) and individuals must deal with multiple simultaneous threads of fragmented conversations (Herring, 1999). Tracking and managing these open conversations and switching between them incur a heavy cognitive load (Herring, 1999; Tang et al., 2013), on top of the load from being interrupted. Empirical results show that the number of threaded messages tracked and the use of multiple media to communicate in parallel are both positively associated with cognitive overload (Bellotti, Ducheneaut, Howard, & Smith, 2003; Cameron & Webster, 2013). As well, the time separation of messages and the efforts involved in managing the fragmented conversations incur time delays and time pressures, such as delay costs and asynchrony costs (Herring, 1999). Hence:

P3: Communicating in parallel strengthens the effects of IINT and CINT on individual time pressure (P3a) and on individual cognitive workload (P3b), and it strengthens the effect of IINT on individual time delays (P3c).

Using rich symbol sets during interruption episodes operates in contrast to the above effects. It enables the reduction of time and effort to encode and decode messages that are exchanged around the interruptions (Dennis et al., 2008; Tang et al., 2013). For example, it may be more efficient and less cognitively taxing to communicate one's emotions or concerns—or to discuss with the other group members how to manage the consequences of interruptions—through video conferencing than in a text-based email. Hence, we propose the following:

P4: Using rich symbol sets weakens the effects of IINT and CINT on individual time pressure (P4a) and on individual cognitive workload (P4b), and it weakens the effect of IINT on individual time delays (P4c).

Finally, communicating rapidly means that an individual exposed to work interruptions engages in rapid information exchanges with the other group

reprocessability, parallelism, transmission velocity, and symbol sets) to our user-centric context that examines the actual usage of these capabilities.
Each capability (e.g., rehearsability)—if used—induces a particular use of the capability (e.g., rehearsing).

members to respond to the interruptions' demands, communicate reactions, or manage the interruptions' consequences. Because communicating rapidly allows for more information to be exchanged within a given time period, it is not expected to compound the time pressure or delays. However, coordinating such rapid exchanges consumes significant cognitive resources and may amplify the effects of interruptions on cognitive workload, leading to information overload (Maynard & Gilson, 2014). Accordingly,

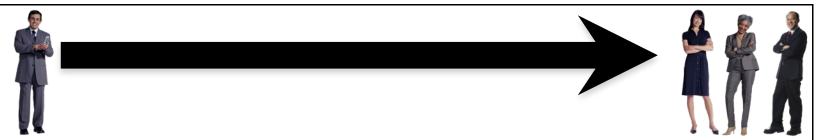
P5: Communicating rapidly strengthens the effects of IINT and CINT on individual cognitive workload.

3.1.2 Individual-Level Constraints and Group-Level Constraints (The Ripple Effects)

We discuss ripple effects that differ in terms of what is diffused in the process and how it is diffused (see Table 2). Because we argue that the individual-level constraints ripple out to groups and create analogous collective-level constraints, we account for the similarities and differences between the constructs across levels. In Appendix C, we compare the individual- and collective-level constructs based on the following aspects: the meaning of the construct across levels (similar or different), the nature of the ripple effects (isomorphic or discontinuous), the nature of the contextual constraints (sharing or flow dependencies), and the conditional nature of the collective constructs (conditional or unconditional) (Kozlowski & Klein, 2000).

Time pressure ripple effects. The time pressure induced by IINT or CINT ripples out to a group through a process of *stress/emotional contagion*. Research indicates that individuals can transmit general affective experiences (e.g., Barsade, 2002) or stress perceptions (e.g., time pressure) along with their accompanying emotions (e.g., frustration, anxiety, anger) (Westman, 2001). Emotions and stress can be expressed explicitly (e.g., voicing frustration or anger about the time pressure either face-to-face or through CT) and/or implicitly (e.g., through facial or vocal gestures, or the tone inferred from a digital message). Consequently, contagion occurs in three possible ways. First, group members automatically and subconsciously mimic the expressions and behaviors of others regarding the stressful situation as a result of an intrinsic human mimicking tendency, especially when these negative expressions and their underlying stress appraisals are forceful and intense (Barsade, 2002). This behavioral mimicry produces a corresponding stress perception along with its accompanying emotions (Gump & Kulik, 1997). Second, the distress of one individual can produce a conscious empathic reaction in other group members, which increases their levels of distress as well. Others imagine how they would feel in the position of the distressed individual and thereby come to share the stressful experience (Westman, 2001). Third, group members are exposed to a similar stressful situation (e.g., a looming deadline for a project that is constantly interrupted), creating pressures to establish a common social reality. Group members experiencing high levels of time pressure will thus influence others' appraisals of the situation and converge on a common reaction to the stressful situation (Chong, Van Eerde, Chai, & Rutte, 2011; van Emmerik & Peeters, 2009).

Table 2. The Ripple Effects of Work Interruptions

Constraints that ripple out from individuals to groups	**Sub-processes responsible for ripple effects**					
Time pressure	Stress/ emotional contagion	Individual faces IINT or CINT	→ Individual experiences time pressure (a stress perception or distress with accompanying emotions) and expresses the distress explicitly or implicitly	→ Others detect the expression about time pressure and/or its accompanying emotions.	→ Others "catch" the stress perception through subconscious mimicking, conscious emphatic reaction, or exposure to the common stressor.	→ Group experiences collective time pressure
Cognitive workload	Stress/ emotional contagion	Individual faces IINT or CINT	→ Individual experiences increased workload (a stress perception or distress with accompanying emotions) caused by task switching and expresses the distress explicitly or implicitly	→ Others detect the expression about cognitive workload and/or its accompanying emotions.	→ Others "catch" the stress perception through subconscious mimicking, conscious emphatic reaction, or exposure to the common stressor.	→ Group experiences collective workload
	Switching costs	Individual faces IINT or CINT	→ Individual experiences increased workload caused by task switching and informs other members about the interruptions-induced workload	→ Others discuss with individual the interruptions and their impact on group work	→ Others increase switching between their own taskwork and teamwork as a result of the ongoing discussions	→ Group experiences collective workload
	Social loafing	Individual faces IINT or CINT	→ Individual experiences increased workload caused by task switching and reduces effort expenditure in task	→ Others detect the reduced effort expenditure	→ Others are pressured to pick up the slack	→ Group experiences collective workload
Time delays	Sequential workflow disruption	Individual faces IINT	→ Individual experiences time delays in task	→ Other tasks in sequential workflow are delayed	→ Others downstream performing those tasks are delayed	→ Group experiences collective delays
	Temporal tensions	Individual faces IINT	→ Individual experiences time delays in task	→ Other interdependent tasks are delayed	→ Others performing those tasks are delayed, leading to tensions and counterproductive behaviors and diverting attention to conflict resolution (i.e., more delays)	→ Group experiences collective delays
Output errors	Sequential workflow disruption	Individual faces IINT	→ Individual commits output errors (defects)	→ Other tasks in sequential workflow are affected by errors	→ Others downstream working on tasks that call upon the defective output(s) build on errors	→ Group experiences collective errors

The ripple effect is shaped by the group's task interdependence, especially sharing dependencies (see Appendix C). Because group members share project goals and resources (e.g., information, time), they have a greater opportunity and a higher need to develop a common perception and experience about time pressure (Maruping, Venkatesh, Thatcher, & Patel, 2015). These dependencies help create a common understanding of a situation, which is the basis for the comparison process underlying stress/emotional contagion (Barsade, 2002). Members using similar resources as task inputs are likely to look at how others react to their time-pressured task environment as a basis for forming their own reactions. In other words, this ripple effect has an isomorphic nature (Kozlowski & Klein, 2000), meaning that individuals contribute a similar type and amount of elemental content (i.e., the stress perception) to the collective. As indicated in Appendix C, the perception of time pressure also has essentially the same meaning across levels, namely that task demands exceed the time available.

