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No teleworker is an island: The impact of temporal and spatial separation along with media use on knowledge sharing networks

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Abstract

Despite its prevalence, there is a lack of understanding regarding the effect of telework on an organization's knowledge base. Recognizing the enabling role of electronic communication media, this article therefore addresses the interaction effects of media synchronicity and temporal as well as spatial separation among colleagues on sharing in knowledge networks. Special attention is paid to knowledge awareness (a form of metaknowledge representing "who knows what") as well as homogeneous and heterogeneous knowledge sources to further explicate the relationship between coworker separation and knowledge sharing. Multiple surveys were placed between two smaller ethnographic investigations and combined with whole network data to form an in-depth study of 64 knowledge workers at a medium-sized European research and advisory organization. The results reveal that spatial separation directly reduces the frequency of knowledge sharing between colleagues, whereas temporal separation affects knowledge sharing through reduced knowledge awareness, resulting in lower job and proactive performance. The use of asynchronous media can serve to mitigate most of the negative effects of spatial separation on knowledge sharing but may also exacerbate the negative effect of temporal separation on teleworkers' knowledge awareness of colleagues with identical expertise.

Keywords

innovation, media synchronicity theory, performance, structural social capital, telework

Introduction

The ubiquitous presence of powerful mobile computers, a high penetration rate of cheap and reliable broadband communications, unified communication and collaboration software, cloud computing, and software as a service solutions have changed the way we work and live. One of these changes is that in the past two decades, teleworking has become a viable alternative to regular office-based work for most job types and functions—especially knowledge work. Recent census data from the European Union and United States show that approximately 15% and 22% of employees (respectively) telework at least "some of the time" (Eurostat, 2017; US Department of Labor, 2017). With the help of aforementioned information and communication technologies (ICTs), these employees can work at any time and at any place without losing touch with their colleagues in the organization. Yet research has shown that such "losing touch" with others through temporal or spatial separation offers certain productivity benefits (such as increased privacy or reduced work interruptions; Espinosa, Nan, & Carmel, 2015) and that teleworkers may therefore use the connective capabilities offered by ICTs in a strategic fashion to further increase (rather than decrease) their separation (Leonardi, Treem, & Jackson, 2010). While such

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choices might improve teleworkers' performance in the short term, it may be harmful in the mid to long term as the distance involved may negatively impact an organization's knowledge base as well as interdependent and collaborative work elements. Several multinational firms (including Yahoo!, Best Buy, and HP) have therefore abandoned or severely curtailed telework practices in recent years, claiming that doing so will create a "connected workforce [which is] more collaborative, productive, and knowledgeable" (Hesseldahl, 2013). Whether such claims are warranted is yet to be seen, however, as there has been hardly any research that has empirically assessed the impact of telework on actual knowledge sharing (Allen, Golden, & Shockley, 2015; Taskin & Bridoux, 2010). Our goal for this article is therefore to examine the effect of temporal and spatial separation on knowledge sharing as well as subsequent performance and to tease out possible interaction effects of communication media use. We do so via an in-depth study of interdependent teleworkers' knowledge networks, in which we pay special attention to the heterogeneity of knowledge being shared between these individuals.

The proposition that the competitiveness of modern organizations is increasingly based on their ability to acquire, transform, and exploit knowledge has become a common truism in management research. Organizations are considered part of the knowledge economy and employ knowledge workers, whose performance is generally the product of obtaining the right input from others to solve novel and complex problems (Davenport, 2005) and whose creativity and innovative capability is dependent on colleagues with heterogeneous knowledge (Tortoriello, Reagans, & McEvily, 2012). Given this importance of knowledge sharing for performance and innovation, it is not surprising that a considerable amount of research has focused on the antecedents of knowledge sharing behaviors and theories that might stimulate it. A theoretical framework that has received a lot of attention in this area is Nahapiet and Ghoshal's (1998) framework of social capital, which posits that networks of relationships—and the resources embedded within them—influence the extent to which interpersonal knowledge sharing occurs among actors within work groups (Yang & Farn, 2009; Yu, Hao, Dong, & Khalifa, 2013), intracorporate networks (Hau, Kim, Lee, & Kim, 2013; Maurer, Bartsch, & Ebers, 2011), and interorganizational/customer networks (Chen, Lin, & Yen, 2014; Tsai & Ghoshal, 1998; Yli-Renko, Autio, & Sapienza, 2001). The *structural* dimension of social capital is especially important in this regard, as it represents the presence or absence of network ties among actors (i.e. the "social network"; Nahapiet and Ghoshal, 1998). In the case of knowledge networks, this structural element encompasses not only the actual knowledge exchange among actors, but also their *knowledge awareness* (or *metaknowledge*): knowledge of "who knows what" (Leonardi, 2015), which serves as a precondition for individuals to reach out to others for knowledge (Alavi & Tiwana, 2002; Borgatti & Cross, 2003; He, Butler, & King, 2007). Social capital further contains a relational as well as a cognitive dimension, and it is stated that all three dimensions can easily be disrupted by the use of flexible (distributed) work practices (Huysman & de Wit, 2004). Yet whereas we know a great deal about these disrupting effects for certain types of distributed work (such as virtual teams or electronic networks of practice) and a little in the case of telework versus relational and cognitive dimensions of social capital (e.g. Golden, 2007; Golden & Raghuram, 2010), we know hardly anything about its structural effects on individual teleworkers as actors in a knowledge network (Peters & Batenburg, 2015). In this study, we therefore specifically focus on the structural dimension of social capital, for which we identified two principal paths through which telework may negatively impact knowledge sharing. The first (direct) pathway involves reduced opportunities for knowledge sharing due to increased temporal and spatial separation between employees in the network, whereas the second pathway investigates the mediating role of reduced knowledge awareness therein. In addition, we address the moderating role of communication media on these pathways; while prior studies on telework have firmly established the importance of communication media as an enabler of telework (Allen et al., 2015), many have treated these media as a singular artifact without further examination of their capabilities (e.g. Golden & Raghuram, 2010; Weber & Kim, 2015). To address this shortcoming, we draw on the theory of media synchronicity (Dennis, Fuller, & Valacich, 2008) and theorize how such synchronicity could help overcome temporal and spatial divides in relation to knowledge awareness and knowledge sharing.