Collective pressure signifies coordination problems for the group because it creates a perceived shortage of resources (time; effort; attention) that group members can put into their interdependent tasks. Based on the above arguments and the empirical evidence supporting a time pressure contagion effect (Chong et al., 2011; Maruping et al., 2015), we propose:

P6a: The greater the individual time pressure induced by IINT or CINT, the greater the collective time pressure.

Cognitive workload ripple effects. The cognitive workload induced by exposure to IINT or CINT can ripple out and form a collective workload, defined as the perceived cognitive demands placed on a group by its task environment relative to its finite capacity (Bowers et al., 1997). Collective workload is created by taskwork demands (i.e., interactions with tasks, tools, and systems), teamwork demands (interpersonal interactions that are necessary for exchanging information, developing and maintaining communication patterns, coordination actions, maintaining social order, etc.), and demands for switching between taskwork and teamwork (Bowers et al., 1997).

We propose that cognitive workload can ripple out to groups through three mechanisms. The first one is stress/emotional contagion. Like time pressure, cognitive workload is a stress perception that can be transmitted through subconscious mimicking, empathic response, or exposure to a common stressful environment. Contagion is triggered by an expressive display of the distress and its attached emotions, such as when people frequently complain about their workload (Bakker, van Emmerik, & Euwema, 2006; van Emmerik & Peeters, 2009). This contagious transmission of cognitive workload has been observed in various contexts, such as among government workers (van Emmerik & Peeters, 2009) and nurses in intensive care units (Bakker et al., 2006).

Interruptions-induced cognitive workload also ripples out to a group owing to the effort required for switching between primary tasks and interruptions, which adds to the switching costs associated with doing normal group work (i.e., allocating limited attention resources among task activities, team activities, and switching between the two) (Bowers et al., 1997). Interrupting individuals creates additional switching efforts for the group because the non-interrupted group members can react by switching attention from their own tasks toward team activities (e.g., discussing how to adapt to the demands imposed by the interruptions). This increased switching and communication overhead will incur additional cognitive demands on the group as a whole, thereby increasing collective workload.

Finally, the individual-level cognitive workload can ripple out as a result of social loafing (i.e., when an interrupted individual decides to reduce one's effort expenditure assuming that other group members will take more responsibilities and work harder to compensate for one's limited contributions) (Pinsonneault, Barki, Gallupe, & Hoppen, 1999). Social loafing is particularly acute in groups when individuals perceive their efforts as being dispensable, when there is diffused responsibility, or when members can obtain benefits from the group without contributing a fair share of the efforts. Interrupted individuals feel overloaded and frequently react by reducing effort expenditure in their tasks, which puts pressures on the group to pick up the slack and leaves the group with fewer resources to apply to their tasks (Jackson & Harkins, 1985).

As in the case of time pressure, the ripple effect of cognitive workload occurring through emotional contagion is shaped by sharing dependencies and has an isomorphic nature (see Appendix C). Sharing dependencies also strengthen the ripple effect that occurs through social loafing because dispensability of effort is high and individual contributions are less identifiable when working jointly on a common task. However, the ripple effects occurring through social loafing and switching costs have a discontinuous, rather than an isomorphic nature (Kozlowski & Klein, 2000). This is because the elemental content that each member contributes to the collective (i.e., the perception of high cognitive demand relative to capacity) can differ significantly in amount (e.g., some members may not switch their attention toward team activities to discuss adapting to interruptions; others may decide not to pick up the slack left by the interrupted member; some may be endowed with higher cognitive capacities, etc.). Hence, the collective construct is not a simple sum of its constituent's parts as in the case of time pressure. Additionally, as indicated in Appendix C, the meaning of the construct is different across levels with collective workload including more components than individual-level workload, namely teamwork and timesharing. Accordingly,

P6b: The greater the individual cognitive workload induced by IINT or CINT, the greater the collective workload.

Time delays ripple effects. We argue that individual time delays induced by IINT ripple out through a structural mechanism (sequential workflow disruption) and an affective/behavioral mechanism (temporal tensions). When an individual's work in a group is delayed because of IINT, a sequential workflow design characterized by flow dependencies can cause these delays to ripple out to others, leading to collective or coordination delays (Cummings, Espinosa, & Pickering, 2009). In groups subject to sequential dependencies, delays in one activity (e.g., coding activity in a software project) residing on a project's critical path lead to delays in subsequent activities (e.g., software testing).

Individual time delays induced by IINT can also ripple out by creating temporal tensions in groups. When an individual's contribution to a project is considerably delayed, other members can perceive such delay as a violation of norms and temporal expectations (Sheldon, Thomas-Hunt, & Proell, 2006). This creates anger and frustration, and it may lead to devaluing the contribution of the person responsible for the delay (Sheldon et al., 2006). Group members may also react by engaging in counterproductive behaviors such as questioning, complaining, and withdrawal (Guenter, van Emmerik, & Schreurs, 2014). These negative attitudes and tensions between group members are shaped by sharing dependencies (group members share project goals and resources) and can trigger collective delays as the group diverts more attention and dedicates more time to conflict resolution rather than to task accomplishment (McGrath, 1991).

Collective delays, defined as the time spent waiting for tasks to be processed by others (Cummings et al., 2009), are conceptually different from individual delays (Appendix C). They are embedded in interdependent interactions and can manifest in coordination problems whereby a group fails to move resources at the right time (Strode, Huff, Hope, & Link, 2012) (e.g., missing group milestones; failing to demonstrate a product prototype to a customer at a given deadline). The ripple effects of collective delays are isomorphic (for temporal tensions) and discontinuous (for sequential workflow constraints). Further, like the previously discussed ripple effects, the ripple effect occurring through temporal tensions is conditional on the specific actions undertaken that we describe above. However, the ripple effect occurring through sequential workflow disruption is unconditional (i.e., it requires only the passage of time). Accordingly,

P6c: The longer the individual time delays induced by IINT, the longer the collective delays.

Output errors ripple effects. Undetected individual errors induced by IINT ripple out to a group owing to the sequential nature of a group's workflow. Because of flow dependencies (Crowston, 1997), errors in an output can ripple out across a group's project lifecycle. For example, Wohlin and Koemer (1990) show that a single, undetected error in a software project can cause four errors in the subsequent phase and up to 250 errors four phases downstream. Another study on a new product development (NPD) group developing an engine control system finds that errors committed early on multiply and propagate through a bow-wave effect (Powell, 2001). And in the context of a case study of a software group developing a large commercial legacy system, Li (2010) reports that architectural errors are especially persistent in propagating across development phases and product releases. As group members worked downstream on modules that called upon or shared data with the defective architecture, the defects multiplied, leading to architectural degeneration. While those multimodule errors comprised only 8% of the number of total errors, they required over 50% of the change effort as a result of changing multiple modules each time (Li, 2010).

The ripple effect for collective errors has a discontinuous nature (Appendix C), because group members contribute different types of content (e.g., in a software project the errors made can be related to design, coding, testing, etc.) as well as different amounts (more or fewer errors). Consequently, the combination of the individual contributions to collective errors is conjunctive rather than additive (Kozlowski & Klein, 2000). For example, some errors on the part of certain members may jeopardize the whole system.

Furthermore, the meaning of the construct is different across levels (Appendix C). Conceptually, collective errors represent a type of coordination problems for groups. They are embedded in interdependent interactions and are defined as failing to integrate a group's outputs (Sieweke & Zhao, 2015). For example, while individual errors in a software project may be restricted to specific modules (e.g., coding errors), collective errors are manifested when the group fails to integrate multiple modules because errors have propagated in these modules.

Finally, output errors have a ripple effect that is unconditional (Kozlowski & Klein, 2000). No specific action is needed to trigger the ripple effect, as long as the group has flow dependencies and errors go undetected over time (Appendix C). Based on the above, we propose the following:

P6d: The greater the number of individual output errors induced by IINT, the greater the number of collective errors.

3.1.3 Impact of Use of CT Capabilities on the Ripple Effects

Rehearsing messages during interruption episodes can limit some of these ripple effects. Taking the time to think and carefully articulate the messages sent to other members regarding one's reaction to being interrupted increases the likelihood of a more measured response. For example, research shows that email senders are judged based on the content and communication style of their messages (Brown, Fuller, & Thatcher, 2016). Digital messages provide an accountability cue, a permanent record that can be repeatedly accessed and evaluated by others (Pinsonneault & Heppel, 1997). A group member's actions are constrained by one's perception of how one will be evaluated and judged by others (Pinsonneault & Heppel, 1997). Because of this constraint, rehearsing can impede or limit the dissemination of extreme emotions and distress about interruptions. Accordingly, we propose:

P7: Rehearsing weakens the ripple effects of time pressure (P7a) and cognitive workload (P7b) occurring through emotional contagion.

We contend that rehearsing has no effect on collective errors and that it has counteracting effects on collective delays, leading to no net effect. On the one hand, rehearsing strengthens the ripple effect of time delays because it delays information transmission to the group (e.g., addressing the interruptions' demands or discussing how to adapt and manage the interruptions' consequences), potentially disrupting sequential workflow. Cummings et al. (2009) argue that delays in message response (in their case created by temporal distance) lead to collective coordination delays. On the other hand, rehearsing weakens the ripple effect by easing temporal tensions. That is, rehearsing allows individuals to be more attentive and considerate to their audience. Such attentiveness can trigger feelings of closeness and intimacy and create a more harmonious communication environment (Tang et al., 2013).

Similar to rehearsing, reprocessing messages during interruption episodes consumes time resources. While the individual-level effect of this capability is captured in P2, a separate effect occurs at the group level. Reprocessing messages—whether the original interrupting messages or responses that address the interruptions' demands or how to adapt to them—means that the transmission of potentially important information to other group members will be delayed. Therefore, all else being equal, the effects of individual time delays on collective delays will be higher for people who engage more extensively in reprocessing and thereby delay their message responses and disrupt the sequential workflow of the group (Cummings et al., 2009). Hence,

P8: Reprocessing strengthens the ripple effect of time delays occurring through sequential workflow disruption.

Communicating in parallel during interruption episodes implies that an individual's reactions to interruptions (e.g., expressing emotional distress) are spread widely within the group and received simultaneously by group members (Dennis et al, 2008). This practice amplifies the emotional contagion process. Additionally, the workload ripple effect occurring through switching costs is strengthened by the fact that communicating in parallel hinders the group from focusing on a single conversation at a time; members need to shift from one conversation to another (Ahuja, Fuller, & Magni, 2015). Accordingly, we propose:

P9: Communicating in parallel strengthens the ripple effect of time pressure occurring through emotional contagion (P9a), and it strengthens the ripple effects of cognitive workload occurring through emotional contagion and switching costs (P9b).

We also suggest that communicating in parallel has counteracting effects on collective delays leading to no net effect. On the one hand, managing many fragmented conversations distracts group members, makes them less attentive to each other, reduces their perceptions of closeness, hinders the development of a harmonious communication environment, and increases the possibilities for misunderstanding (Tang et al., 2013), all of which can lead to escalating temporal tensions. On the other hand, communicating in parallel to respond to the interruptions' demands or to manage their consequences can weaken the ripple effect of time delays because group members can put together and share unique pieces of information relevant to the conversation. With parallel communications, there is also no need for excessive turn taking since a group member can contribute anytime, which leads to faster and greater information flow (Espinosa, Nan, & Carmel, 2015). Hence, more information about managing the interruptions will be disseminated in a given time period (Dennis et al., 2008).

We do not propose any effects of using rich symbol sets on the ripple effects of time pressure or cognitive workload that occur through emotional contagion. While communicating using nonverbal cues (e.g., F2F; video conferencing) may convey more emotional information and intensify the emotion expression (Derks, Fischer, & Bos, 2008), there is evidence suggesting that emotional contagion also occurs through text-based media that lack such cues (Cheshin, Rafaeli, & Bos, 2011; Derks et al., 2008). There is no conclusive evidence, to our knowledge, that indicates whether emotional contagion is higher or lower with the use of richer symbols sets.

Regarding collective delays, we propose an effect only in the case of CT allowing visual displays (e.g., video conferencing). Through using visual cues to communicate about the adverse effects of exposure to interruptions, there is a lesser likelihood of being misunderstood, which reduces the prevalence of temporal tensions. Tang et al. (2013) argue that such cues help group members feel closer and more connected. By contrast, misunderstandings can occur through the use of other types of rich symbol sets, such as emoticons (Walther & D'Addario, 2001) and vocal cues (Derks et al., 2008). Hence, we propose:

P10: Using rich symbol sets (visual displays) weakens the ripple effect of time delays occurring through temporal tensions.

Finally, communicating one's reaction to interruptions rapidly (e.g., expressing emotional distress) can lead to sending more negative messages without sufficient consideration to the consequences (Maynard & Gilson, 2014). Cheshin et al. (2011) argue that emotional contagion is stronger when individuals use CT to send responses rapidly. Accordingly,

P11: Communicating rapidly strengthens the ripple effects of time pressure (P11a) and cognitive workload (P11b) occurring through emotional contagion.