To gain a better understanding of these conceptual relationships, we examine the knowledge sharing network belonging to the functional core of an organization involved in research and advisory functions to the government and the European Union. Individuals within this functional core belong to one of four distinct units as well as one or more of the organization's 17 cross-unit working groups that represent organization-wide areas of interest. The sharing of knowledge is seen as a critical success factor by the organization's management team and is also explicitly referred to in its mission statement. There is also a formalized teleworking program in place to support employees, providing absolute freedom regarding how often employees work outside of the office—from nearly full-time to not at all—as well as how often they work outside of regular 9-to-5 work schedules. All employees have desktop virtualization systems at their disposal and have access to (cloud-based) solutions for unified communication and collaboration.

The article is structured as follows. First, we present our theoretical logic and hypotheses, based on existing research on separation as well as structural social capital and media synchronicity. The resulting conceptual model is tested with three surveys among 64 knowledge workers (and their supervisors) from the research and advisory organization. The results of this study show that temporal and spatial separation both influence knowledge awareness through distinct causal pathways, and that communication media may serve to bridge spatial and exacerbate temporal divides. Finally, we conclude with an in-depth discussion regarding the explanations and implications of these findings.

Theory and hypotheses

Knowledge sharing and teleworker performance

The term telework may cover a variety of work arrangements, yet typically involves work that would normally be organized and performed at an employer's premises, but is instead carried out away from this office on a regular basis with the help of ICTs (Monks, de Buck, Müller, & Plassmann, 2006). Basic forms of telework (enabled by the telephone and mainframe technologies) have been around for nearly half a century. What started out as a solution for societal problems such as traffic congestion and pollution in densely populated areas (Nilles, Carlson, Gray, & Hanneman, 1976) was soon considered an idyllic work–life policy where "electronic cottages" would "glue the family together again [and] provide greater community stability" (Toffler, 1980, p. 219). Yet the uptake of telework by organizations since then has been slow (Siha & Monroe, 2006), which might partly be explained by its inconclusive effects on employee outcomes. Telework is found both positively and negatively related to individual factors such as morale, job satisfaction, commitment, engagement, and most notably performance (McCloskey & Igbaria, 2003; Pinsonneault & Boisvert, 2001). While meta-analytic studies show that the majority of findings indicate telework as a "good thing" for individuals (Gajendran & Harrison, 2007, p. 1535) and organizations (Martin & MacDonnell, 2012, p. 611), there has long been a lack of theoretical understanding as to why this would be the case—especially for the relationship between telework and performance (Bailey & Kurland, 2002). Suggested reasons for teleworker performance improvements include working at hours of optimal personal efficiency, stress reduction as a result of no commute, a willingness to work harder to "compensate" for idiosyncratic telework benefits, and being in a comfortable environment conducive to increased concentration (Gajendran, Harrison, & Delaney-Klinger, 2015; Westfall, 2004). These explanations, however, focus solely on the teleworker as an independent actor. Such a view does not accurately represent the majority of teleworkers, who are typically classified as knowledge workers (Moore, Rhodes, & Stanley, 2011; Peters & Batenburg, 2015) characterized by interdependence (Davenport, 2005). And it is in conjunction with this interdependence that telework-induced separation poses a possible threat to performance.

Numerous authors have asserted that telework leads to social and professional isolation (Nicklin, Cerasoli, & Dydyn, 2016) noting that teleworkers become invisible to their peers, miss out on spontaneous office interactions, receive less informal feedback and training, and lack social support needed for high performance (e.g. Cooper & Kurland, 2002; Golden, Veiga, & Dino, 2008; Whittle & Mueller, 2009). Yet hardly any studies have theoretically linked this risk of teleworker isolation with the risk of a deteriorating knowledge network (Taskin & Bridoux, 2010), and none have empirically examined this link (Allen et al., 2015; Peters & Batenburg, 2015). This is surprising, especially because the job performance of knowledge workers is considered dependent on the ability to obtain the right knowledge from others to solve novel and complex problems (Davenport, 2005). Obtaining the *right* knowledge means that it is not necessarily just the *amount* of knowledge sharing that benefits performance but much rather the *type* of knowledge that benefits performance. Network theory has shown that employees with connections that span functional, specialist, or business unit boundaries (i.e. those that have access to unique or *heterogeneous knowledge*) are more effective knowledge sharers who perform better (Cross & Cummings, 2004; Mesmer-Magnus, DeChurch, Jimenez-Rodriguez, Wildman, & Shuffler, 2011; Tsai, 2001; Wong, 2008). The reasoning behind this is that exchanging knowledge with someone who differs in terms of knowledge, know-how, or expertise provides the opportunity to look at one's own problem or task from an alternative perspective (Tortoriello et al., 2012). As such, heterogeneous knowledge sharing is beneficial not only to (in-role) job performance—as work output can, for instance, be of higher quality and more in line with requirements—but also to proactive (or innovator-based) performance (Tortoriello, McEvily, & Krackhardt, 2015) which is defined by one's level of creativity and innovation on the job (Griffin, Neal, & Parker, 2007; Welbourne, Johnson, & Erez, 1998). For years, knowledge has been considered the primary source of an organization's innovative potential (Grant, 1996; Newell, 2015; Zhou & Li, 2012), which is also reflected in the community networking model of knowledge management (Swan, Newell, Scarbrough, & Hislop, 1999). This model explicitly underwrites the importance of heterogeneous knowledge through an individual's boundary-spanning activities within knowledge networks for both sense making as well as the development and implementation of new ideas for innovation.

All of this is not to say that heterogeneous knowledge is easy to share. On the contrary, it is generally harder to share than homogeneous knowledge, as it is more difficult for the source and recipient to associate ideas with what they already know (Tortoriello et al., 2012). As such, heterogeneous knowledge is typically shared less often than homogeneous knowledge (Wei, Zheng, & Zhang, 2011). But when successfully shared, we expect heterogeneous knowledge to be of greater value to job and proactive performance. It is therefore that we formulate our first hypothesis:

> *Hypothesis 1*. Heterogeneous knowledge sharing has a stronger positive relation with (1) (in-role) job performance and (2) proactive performance than homogeneous knowledge sharing.

Sharing between separated employees

Negative social effects of telework stem from an increase in both temporal and spatial separation of teleworkers from colleagues in an organization. Yet research on *spatial* separation of employees dates back as far as several decades (e.g. Allen, 1977; Monge & Kirste, 1980), but relatively few empirical studies have incorporated the challenges—let alone a measured degree—of *temporal* separation in the context of collaborative work (Ibrahim, 2012; O'Leary & Cummings, 2007). This holds especially for telework research, where temporal separation is mostly an implicit dimension as the bulk of research has focused on extreme types of spatial separation from a physical location (e.g. fully at the office vs fully at home) as a proxy for separation from colleagues (Allen et al., 2015). For this reason, we propose to focus on a more fine-grained conceptualization of separation from colleagues, in which we tease out the effects of daily schedule and location differences between employees in conjunction with communication media use. This interaction effect is important, as each type of separation imposes distinct limits on communication. Whereas spatial separation only removes the ability for face-to-face communication, temporal separation also removes the ability for synchronous (real-time) communication (Marlow, Lacerenza, & Salas, 2017; O'Leary & Cummings, 2007). This might be why initial examinations showed that spatial divides are easier to bridge via communication media than temporal divides (Cummings, Espinosa, & Pickering, 2009). Temporal separation might therefore be considered more distant than spatial separation, which is why we expect that the network effects of the former will be more pronounced than those of the latter. In the remainder of this subsection, we discuss these direct effects of the interaction between communication media use and separation on knowledge (sharing) networks. An outline of the indirect effects via structural social capital is provided in the next subsection.

Past research efforts have found a strong relationship between dimensions of spatial distance and knowledge sharing (Weber & Kim, 2015). More specifically, we know that individuals naturally tend to place higher importance on what is closest to them and that they are more likely to interact and share knowledge with physically proximate others due to serendipitous interaction and sheer exposure (Allen & Henn, 2007). Physical proximity is furthermore preferred for tacit knowledge sharing, which is inherently rooted in action and based on involvement in a specific context (Roberts, 2000). When employees become separated in space, they lose their face-to-face knowledge sharing capability and instead have to rely on electronic communication media to bridge the lack of interactivity and natural (i.e. physical, visual, and verbal) symbol sets. Theoretically, highly synchronous media (such as videoconference) could help partly mitigate the loss of face-to-face communication (Dennis et al., 2008) and thus reduce such negative effects of spatial separation on knowledge sharing. Yet prior qualitative investigations have shown that in practice teleworkers rather prefer to use less synchronous media to reap the benefits of separation (Leonardi et al., 2010)—a choice that would likely exacerbate the negative effect of spatial separation on (tacit) knowledge sharing.

One might expect the effect of temporal separation from colleagues to be similar to that of spatial separation; after all, each deviates from the optimal "same time, same place" situation and increases distance. Yet temporal separation is unique in that it reduces the time available for real-time interaction, thereby further restraining choices in how and when to communicate. Temporally separated individuals that rely primarily on highly synchronous media will thus have fewer (and less regular) opportunities for communication (Espinosa et al., 2015; Marlow et al., 2017), which will negatively impact the frequency of knowledge sharing between colleagues. The alternative, using asynchronous media, may help partially maintain the frequency of knowledge sharing (potentially at a lower quality) across working times, although—overall—this frequency will still be negatively affected as sharing costs will be higher. Specifically, the combination of temporal separation and asynchronous media use (such as e-mail) requires the development of new signaling strategies and interaction routines (Thatcher & Zhu, 2006), making knowledge sharing more arduous, formalized, and less spontaneous (Bélanger & Allport, 2008). This difference between the two types of separation and their interaction effects with the level of communication media synchronicity is reflected in the following hypotheses:

> *Hypothesis 2*. The negative effect of teleworkers' temporal separation from colleagues on the frequency of knowledge sharing with these colleagues will be more pronounced than the negative effect of teleworkers' spatial separation.

> *Hypothesis 3a*. The use of communication media with higher synchronicity positively moderates the relationship between teleworkers' temporal separation from colleagues

and the frequency of knowledge sharing with these colleagues, such that for high levels of synchronicity the negative effect of temporal separation on the frequency of knowledge sharing will be more pronounced.

Hypothesis 3b. The use of communication media with higher synchronicity negatively moderates the relationship between teleworkers' spatial separation from colleagues and the frequency of knowledge sharing with these colleagues, such that for high levels of synchronicity the negative effect of spatial separation on the frequency of knowledge sharing will be less pronounced.

Teleworkers' structural social capital

Temporal and spatial separation could, in addition to their aforementioned *direct* effect on knowledge sharing, also have an *indirect* effect through structural social capital. This principal dimension of social capital posits that an employee's network of working relationships can supplement his or her ability to adequately respond to problems or tasks at work (Nahapiet & Ghoshal, 1998) and is typically operationalized as relationship strength between dyadic linkages or through network properties such as structural equivalence, network range, cohesion, or network density (Reagans & McEvily, 2003; Wong, 2008). In our case of knowledge networks, we focus on the development of dyadic sharing linkages, which requires that individuals have developed an overview of "who knows what" in the organization (Alavi & Tiwana, 2002; Borgatti & Cross, 2003; He et al., 2007). This prerequisite is better known as knowledge awareness (Cross & Cummings, 2004) or meta-knowledge (Leonardi, 2015) of an individual (forming the basis for related concepts on the level of team cognition, such as transactive memory systems or shared mental models). Prior research has shown that knowledge awareness stimulates knowledge sharing (Engelmann & Hesse, 2011) and that, through increased knowledge sharing, knowledge awareness improves job and proactive performance by enhanced knowledge recombination and reduced work duplication (Leonardi, 2014; Majchrzak, Cooper, & Neece, 2004). We therefore hypothesize as follows:

Hypothesis 4. The knowledge awareness level of teleworkers is positively related to their frequency of knowledge sharing with colleagues.

Knowledge awareness can develop through both interpersonal and technology-mediated interaction (Leonardi, 2014; Moreland, 1999). Prior studies have shown that from an interpersonal perspective physically proximate employees engage in higher levels of self-disclosure; as they come to know each other better and overhear or observe each other in action, colleagues develop a more accurate as well as current understanding of their work and expertise (Allen & Henn, 2007; Borgatti & Cross, 2003). In this sense, both spatial and temporal separation are expected to (increasingly) inhibit the development and maintenance of knowledge awareness (Alavi & Tiwana, 2002). As with the frequency of knowledge sharing, so too will the level of knowledge awareness be negatively affected by reduced and irregular opportunities for real-time interaction with colleagues. The use of highly synchronous media could help partly mitigate this loss for spatial separation (Dennis et al., 2008), but this will not be possible for those who are temporally separated—thus potentially exacerbating the effect. For temporally separated individuals, it might therefore be more advantageous to use asynchronous communication media that enable a high level of parallelism and make communication visible to others in the organization. This means that the number of individuals that can "digitally overhear" and be informed of people's knowledge through asynchronous media such as instant messaging and e-mail is much larger than the relatively small audience that is typically reached via more synchronous media (Leonardi, 2014). The positive effect of this increased reach for knowledge awareness is somewhat reduced, however, by the lack of rapid interactivity and natural symbol sets in asynchronous media (Dennis et al., 2008). This lack demands codification of knowledge and "knowers" (i.e. those who use knowledge to solve problems or transform their expertise, and whose characteristics would have to be documented—see Kotlarsky & Scarbrough, 2014), which requires time and ongoing effort to adequately maintain in the face of a continuously changing knowledge base.