We further argue that communicating rapidly has counteracting effects on collective delays, leading to no net effect. On the one hand, complaining about interruptions or discussing how to manage the consequences can lead to temporal tensions if the messages are put together and sent rapidly without considering how they will affect the other group members. On the other hand, sharing information about interruptions or their consequences rapidly enables faster and greater information flow, and faster real-time assessment of the information exchanged (Tang et al., 2013; Maynard & Gilson, 2014).

3.1.4 Group-Level Constraints and Group Performance

We propose that the group-level constraints created by the ripple effects can hinder group performance in four ways. This relationship is not directly related to work interruptions, but we present it for completeness and to explain the ultimate effects of work interruptions on group performance. Group performance includes several dimensions, such as productivity (i.e., the extent to which a group's output meets or exceeds the standards of those receiving it,), viability (i.e., satisfaction and willingness to work together in the future), and member development (i.e., personal needs fulfillment, growth, and well-being) (Caya et al., 2013). We focus on output quality and timeliness as two key measures of productivity (Caya et al., 2013). Because these measures tap into both the group's output results (output quality) and the cost of achieving these results (timeliness), they provide a parsimonious yet comprehensive assessment of group performance (Beal, Cohen, Burke, & McLendon, 2003).

First, groups experiencing time pressure focus on a restricted range of task-relevant cues and resort to quick-fix efforts and taking shortcuts to meet task demands (Chong et al., 2011; McGrath, 1991). While this practice may help push work along in a timely manner, the output quality is likely to be inferior leading to failure to meet expectations and possible redoing of the work (i.e., lower group performance) (Maruping et al., 2015).

Second, when the combined demands of collective workload (taskwork, teamwork, and switching between the two) exceed a group's capacity, members experience fatigue and, as a result, have fewer resources available to coordinate and perform their activities effectively (Bowers et al., 1997). Indeed, evidence from flight simulation teams (Funke & Galster, 2009) and NPD teams (Cataldo & Ehrlich, 2012) shows that collective workload impairs group performance.

Third, because they introduce slippages that accumulate over a group's project lifecycle, collective time delays decrease group performance, especially in groups with significant flow dependencies (Reichelt & Lyneis, 1999). Cummings et al. (2009) surveyed 675 project members in a semiconductor firm and found that collective delays decreased group performance in terms of timeliness and quality (final product meeting requirements).

Fourth, we expect that collective errors as manifested by failure to integrate group efforts will decrease group performance. This is because these errors hinder group members from applying their skills and expertise to bear in a timely and effective manner (Faraj & Sproull, 2000). For example, using panel data from the National Basketball Association (NBA), Sieweke and Zhao (2015) found that collective errors decreased the performance of NBA teams (win/loss ratio). Hence,

P12: The greater the group-level constraints (collective time pressure; collective workload; collective time delays; collective errors), the lower the group performance.

3.1.5 Moderating Effects of Task Organization Coordination Mechanisms

During interruption episodes, groups can employ task organization coordination to mitigate the effects of group constraints on group performance. Two specific mechanisms can be used to effectively cope with the disruptive effects: role switching (organizing people resources), and temporal coordination (organizing task resources and time resources).

Role switching. Groups exposed to interruptions can mitigate the negative effects through role switching. For this to work, group members must share some level of expertise and skills so that they become relatively interchangeable on project tasks (Chong & Siino, 2006; Crowston, 1997; Faraj & Xiao, 2006). With shared expertise, individuals can integrate the work of an interrupted group member into their activities, even if the task distribution within the group has no redundancy (i.e., each task is performed by exactly one person). Mitigating disruption through role switching has been observed in several settings, such as software groups (Chong & Siino, 2006; Crowston, 1997) and healthcare provision groups (Faraj & Xiao, 2006; Ren et al., 2008).

The moderating effect of role switching is attributed to the ways it helps groups overcome some of the additional constraints created by interruptions in task execution. First, role switching can alleviate the effects of collective time pressure by allowing members to replace their interrupted groupmates, work flexibly on segmented activities, keep activities on track, and restore attention on coordination efforts (e.g. Ren et al., 2008). Role switching can also help groups to offset the effects of collective workload. This is because it creates redundancy and slack resources that can buffer the technical core from the discontinuities presented by environmental demands (Thompson, 1967), such as those imposed by work interruptions.

Role switching can also mitigate the effects of collective time delays, because it helps groups reallocate members with less work, or temporarily assign more members to a specific task. For example, in their study of software project groups, Chong and Siino (2006) find that role switching—achieved by pairing programmers with similar skills—provided task continuity and enabled group members to resume their work more quickly because they relied on one another to remember details of the interrupted tasks.

Finally, role switching mitigates error propagation by allowing members to better verify one another's work to ensure conformity before passing it over to the next task (Crowston, 1997). This verification eases the constraints imposed by flow dependencies where errors ripple out across the project lifecycle. For example, a study of software groups working in pair programming mode finds that programmers replaced each other when interrupted and monitored each other's work to cope with adverse consequences (Chong & Siino, 2006). We thus propose:

P13a: Role switching will moderate the relationship between group-level constraints and group performance such that the greater the use of role switching, the weaker the effect of group-level constraints on group performance.

Temporal coordination. A second task organization mechanism that can be used by groups is temporal coordination (i.e., matching of bundles of activities to particular periods of time) (McGrath, 1991). Temporal coordination may contain various activities such as scheduling and deadlines, sequencing, prioritizing, and synchronizing (McGrath, 1991). It enables group members to streamline interrupted tasks and resume their work effectively and efficiently in at least three different ways (McGrath, 1991; Waller, 1999). First, groups can mitigate the negative effects of work interruptions on group performance by setting clear schedules and deadlines for activities. These deadlines act as reminders for group members to return quickly to their primary activities and to break out of the "chain of diversions" described earlier (Iqbal & Horvitz, 2007).

Second, group members may cope with interruptions-induced constraints by sequencing and prioritizing their activities (Crowston, 1997; Malone & Crowston, 1994). For example, Waller (1999) examines how airline crews reacted to interruptions during flight simulations. She finds that timely application of task reprioritization and redistribution after interruptions significantly enhanced the group's performance.

Third, synchronizing activities by adjusting the pace of effort across group members (McGrath, 1991) can reduce the detrimental temporal effects of interruptions. This is achieved by overlapping activities and information processing across the whole group (e.g., by performing some design and development activities concurrently in a software project) and/or within a particular task (e.g., pair programming; simultaneous access to a module). Groups can also share information between upstream activities (e.g., requirements analysis in a software project) and downstream activities (e.g., software design) so that members can get a head start, receive early warnings of issues, and avoid costly delays of interruptions later on. Ren et al. (2008) observe that, to cope with interruptions, a hospital operating group synchronized their activities by joint problem solving, which included upstream (e.g., preoperative holding; anesthesia group) and downstream subgroups (e.g., postanesthesia care; care nurses). This coordination mechanism helped to resolve coordination breakdowns and delays (e.g., putting operating rooms on hold, keeping patients and/or staff waiting). Therefore, we propose the following:

P13b: Temporal coordination will moderate the relationship between group-level constraints and group performance such that the greater the use of temporal coordination, the weaker the effect of group-level constraints on group performance.