Empirical investigations into the potential role of communication media for maintaining the knowledge awareness of separated individuals are small in number and have thus far yielded ambiguous results. Kanawattanachai and Yoo (2007), for instance, found that virtual teams of MBA students were able to develop knowledge awareness through the use of mailing lists, whereas He et al. (2007) contradict this finding; in their case, the frequency of e-mail interaction among partially separated undergraduate project teams had no effect on knowledge awareness. We posit that this difference in findings could (in part) be the result of a difference in the extent of temporal and spatial separation of their respective subjects. Where the MBA students of Kanawattanachai and Yoo (2007) were unable to meet in person and had to solely rely on asynchronous media, the undergraduate students of He et al. (2007) could meet face to face or via teleconference whenever they preferred. Whether these results hold in actual organizations is unclear, but they do illustrate the need for additional research in this area as the findings hint at the potential interaction effect of separation and asynchronous media use:

Hypothesis 5. The negative effect of teleworkers' temporal separation from colleagues on their level of knowledge awareness will be more pronounced than the negative effect of teleworkers' spatial separation.

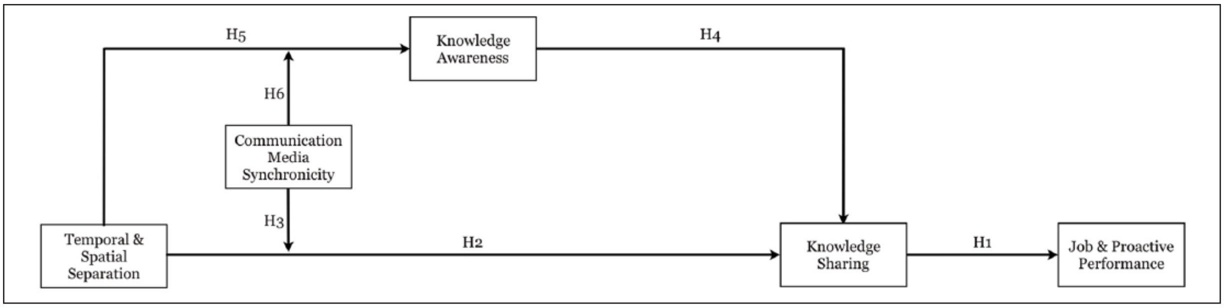

Figure 1. Conceptual model.

Hypothesis 6a. The use of communication media with higher synchronicity positively moderates the relationship between teleworkers' temporal separation from colleagues and their level of knowledge awareness, such that for high levels of synchronicity the negative effect of temporal separation on the level of knowledge awareness will be more pronounced.

Hypothesis 6b. The use of communication media with higher synchronicity negatively moderates the relationship between teleworkers' spatial separation from colleagues and their level of knowledge awareness, such that for high levels of synchronicity the negative effect of spatial separation on the frequency of knowledge sharing will be less pronounced.

The conceptual model in Figure 1 provides an overview of our hypotheses and forms the basis for our empirical investigation. In the next section, we will discuss the methodological specifics of this investigation.

Methodology and data analysis

Study setting and sampling

To empirically test our hypotheses, we examined a knowledge-intensive, semi-public organization of approximately 300 full-time equivalents (FTEs) that is involved in research and advisory functions to the government and the European Union. The organization operates from a single (centralized) location but enables all of its employees to telework via a company token and desktop virtualization system, which allows remote access to the company's digital work environment on a company-issued thin client laptop. Also, several solutions for enterprise unified communication and collaboration (i.e. Skype for Business, SharePoint, and an in-house project management system) are available through the virtual desktop and a company-issued smartphone. This ensured that employees had communication media with various degrees of synchronicity at their disposal. Employees are given a lot of autonomy in their work, and they can decide for themselves when, where, how, and on which projects they would like to work. There are no limitations on the timing or number of days they can telework, though employees are expected to keep the interests of the company at heart when they make their decisions regarding work times and locations.

Data collection took place in 2014—2 years after the organization introduced its active teleworking program—and consisted of three separate online surveys to prevent common method bias and survey fatigue. In addition, we used the "ethnographic sandwich" approach, placing our quantitative studies between two smaller ethnographic investigations (consisting of participant observations and interviews). The goal of this method is to better align the research question and approach with its context, and to better interpret the findings once these have been obtained (Ofem, Floyd, & Borgatti, 2012). To ensure that we could do a whole (bounded) network survey, we limited our sample to 90 interdependent knowledge workers who are involved in the organization's primary (core) advisory function. Each of these knowledge workers belongs to one of four distinct units, as well as one or more of the organization's 17 cross-unit working groups (which cover areas of interest in which best practices and related knowledge are shared).

Through our initial qualitative investigation of these units and working groups, we were able to compile a list of 30 areas of expertise that were used by the organization to categorize its shared work projects. Questions regarding these 30 areas of expertise were part of a social network survey, in which we also gathered sociometric data on temporal and spatial separation, knowledge awareness, and knowledge sharing (77% response rate). Data on communication synchronicity were obtained via a second survey to the participants (71% response rate), which also asked for the number of work hours and years of tenure within the organization. The latter two questions serve as controls to rule out (partial) spurious effects with the aforementioned measures. Finally, we obtained data on job and proactive performance via a third survey to the participants' supervisors (80% response rate). The three surveys combined led to a unique dataset consisting of 64 participants, including 27 males and 37 females with ages spread almost evenly from 25 to 66 years. All participants were highly educated, with doctorate (45%) or graduate (55%) degrees.

Table 1. Quality criteria of survey measures.

Measures and items	Mean	SD	Standard factor loading	AVE	CR	CA
Job (in-role) performance (based on Welbourne et al., 1998)				0.708	0.922	0.913
JP1. The quality of [name]'s work output is good.	4.08	0.84	0.950			
JP2. [Name] is a highly productive employee.	3.70	1.05	0.694			
JP3. [Name] is an effective employee.	4.02	0.86	0.963			
JP4. [Name] regularly misses [his or her] deadlines.[a]	3.66	0.88	0.640			
JP5. The work output of [name] typically meets the corresponding requirements.	4.05	0.83	0.904			
Proactive performance (based on Welbourne et al., 1998)				0.829	0.951	0.950
PP1. [Name] regularly thinks of new ideas and new approaches to problems.	3.38	1.05	0.943			
PP2. [Name] regularly supports new ideas that benefit the organization.	3.56	0.91	0.893			
PP3. [Name] cannot be counted on to consider improved methods or procedures to do [his or her] job.[a]	3.39	0.97	0.913			
PP4. When a non-routine business situation arises, [name] is able to develop new ways of dealing with this situation.	3.62	1.00	0.892			

SD: standard deviation; AVE: average variance extracted; CR: composite reliability; CA: Cronbach's α.
[a]Responses have been reversed prior to evaluation.

Measures

For our measuring instrument, we mostly relied on existing studies to create seven measures that fit the organizational context. The basis for the two composite measures—all of which were measured with Likert-type scales ranging from 1 = "completely disagree" to 5 = "completely agree"—is summarized in Table 1. In addition, the sociometric questions for knowledge awareness and knowledge sharing were based on Cross and Cummings (2004) and the score for communication synchronicity was based on Dennis et al. (2008). The measures for temporal and spatial separation were newly designed. In the final stages of survey development, the measures were discussed and pretested by several participants, which led to minor changes in question wording as well as the addition of fill-in instructions. What follows is an outline of the questions, scales, and calculations for each of these measures.

Temporal and spatial separation. To assess the temporal and spatial separation from colleagues, each participant was asked to indicate—for a typical workweek—their working times and locations on a 3×5 "time/place grid" outlining the times of the day (morning, afternoon, and evening) and days of the week (Monday through Friday). Participants were asked to only fill out a time slot with a location (at the office or elsewhere) if they actually worked at this location for at least 2 h during the time slot. Table 2 provides an example of the grid and summarizes the total percentage of employees working at certain times and locations. The separation scores for each participant were calculated by dividing the number of slot combinations that do not temporally/spatially overlap (with those of all the other colleagues) by the potential maximum of overlapping slots: 945 in case of temporal separation (15 slots × (N – 1) participants) and 630 in case of spatial separation (10 slots × (N – 1) participants). Note that the total number of available slot combinations for spatial separation is lower due to the fact that co-location at the office is not possible during the evenings (see Table 2).

Table 2. Time/place grid with percentages of employees working - (at the office).

	Morning	Afternoon	Evening
Monday	80% – (38%)	83% – (41%)	16% – (0%)
Tuesday	91% – (64%)	92% – (66%)	13% – (0%)
Wednesday	83% – (44%)	75% – (48%)	20% – (0%)
Thursday	94% – (75%)	97% – (80%)	14% – (0%)
Friday	75% – (25%)	66% – (23%)	11% – (0%)

Communication synchronicity. The teleworkers in our study typically use a variety of electronic communication media to connect with colleagues and share knowledge. These media can be categorized as (1) videoconference, (2) telephone conference, (3) instant messaging, (4) electronic project spaces, and (5) e-mail. Categories can cover several technologies: for instance, telephone calls can take place via the organization's conference room system, via mobile phone, or via the voice-over-IP system (available through the virtual desktop). Similarly, technologies can cover multiple media: the unified communications and collaboration software—which offers instant messaging as well as video and teleconference possibilities—is an example of this. To obtain a good image of the level of synchronicity of the participants' typical media usage

Table 3. Media capabilities and communication synchronicity score.

Medium	Media capabilities						Communication synchronicity[a]
	Transmission velocity (+)	Symbol sets (+)	Parallelism (–)	Rehearsability (–)	Reprocessability (–)	Score	Overall
Videoconference	High	Few–Medium	Low–Medium	Low	Low	3	High
Telephone conference	Medium–High	Few	Low–Medium	Low	Low	2.5	Medium
Instant messaging	Medium–High	Few–Medium	Low–Medium	Medium	Medium–High	1.5	Medium
Electronic project space	Low–Medium	Few–Medium	Medium	High	High	0.5	Low
E-mail	Low–Medium	Few–Medium	High	High	High	0	Low

[a]In case of ranged rankings (e.g. Few–Medium), the highest ranking is used for the calculation of the synchronicity score.

repertoire, we asked them to give an indication of how they typically contact their colleagues by distributing 100 points across the five aforementioned media categories. This distribution is then multiplied with synchronicity scores for each medium, which are based on five media capabilities: transmission velocity, symbol sets, parallelism, rehearsability, and reprocessability (Dennis et al., 2008). These capabilities are ranked on a 0–1 scale, where Low/Few = 0, Medium = 0.5, and High/Many = 1. Faster transmission velocity and more symbol sets are related to greater synchronicity, whereas higher levels of parallelism, rehearsability, and reprocessability are related to lesser synchronicity. To compute the synchronicity score, these rankings are added to (or subtracted from) a "medium" base score of 2: this results in synchronicity scores ranging from 0 (e-mail/low synchronicity) to 3 (videoconference/high synchronicity). Table 3 provides an overview of the media and their capabilities.

Knowledge awareness and sharing. We assessed knowledge awareness and sharing via the roster method (listing all 90 colleagues involved in the organization's primary advisory function) in conjunction with single sociometric questions, as is common in sociometric surveys (Borgatti & Cross, 2003). To ensure that our measures were appropriate, we constructed items that were specific and focused on long-term patterns rather than one-time events. A roster approach typically enhances the user friendliness of a survey and improves the accuracy of reports on weaker ties (Ferligoj & Hlebec, 1999).

For the directed knowledge awareness network, the participants were asked to assess for each colleague on the roster to what extent they are aware of the colleague's knowledge and expertise (from 0 = "not at all aware" to 4 = "very well aware"). We then calculated a participant's out-degree centrality (the extent to which a participant is aware of the knowledge and expertise of his or her colleagues) by aggregating his or her responses and dividing this score by $(N-1)$, where N represented the number of employees in the network. This number comprised a participant's knowledge awareness score, depicted as a node's size in the knowledge awareness sociogram in Figure 2.