3.2 The Cross-Level Direct Effect and the Use of CT Capabilities

Beside the ripple effects presented above, we theorize a cross-level direct effect whereby CINT increases group problem-solving coordination (P14) and, ultimately, group performance (P20). Use of CT capabilities moderates this effect (P15–P19).

3.2.1 Congruent Interruptions and Group-Problem Solving Coordination

Because they provide information that is pertinent to performing primary activities (e.g., new task information, information about a problem or discrepancy, feedback), CINT can impel individuals to stop their current work, identify an unknown problem or a discrepancy, and enter into a mindful processing mode (Addas & Pinsonneault, 2018; Jett & George, 2003; Okhuysen & Eisenhardt, 2002). As such, CINT can make individuals actively attend to new information, become open to different points of views, and heedfully relate their actions to those of others (Jett & George, 2003; Zellmer-Bruhn, 2003). This mindful approach can result in members coordinating their work organically and more efficiently through group problem-solving coordination (e.g., discussing and sharing knowledge about the source and scope of the problem and orchestrating a collective solution approach) (Okhuysen & Eisenhardt, 2002; Zellmer-Bruhn, 2003). Hence, we theorize a cross-level direct relationship between exposure to CINT and group problem-solving coordination.

This relationship is supported by empirical evidence. In a study of 45 problem-solving groups, interventions (a type of CINT) led group members to engage in intense discussions, reorient their work processes, rethink how their tasks were performed, and better coordinate knowledge and expertise use (Okhuysen & Eisenhardt, 2002). Another study of 90 operational groups from the pharmaceutical industry finds that interventions induced group members to collectively examine their existing task knowledge and search for new ways to perform their tasks (Zellmer-Bruhn, 2003). In a similar vein, Faraj and Xiao (2006) investigate a medical trauma center and report that when group members faced crisis situations, such as failing patient procedures, they resorted to dialogic coordination modes characterized by joint sensemaking and/or collective resolution of discrepancies. Bertram, Voida, Greenberg, and Walker (2010) find that, when software debugging tools identified important discrepancies and interrupted developers, group members engaged in social processes to collectively conduct running dialogs on the bugs and to figure out ways to resolve them. CINT thus provided a "focal point for communication and coordination for many stakeholders within and beyond the software team" (p. 1). Accordingly,

P14: The greater the exposure to CINT, the greater the group problem-solving coordination.

3.2.2 Impact of Use of CT Capabilities on the Cross-Level Direct Effect

Three CT capabilities used during interruption episodes—rehearsing, reprocessing, and communicating in parallel—are most conducive to asynchronous communication between group members. However, group problem solving is best done with synchronous capabilities to converge on solutions to problems (Dennis et al., 2008). Typically, such convergence processes are hindered when individuals use media in ways that promote rehearsing, reprocessing, and parallel communication (Dennis et al., 2008). With rehearsing, individuals focus their efforts on carefully crafting their messages, which deters the development of coordinated behavior and shared focus that are necessary for group members to converge on solutions to problems (Dennis et al., 2008). Thus, we propose:

P15: Rehearsing weakens the effect of CINT on group problem-solving coordination.

Similarly, reprocessing messages during interruption episodes diverts attention to reexamining and scrutinizing aspects of messages rather than developing a shared focus to reconcile different viewpoints and mutually agree on a solution (Münzer & Holmer, 2009; Tang et al., 2013). Hence, reprocessing reduces convergence on solutions. Accordingly,

P16: Reprocessing weakens the effect of CINT on group problem-solving coordination.

Likewise, parallel communications fragment problem solving because messages get interspersed with other related or unrelated messages, and it becomes harder to develop a shared focus (Dennis et al., 2008). Parallel conversations also hinder information integration, a key step for collaborative problem solving (Münzer & Holmer, 2009). Thus, we propose:

P17: Communicating in parallel weakens the effect of CINT on group problem-solving coordination.

Using rich symbol sets during interruption episodes, such as communicating through video calls (with visual and verbal symbols), allows for fast encoding and decoding and facilitates turn taking and coordination. Group members can be more involved in the communication process and they focus on converging on solutions to problems (Tang et al., 2013). Accordingly,

P18: Using rich symbol sets strengthens the effect of CINT on group problem-solving coordination.

Finally, communicating rapidly during interruption episodes enables a greater and faster information exchange and allows group members to obtain quick feedback (Tang et al., 2013). Group members can thus refine their communications in a coordinated way, which facilitates convergence. This leads to the following proposition:

P19: Communicating rapidly strengthens the effect of CINT on group problem-solving coordination.

3.2.3 Group Problem-Solving Coordination and Group Performance

We expect that group problem-solving coordination will improve group performance, because it enables group members to pool their knowledge and expertise together to collectively discover effective and efficient strategies to accomplish their tasks (Andres & Zmud, 2002; Okhuysen & Eisenhardt, 2002). Group problem-solving coordination allows groups to identify problem sources and develop better solutions. The knowledge integration literature provides support for this relationship. For instance, Grant (1996) theorizes that high-interaction group problem solving is one of the primary coordination mechanisms to achieve effective knowledge integration. Okhuysen and Eisenhardt (2002) find that following exposure to CINT, groups engaged in group problem-solving coordination. Group members collectively sought different kinds of evidence to identify the problem and continuously pursued the contribution of all members. This coordination mechanism enabled groups to effectively integrate the separate pockets of knowledge of their members, create new knowledge, and adaptively improve the groups' tasks. Andres and Zmud (2002) find that groups engaging in organic coordination increased their information exchange, which led to significant improvements in group performance and process satisfaction. Hence, our final proposition (Appendix D summarizes all the propositions):

P20: The greater the group problem-solving coordination, the higher the group performance.

4 Discussion

Past research provides separate insights into the immediate effects of work interruptions on individuals and on groups. However, its focus has been on interruptions as discrete one-time events that produce a relatively localized impact, rather than on the actions and interactions that occur during interruption episodes that can strengthen or weaken the impact of interruptions or extend it to groups. Consequently, our knowledge of the processes and mechanisms through which interruptions targeting individuals may affect other members of groups remains limited and undertheorized. Further, the extant research has not theorized the impact of using capabilities of CT to respond to interruptions during interruption episodes (after the initial interruption trigger).

The present paper addresses these two knowledge gaps. We ask the following question: How do work interruptions that target a single individual ripple out to others, and with what outcomes? Our theoretical model suggests that owing in part to group interdependencies, the impact of work interruptions is not localized. In fact, the impact can be assessed at multiple levels of analysis as a result of the actions and interactions instigated by individuals exposed to interruptions and the usage of CT capabilities. We theorize three kinds of impact: (1) ripple effects, which explain how individual-level constraints created by interruptions produce constraints at the group level that are detrimental to group coordination and performance, (2) a cross-level direct effect, through which an individual's exposure to CINT enhances group coordination and, ultimately, performance, (3) and the multilevel effects of using CT capabilities during interruption episodes.