In terms of knowledge sharing, we asked participants to indicate how often they exchanged knowledge with each colleague on the roster in the 2 months prior to the survey (to prevent recall bias). Possible answers were "never," "less than once a month," "1 to 4 times a month," "once a week," "several times a week," and "daily," which were, respectively, recorded as 0, 0.5, 2, 4, 12, and 21 times a month. The undirected network was based on estimate pooling, meaning that we took the average of (1) the response of a participant's frequency of knowledge sharing with a colleague and (2) this colleague's response regarding his or her frequency of knowledge sharing with the participant—resulting in a symmetric adjacency matrix. From this matrix, we calculated a valued degree centrality measure by aggregating a participant's responses and dividing this score by $(N-1)$, which we used as an indicator of a participant's frequency of knowledge sharing with colleagues. This measure is depicted as a node's size in the knowledge sharing sociogram in Figure 3.

Homogeneous and heterogeneous knowledge. To examine distinctions regarding the sharing of homogeneous and heterogeneous knowledge (required for the testing of hypothesis 1) and to check for potential data nesting, we asked the participants to indicate their specific areas of expertise from a list of 30 specialisms that were used by the organization to categorize its shared work projects. As such, we could incorporate a more nuanced view of participants' knowledge, as opposed to using unit membership as a proxy for knowledge stocks and rationale for sharing. This approach also does justice to the recent view that knowledge diversity and network structure are not perfectly overlapping (Tortoriello et al., 2015). We examined our full structural model an additional two times to assess differences between homogeneous and heterogeneous knowledge networks: the homogeneous knowledge version of the model involves network ties between participants that have one or more of the 30 listed expertise areas in common,

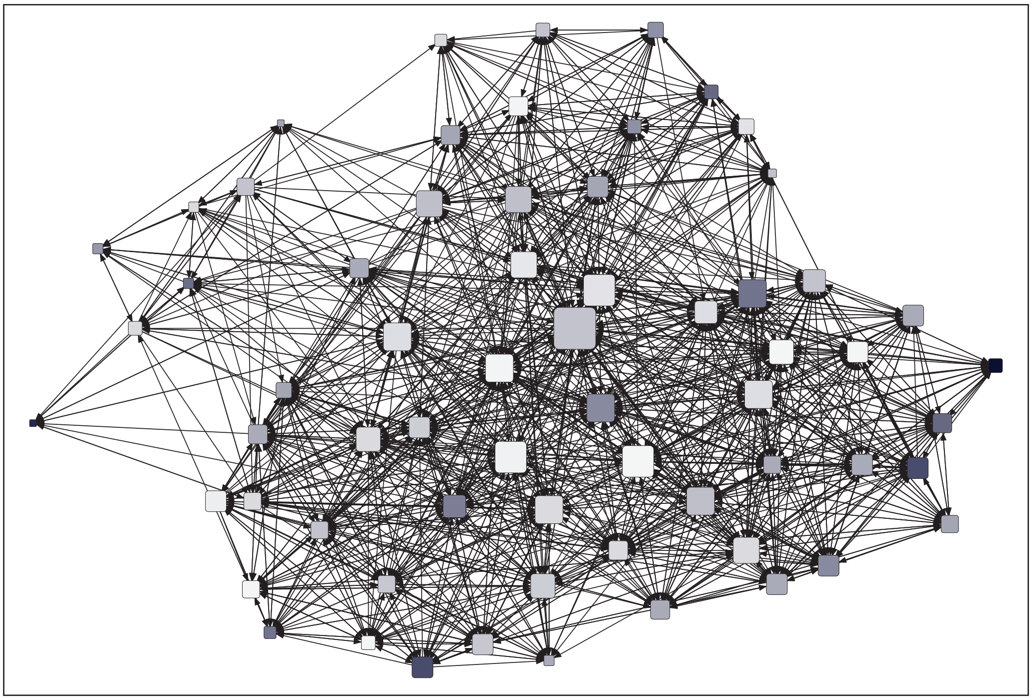

Figure 2. Knowledge awareness sociogram.
Generated with NetDraw version 2.154. Contains edges when participants are (very well) aware of each other's knowledge. Node placement is based on MDS (geodesic distances) with spring embedding. Node size is based on out-degree centrality. Node color is based on temporal separation (darker colors represent greater separation).

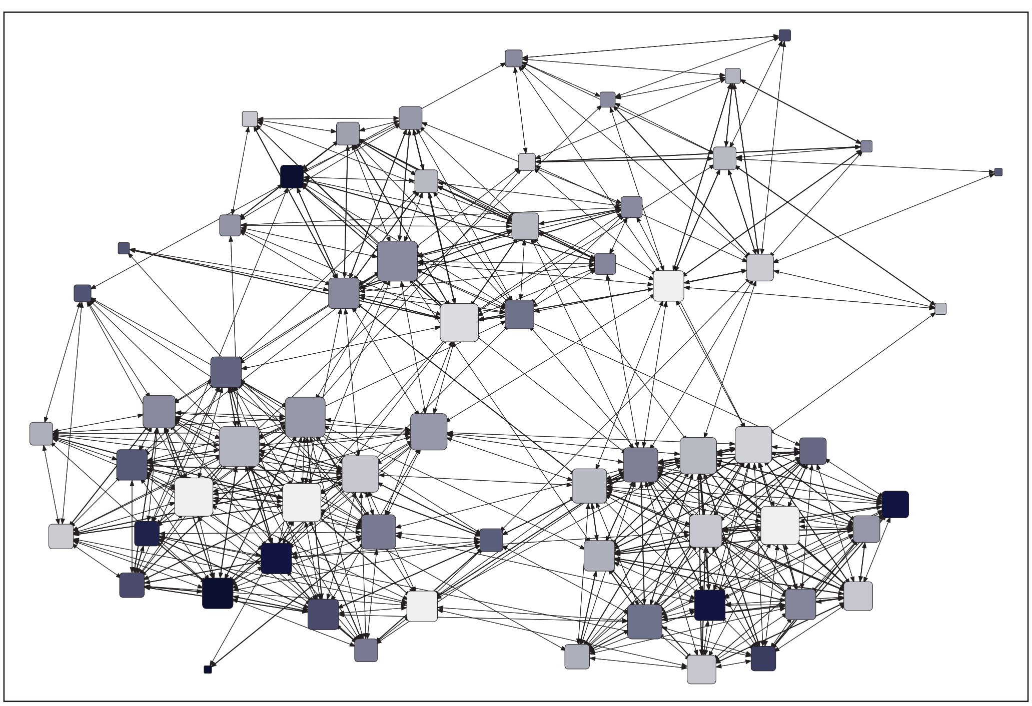

Figure 3. Knowledge sharing sociogram.
Generated with NetDraw version 2.154. Contains edges when participants share knowledge at least once a week. Node placement is based on MDS (geodesic distances) with spring embedding. Node size is based on degree centrality. Node color is based on spatial separation (darker colors represent greater separation).

Table 4. Goodness-of-fit measures for confirmatory factor analysis and path models.

Goodness-of-fit measure	Recommended cutoff criterion (Hair, Black, Babin, and Anderson, 2009)	CFA	Structural model	Structural model (homogeneous knowledge)	Structural model (heterogeneous knowledge)
χ^2 p-value	Insignificant at the 5% level	0.087	0.145	0.233	0.090
χ^2/df	<2 for adequate fit	1.395	1.288	1.184	1.380
CFI	0.95 or better	0.982	0.968	0.976	0.963
TLI	0.95 or better	0.975	0.935	0.952	0.924
SRMR	<0.08 (with CFI > 0.95)	0.045	0.088	0.088	0.088
RMSEA	<0.08 (with CFI > 0.95)	0.079	0.067	0.053	0.078

CFA: confirmatory factor analysis; CFI: comparative fit index; TLI: Tucker-Lewis index; SRMR: standardized root mean square residual; RMSEA: root mean square error approximation.

Table 5. Square root of AVE (diagonal) and correlation between variables (off-diagonal).

Measure	Mean	SD	1	2	3	4	5	6	7	8	9
1. Work hours (control)	34.70	7.80	1								
2. Years of tenure (control)	7.14	5.14	−0.002	1							
3. Temporal separation	0.51	0.11	−0.793**	−0.089	1						
4. Spatial separation	0.70	0.14	−0.411**	0.058	0.437**	1					
5. Communication synchronicity	0.67	0.34	−0.052	−0.160	0.007	−0.032	1				
6. Knowledge awareness	1.75	0.61	0.361**	0.435**	−0.453**	−0.133	−0.043	1			
7. Knowledge sharing	2.12	0.89	0.259*	0.361**	−0.312*	−0.265*	0.136	0.579**	1		
8. Job performance	3.90	0.77	0.246	−0.024	−0.237	−0.094	0.099	0.211	0.360**	0.841	
9. Proactive performance	3.49	0.92	0.229	0.090	−0.126	−0.268*	0.016	0.184	0.325**	0.511**	0.910

AVE: average variance extracted; SD: standard deviation.
*Significance at 5%; **significance at 1%.

whereas the heterogeneous knowledge version of the model only involves network ties between participants that have none of the listed areas in common.

Confirmatory factor analysis

We assessed the reliability and validity of our composite measures by means of confirmatory factor analysis (CFA) with maximum likelihood using lavaan version 0.5-23.1097. Lavaan is a package for structural equation modeling implemented in the R system for statistical computing (Rosseel, 2012). In this model, the observed items were loaded on their respective latent measures, which were in turn allowed to covariate. The model provided good overall fit (χ^2/df = 1.395, comparative fit index (CFI) = 0.982, Tucker–Lewis index (TLI) = 0.975, standardized root mean square residual (SRMR) = 0.045, root mean square error approximation (RMSEA) = 0.079), with all indicators outperforming the recommended cutoff criteria. In addition, the ratio of participants to observed items exceeds the recommended 4:1 ratio for models with good communalities (MacCallum, Widaman, Preacher, & Hong, 2001) meaning that the CFA results in Table 4 are based on sufficient samples.

Overall, our CFA results show that all composite measures are both reliable and valid. First, indications for internal consistency are good, with Cronbach's α scores well above the recommended 0.7 cutoff point (Hair, Black, Babin, & Anderson, 2009). Second, all major criteria regarding convergent validity were met: factor loadings were significant and above 0.5, composite reliability scores were above 0.7, and the average variance extracted (AVE) scores were above the recommended 0.5 cutoff point—indicating that variance in the measures consists of explained variance rather than error variance (Hair et al., 2009). Finally, Table 5 as well as Tables 7 and 8 in Appendix A (for the homogeneous and heterogeneous knowledge models, respectively) shows that the square root of AVE scores (on the diagonal) is greater than the squared correlation estimates between the composite measures, indicating good discriminant validity as well.

Results

As most measures in our structural model consist of single indicators, we conducted path analyses without latent measures to test our (covariance-based) structural model using lavaan version 0.5-23.1097 (Rosseel, 2012). This

Table 6. Standardized path coefficients and hypothesis evaluation.

Hypothesis	Construct A → Construct B	Path coefficient (combined model)	Path coefficient (homogeneous knowledge model)	Path coefficient (heterogeneous knowledge model)	Rejected/ supported
H1a	Knowledge sharing → job performance	**0.221****	0.083	**0.277****	**Supported**[a]
H1b	Knowledge sharing → proactive performance	**0.254***	**0.238***	**0.334*****	**Supported**
H2	Temporal separation → knowledge sharing	−0.019	−0.104	0.024	**Rejected**[a]
	Spatial separation → knowledge sharing	**−0.236*****	**−0.319*****	**−0.193****	
H3a	Temporal separation*communication synchronicity → knowledge sharing	0.349	0.187	0.165	No support
H3b	Spatial separation* communication synchronicity → knowledge sharing	**−0.442****	−0.258	−0.168	**Rejected**[a]
H4	Knowledge awareness → knowledge sharing	**0.542*****	**0.403*****	**0.776*****	**Supported**
H5	Temporal separation → knowledge awareness	**−0.356***	−0.313	**−0.339***	**Supported**[a]
	Spatial separation → knowledge awareness	0.039	0.032	0.026	
H6a	Temporal separation*communication synchronicity → knowledge awareness	0.109	**0.393***	−0.069	**Rejected**[a]
H6b	Spatial separation*communication synchronicity → knowledge awareness	−0.030	−0.366	0.122	No support

[a]Refer to the section "Results" for further details.
*Significance at 5%; **significance at 1%; ***significance at 0.1%.

approach is commensurate with our sample size and required the averaging of items for each of our composite measures. In total, we ran this structural model three times: the combined model involves all network ties and is used for the main results, whereas the homogeneous and heterogeneous knowledge models only include network ties if participants have overlapping areas of expertise (or not). Outcomes for all three models are summarized in Table 6 and covariance matrices for all three versions of the model are provided in Tables 9 to 11 in Appendix B. All paths in our structural model were in line with our hypotheses and control conditions. Exogenous variables were allowed to covary among each other (including the interaction terms with their parent measures) to account for systematic statistical correlations, as was the control measure regarding the number of work hours with temporal separation. The residuals of job and proactive performance were allowed to covary for the same reason.