4.1 Contributions to Research and Practice

This paper contributes to research and practice. Our contribution to research is a theory that accounts for the multilevel effects of work interruptions and the role of the use of CT capabilities. This theory has implications for interruptions research, information systems research, and research on media use and media effects. Our work draws attention to the importance of examining the individual-to-group processes to better understand the impact of interruptions in group environments. Drawing on coordination theory and the group literature, we distinguish between two types of effects through which interruptions extend from individuals to groups: ripple effects that are detrimental to group performance and a cross-level direct effect that is beneficial to performance. The theory we develop can be used not only to study other types of interruptions but also other types of stressors in the work environment (e.g., complex task demands) that create individual-level constraints with the potential to affect other group members.

Furthermore, by accounting for the role of use of CT capabilities during interruption episodes, our theoretical model has implications for the interruptions literature—which dedicates scant attention to the role of media in interruptions—to consider the medium as well as the message. Our work also contributes to information systems research on media use and media effects. Our model suggests a complex role of the usage of the technology's capabilities and that there is no one medium or capability used that provides the best results. For example, rehearsing strengthens the negative effects of interruptions on an individual's perceptions of time pressure and cognitive workload, yet it weakens the spread of these effects to the group. It also lessens the positive effect of CINT on group problem-solving coordination. Usage of two other capabilities, namely communicating rapidly and using rich symbol sets, also have a mix of positive and negative effects when considering the multiple levels of analysis. By contrast, reprocessing and communicating in parallel have consistently negative effects at the different levels of analysis in our model.

Stated differently, our model suggests that while particular CT capabilities used during interruption episodes may weaken some of the negative impacts of work interruptions or strengthen some of the positive ones, there will always be negative outcomes—at one or more levels of analysis—associated with any CT capability used. In short, our research opens up the black box of technology and reveals its complex effects on the outcomes of interruptions.

An important implication of our analysis of the use of CT capabilities is its potential to extend research on media use and media effects to multilevel contexts. To our knowledge, this paper is the first to examine the effects of usage of CT capabilities at multiple levels of analysis. Our research can serve to guide research in developing an understanding of the multilevel effects of CT capabilities in other contexts and for other phenomena.

Further, our work extends media theories by shifting the focus from the physical media capabilities (e.g., rehearsability, reprocessability) to a user-centric perspective that accounts for how these capabilities are actually used (e.g., rehearsing, reprocessing). Media use has been recognized, but not directly examined, as a determinant of group outcomes (Dennis et al., 2008).

The present research can also be positioned more broadly within mainstream IS research that examines the relationship between technology and organization. For decades, researchers have argued that the impact of IT cannot be seen separately from the organizational practices and processes that happen around the technology use (e.g., Markus & Robey, 1988). More recently, research on sociomateriality and the affordance lens has looked at how technology and organizational practices are entangled (e.g., Jones, 2014). Our research contributes to this discourse by theorizing how the use of technology (i.e., technological capabilities used during interruptions episodes) can shape the evolving outcomes of organizational processes (i.e., the ripple effects of interruptions on groups). Importantly, we do so by theorizing this interplay between IT capabilities and organizational processes at multiple levels of analysis (the individual level, the group level, and the individual-to-group processes).

Our theory can also help practitioners to understand and manage the processes by which work interruptions lead to negative or positive outcomes in organizations. For example, groups can manage the ripple effects by directly intervening before the impact of individually experienced interruptions spreads within groups (e.g., by implementing programs that enhance group cohesion to reduce social loafing and/or temporal tensions). Even if the effects ripple out to other group members, our research identifies opportunities to intervene through coordination mechanisms (role switching; temporal coordination) to mitigate the adverse effects of interruptions. Alternatively, groups can be advised to limit their use of CT capabilities during interruption episodes, or at least to restrict the usage of the more harmful capabilities.

4.2 Limitations and Future Research

The present work has five limitations that can be addressed in future research. First, in theorizing the linkages between work interruptions and group performance, we considered only explicit coordination. Implicit coordination mechanisms (e.g., shared mental models; transactive memory) can be added to the model because they can also influence group performance (Espinosa, Lerch, & Kraut, 2004).

Second, future research can examine—both theoretically and empirically—the impact of work interruptions on groups in different task and media contexts. Our examination of the cross-level direct effect of CINT assumes that group members use CINT to resolve problems or discrepancies in their tasks and to converge on solutions. These types of tasks are known as convergence tasks (Dennis et al., 2008). However, group members may also use CINT to generate new ideas in their tasks (i.e., conveyance tasks) (Dennis et al., 2008). For conveyance tasks, usage of asynchronous CT capabilities is generally beneficial for groups (Dennis et al., 2008). Yet, it is unclear whether usage of those CT capabilities would still be beneficial when done during interruption episodes. Alternatively, comparing media contexts (e.g., interruptions delivered by synchronous or asynchronous media) could also provide important insights. While recent evidence suggests that synchronous and asynchronous interruptions may have different effect magnitudes on individuals (Nees & Fortna, 2015), efforts are needed to examine whether these differences extend to groups.

Third, our conceptualization of the use of CT capabilities does not consider the heterogeneous ways with which individuals can appropriate and use the technology. Our theory can be extended by using an affordance lens to provide insights into how or why individuals use CT capabilities the way they do, depending on their goals and the technology's affordances, and with what results.

Fourth, our theory development efforts are guided by parsimony at the expense of excluding moderating effects that could add precision to the theory. Our model can be extended by including additional moderating variables that elucidate under what conditions the relationships we develop are expected to hold or to be stronger. As an example, group size may negatively moderate the relationship between CINT and group problem solving coordination. Indeed, larger groups can struggle in coordinating problems revealed by CINT because of the increased communication and coordination costs incurred by adding more members (Brooks, 1979).

Finally, we have essentially developed a variance model that explains relationships between variables. While our model employs a limited use of process logic to explain the causal relationships (i.e., how the individual-level constraints lead to group-level constraints), it is less capable of accounting for the complexities of processes, events, and interactions that unfold and change over time. Future research can move from employing process as an explanation of variance effects to a deeper use of process theory (Burton-Jones, McLean, & Monod, 2015) to enrich our understanding of the multilevel effects of work interruptions as they develop over time.

5 Conclusion

Little attention has been given to studying how interruptions might spread from an individual to a group. Our work theorizes the processes through which work interruptions that target an individual extend to groups and the role of use of CT capabilities during interruption episodes. Rather than examining interruptions as isolated events, we focus on interruption episodes that extend over time and during which group members' actions and interactions through CT can shape the effects of exposure to interruptions. We develop a conceptual multilevel model that examines these processes and outcomes. We argue that incongruent interruptions (IINT) have effects that ripple out to groups and ultimately decrease group performance. Groups mitigate these effects by applying task organization coordination. We also propose that congruent interruptions (CINT) are beneficial to group performance because they enable group problem-solving coordination. Using CT capabilities during interruption episodes has multilevel moderation effects.

Our work is important for research on technology-mediated interruptions, as it helps bridge between the individual and group levels of analysis, and contributes to IS research seeking to understand the multilevel effects of CT. It also informs practitioners about measures that can be taken to control the impact of interruptions both before and after they spread within groups.

While this research answers several questions about the multilevel effects of work interruptions, it also opens new avenues for future research. Because we have articulated the theoretical components, defined the key constructs, and specified all propositions precisely, we have generated a theory that is falsifiable (Weber, 2012). Testing the theory empirically will require developing reliable and valid measures of IINT and CINT. Several approaches can be used to obtain these measures—each with advantages and disadvantages—such as self-reported measures, direct observation, or diary studies. Testing the model will also require the use of multilevel modeling techniques. We hope that this paper will stimulate thinking on this important phenomenon and that our theoretical model can serve as a foundation for future theoretical and empirical research on the topic.

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Appendix A: Conceptual Definitions

Concept	Dimensions	Conceptualization
Work interruptions Temporary suspensions of an individual's primary task activities to process information that is delivered by different media including face-to-face (F2F), telephone, and communication technologies (CT) such as email, texting, instant messaging, video conferencing, and social media. The level of analysis constitutes interruption episodes, rather than individual interruption events.	Incongruent interruptions (IINT)	Interruptions that provide or request information or actions that are not relevant for one's primary activities. They may be related to secondary work activities (e.g., message from a coworker requesting help with a work-related issue), or activities that are unrelated to work (e.g., a message regarding a social event).
	Congruent interruptions (CINT)	Interruptions that provide task-pertinent information reveal discrepancies in task processes or outcomes, or request actions that are relevant or complementary to performing one's primary task activities. These interruptions typically concern task-related problems that need to be solved (e.g., clarifying user requirements in a software development project) or decisions that are made (e.g., prioritizing user requirements).
Use of CT capabilities An individual's employment of different CT capabilities during interruption episodes to address the interruptions' demands, communicate reactions to interruptions, or manage the consequences of interruptions.	Rehearsing	The extent to which an individual reviews or fine-tunes their messages before sending them.
	Reprocessing	The extent to which an individual reexamines or processes prior messages again (own or received from others).
	Communicating in parallel	The extent to which an individual engages in multiple conversations simultaneously (i.e., within a given interruption episode).
	Communicating rapidly	The speed with which an individual engages in conversations and receives feedback.
	Using rich symbol sets	The number of ways in which an individual communicates their messages using various types of symbols.

Appendix B: Effects of Use of CT Capabilities

Impact of Usage of CT Capabilities on Individual-Level Effects					
Outcome Impacted	**Rehearsing**	**Reprocessing**	**Communicating in parallel**	**Using rich symbol sets**	**Communicating rapidly**
Time pressure	**P1a:** Positive moderation: planning, editing, and reviewing the intended message and tailoring it to the specific audience, on top of being interrupted [R,C,M][+]	**P2a**: Positive moderation: storing and accessing context of messages, reading and rereading, on top of being interrupted [R,C,M]	**P3a**: Positive moderation: fragmented conversations with multiple others, on top of being interrupted [R,C,M]	**P4a**: Negative moderation: time pressures curbed through use of rich cues (e.g., visual, video, vocal, emoticons, etc.) [R,C,M]	No effect
Cognitive workload	**P1b:** Positive moderation: planning, editing, and reviewing the intended message and tailoring it to the specific audience, on top of being interrupted [R,C,M]	**P2b**: Positive moderation: storing and accessing context of messages, reading and rereading, on top of being interrupted [R,C,M]	**P3b**: Positive moderation: fragmented conversations with multiple others, on top of being interrupted [R,C,M]	**P4b**: Negative moderation: cognitive workload curbed through use of rich cues (e.g., visual, video, vocal, emoticons, etc.) [R,C,M]	**P5**: Positive moderation: need to coordinate rapid exchanges [R,C,M]
Time delays	**P1c**: Positive moderation: planning, editing, and reviewing the intended message and tailoring it to the specific audience, on top of being interrupted [R,C,M]	**P2c**: Positive moderation: storing and accessing context of messages, reading and rereading, on top of being interrupted [R,C,M]	**P3c**: Positive moderation: fragmented conversations with multiple others, on top of being interrupted [R,C,M]	**P4c**: Negative moderation: time delays curbed through use of rich cues (e.g., visual, video, vocal, emoticons, etc.) [R,C,M]	No effect
Output errors	No effect	No effect	No effect	No effect	No effect
Impact of Usage of CT Capabilities on Ripple Effects					
Outcome Impacted	**Rehearsing**	**Reprocessing**	**Communicating in parallel**	**Using rich symbol sets**	**Communicating rapidly**
Collective time pressure	**P7a**: Negative moderation through emotional contagion: thinking, rehearsing, and providing a measured response [C]	No effect	**P9a**: Positive moderation through emotional contagion: stress and emotions spread widely and simultaneously [C]	Inconclusive evidence on whether using rich symbol sets increases or decreases emotional contagion	**P11a**: Positive moderation through emotional contagion: stress and emotions spread rapidly [C]
Collective cognitive workload	**P7b**: Negative moderation through emotional contagion: thinking, rehearsing and providing a measured response [C]	No effect	**P9b**: Positive moderation through emotional contagion and switching costs: • Stress and emotions spread widely and simultaneously [C] • Increased switching between fragmented conversations [R,C,M]	Inconclusive evidence on whether using rich symbol sets increases or decreases emotional contagion	**P11b**: Positive moderation through emotional contagion: stress and emotions spread rapidly [C]

Collective time delays	Counteracting effects through sequential workflow disruption and temporal tensions, leading to no net effect: • Positive moderation: delayed information transmission disrupts sequential workflow [R, M] • Negative moderation: being more considerate and attentive to audience creates a harmonious communication environment that eases temporal tensions [R, C, M]	**P8**: Positive moderation through sequential workflow disruption: delayed information transmission disrupts sequential workflow [R, M]	Counteracting effects through sequential workflow disruption and temporal tensions, leading to no net effect: • Positive moderation: fragmented conversations distract group members and hinders development of a harmonious communication environment [R, C, M] • Negative moderation: sharing unique pieces of information about interruptions or their consequences without excessive turn taking, leading to greater and faster information flow [R, M]	**P10**: Negative moderation through temporal tensions: temporal tensions curbed through use of rich cues (visual only) [R,C,M]	Counteracting effects through sequential workflow disruption and temporal tensions, leading to no net effect: • Positive moderation: sending responses rapidly without considering impact on audience [C, M] • Negative moderation: sharing information about interruptions or their consequences rapidly, leading to greater and faster information flow [R,M]
Collective output errors	No effect	No effect	No effect	No effect	No effect
Impact of Usage of CT Capabilities on Cross-Level Direct Effect					
Outcome Impacted	**Rehearsing**	**Reprocessing**	**Communicating in parallel**	**Using rich symbol sets**	**Communicating rapidly**
Group problem-solving coordination	**P15**: Negative moderation: carefully crafting message responses, rather than converging on common understandings [R,C,M]	**P16**: Negative moderation: reexamining and scrutinizing messages rather than focusing on reconciling different viewpoints and mutually agreeing on a solution [R,C,M]	**P17**: Negative moderation: fragmented conversations with multiple others hinder information integration, problem solving, and developing a shared understanding [R,C,M]	**P18**: Positive moderation: use of rich cues (e.g., visual, video, vocal, emoticons, etc.) supports shared understanding and convergence [R,M]	**P19**: Positive moderation: continuous exchanges and quicker feedback, supporting convergence and shared understanding [R,M]

+ Within the brackets, we illustrate the type(s) of communicative actions for which the CT capabilities are used:

[R]: Directly responding to the interruptions' demands, such as by replying or doing specific actions called for in the interrupting message(s).

[C]: Communicating one's reaction to the interruptions, such as by expressing emotional distress or alerting other members that one's work is falling behind because of the interruptions.

[M]: Managing the consequences of the interruptions with other group members, such as by discussing how to continue or rearrange the work that was interrupted.

Appendix C: Nature of the Collective Constructs

Criteria	Individual time pressure and collective time pressure	Individual cognitive workload and collective cognitive workload	Individual time delays and collective delays	Individual output errors and collective errors
Meaning of constructs across levels (similar or different content)	Similar	Different	Different	Different
Nature of ripple effect (isomorphic or discontinuous)	Isomorphic	Isomorphic (for emotional contagion) and discontinuous (for social loafing and switching costs)	Isomorphic (for temporal tensions) and discontinuous (for sequential workflow constraints)	Discontinuous
Contextual constraints (sharing or flow dependencies)	Sharing dependencies	Sharing dependencies	Sharing dependencies (for temporal tensions) and flow dependencies (for sequential workflow constraints)	Flow dependencies
Conditional nature of ripple effect (conditional or unconditional)	Conditional on actions and interactions related to expressing distress (see Table 2)	Conditional on actions and interactions related to expressing distress (see Table 2), withholding effort expenditure, or managing the consequences of interruptions (switching to teamwork)	Conditional (for temporal tensions) and unconditional (for sequential workflow constraints)	Unconditional (no specific action needed to trigger ripple effect; errors simply need to go undetected)

Appendix D: Summary of Propositions

The ripple effects of IINT and CINT and the use of CT capabilities	Impact of use of CT capabilities on individual-level effects	P1a: Rehearsing will moderate the effects of IINT and CINT on individual time pressure such that the greater the use of rehearsing, the stronger the effect.
		P1b: Rehearsing will moderate the effects of IINT and CINT on individual cognitive workload such that the greater the use of rehearsing, the stronger the effect.
		P1c: Rehearsing will moderate the effect of IINT on individual time delays such that the greater the use of rehearsing, the stronger the effect.
		P2a: Reprocessing will moderate the effects of IINT and CINT on individual time pressure such that the greater the use of reprocessing, the stronger the effect.
		P2b: Reprocessing will moderate the effects of IINT and CINT on individual cognitive workload such that the greater the use of reprocessing, the stronger the effect.
		P2c: Reprocessing will moderate the effect of IINT on individual time delays such that the greater the use of reprocessing, the stronger the effect.
		P3a: Communicating in parallel will moderate the effects of IINT and CINT on individual time pressure such that the greater the use of parallel communicating, the stronger the effect.
		P3b: Communicating in parallel will moderate the effects of IINT and CINT on individual cognitive workload such that the greater the use of parallel communicating, the stronger the effect.

		P3c: Communicating in parallel will moderate the effect of IINT on individual time delays such that the greater the use of parallel communicating, the stronger the effect.
		P4a: Using rich symbol sets will moderate the effects of IINT and CINT on individual time pressure such that the greater the use of rich symbol sets, the weaker the effect.
		P4b: Using rich symbol sets will moderate the effects of IINT and CINT on individual cognitive workload such that the greater the use of rich symbol sets, the weaker the effect.
		P4c: Using rich symbol sets will moderate the effect of IINT on individual time delays such that the greater the use of rich symbol sets, the weaker the effect.
		P5: Communicating rapidly will moderate the effects of IINT and CINT on individual cognitive workload such that the greater the use of rapid communicating, the stronger the effect.
	Individual-level constraints and group-level constraints (the ripple effects)	P6a: The greater the individual time pressure induced by IINT or CINT, the greater the collective time pressure.
		P6b: The greater the individual cognitive workload induced by IINT or CINT, the greater the collective workload.
		P6c: The longer the individual time delays induced by IINT, the longer the collective delays.
		P6d: The greater the number of individual output errors induced by IINT, the greater the number of collective errors.
	Impact of use of CT capabilities on ripple effects	P7a: Rehearsing will moderate the ripple effect of time pressure occurring through emotional contagion such that the greater the use of rehearsing, the weaker the effect.
		P7b: Rehearsing will moderate the ripple effect of cognitive workload occurring through emotional contagion such that the greater the use of rehearsing, the weaker the effect.
		P8: Reprocessing will moderate the ripple effect of time delays occurring through sequential workflow disruption such that the greater the use of reprocessing, the stronger the effect.
		P9a: Communicating in parallel will moderate the ripple effect of time pressure occurring through emotional contagion such that the greater the use of parallel communicating, the stronger the effect.
		P9b: Communicating in parallel will moderate the ripple effects of cognitive workload occurring through emotional contagion and switching costs such that the greater the use of parallel communicating, the stronger the effect.
		P10: Using rich symbol sets (visual displays) will moderate the ripple effect of time delays occurring through temporal tensions such that the greater the use of rich symbol sets, the weaker the effect.
		P11a: Communicating rapidly will moderate the ripple effect of time pressure occurring through emotional contagion such that the greater the use of rapid communicating, the stronger the effect.
		P11b: Communicating rapidly will moderate the ripple effect of cognitive workload occurring through emotional contagion such that the greater the use of rapid communicating, the stronger the effect.
	Group-level constraints and group performance	P12: The greater the group-level constraints (collective time pressure, collective workload, collective time delays, collective errors), the lower the group performance.

	Moderating effects of task organization coordination	P13a: Role switching will moderate the relationship between group-level constraints and group performance such that the greater the use of role switching, the weaker the effect of group-level constraints on group performance.
		P13b: Temporal coordination will moderate the relationship between group-level constraints and group performance such that the greater the use of temporal coordination, the weaker the effect of group-level constraints on group performance.
The cross-level direct effect of CINT and the use of CT capabilities	CINT and group problem-solving coordination	P14: The greater the exposure to CINT, the greater the group problem-solving coordination.
	Impact of use of CT capabilities on cross-level direct effect	P15: Rehearsing will moderate the effect of CINT on group problem-solving coordination such that the greater the use of rehearsing, the weaker the effect.
		P16: Reprocessing will moderate the effect of CINT on group problem-solving coordination such that the greater the use of reprocessing, the weaker the effect.
		P17: Communicating in parallel will moderate the effect of CINT on group problem-solving coordination such that the greater the use of parallel communicating, the weaker the effect.
		P18: Using rich symbol sets will moderate the effect of CINT on group problem-solving coordination such that the greater the use of rich symbol sets, the stronger the effect.
		P19: Communicating rapidly will moderate the effect of CINT on group problem-solving coordination such that the greater the use of rapid communicating, the stronger the effect.
	Group problem-solving coordination and group performance	P20: The greater the group problem-solving coordination, the higher the group performance.

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