We used maximum likelihood estimation with robust standard errors and a Satorra–Bentler scaled test statistic (i.e. MLM estimation) to deal with non-normal distributions of the endogenous job performance (W=0.919, $p<0.01$) and proactive performance (W=0.948, $p<0.05$) variables, which would otherwise violate assumptions of the standard maximum likelihood procedure (Kline, 2012). This resulted in a model that meets most of the recommended cutoff criteria for good model fit (χ^2/df=1.288, CFI=0.968, RMSEA=0.067). Given the sample size, the SRMR score (0.088) can be classified as acceptable (Cangur & Ercan, 2015; Hu & Bentler, 1999; Schermelleh-Engel, Moosbrugger, & Müller, 2003) and the TLI score (0.935) as unsatisfactory however still above the traditional cutoff point of 0.90 (as outlined in Marsh, Hau, & Wen, 2004). It should be noted that the overall fit scores for the two additional versions of the structural model (based on homogeneous and heterogeneous knowledge ties) performed similarly, with most scores in Table 4 indicating an acceptable or a good model fit.

Table 6 summarizes our structural model's standardized path coefficients as well as significance levels on the basis of robust maximum likelihood (MLM). To rule out potential issues of multicollinearity, we also conducted supportive analyses for each step in the structural model via linear regression. These analyses indicated that the variance inflation factor (VIF) scores are generally below 3, which is well within the maximum threshold of 10 (Hair et al., 2009). Nonetheless, it should be noted that the interaction terms had slightly elevated VIF scores: the maximum observed VIF for spatial separation*communication synchronicity equaled 5.136, whereas the maximum observed VIF for temporal separation*communication synchronicity equaled 4.385. Given our sample size, these values might reduce our ability to detect (interaction) effects that could be present in practice (Grewal, Cote, & Baumgartner, 2004).

The results shown in Table 6 provide support for several of our hypotheses. First of all, heterogeneous knowledge sharing is more positively related to job and proactive performance than homogeneous knowledge sharing, providing support for Hypothesis 1. In the case of job performance, the effect of homogeneous knowledge sharing within specialist boundaries is insignificant and only able to explain 1% of variance, whereas heterogeneous knowledge sharing is highly significant and able to explain 12% of variance in job performance. Knowledge sharing is in turn determined by both temporal and spatial separation from colleagues, through two separate pathways. Contrary to Hypothesis 2, only spatial separation shows indications of a direct negative

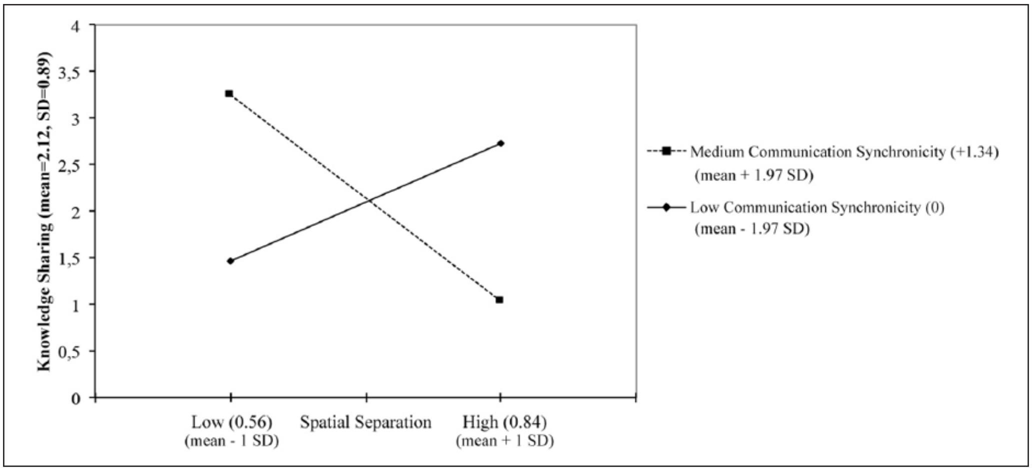

Figure 4. Interaction effect of spatial separation and communication synchronicity on knowledge sharing for the combined model.

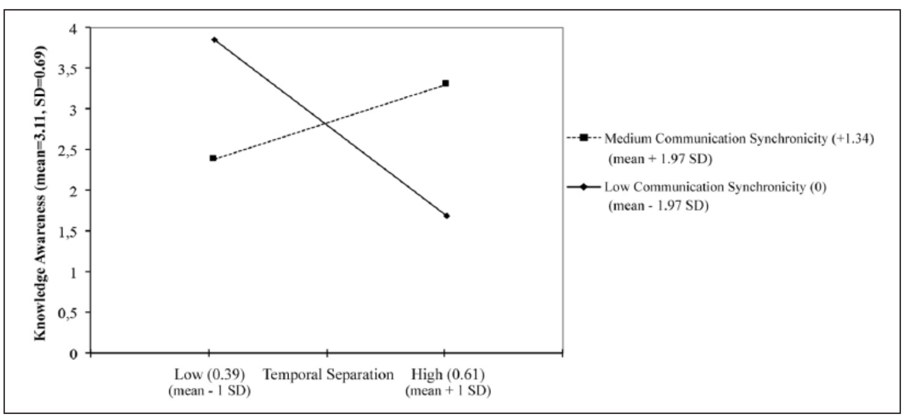

Figure 5. Interaction effect of temporal separation and communication synchronicity on knowledge awareness for the homogeneous knowledge model.

effect on knowledge sharing (particularly with colleagues from one's own area(s) of expertise). Moreover, this effect is positively moderated by the use of synchronous communication media, which refutes Hypothesis 3b. To aid in the assessment of this interaction effect, we plotted simple slopes for high and low levels (+1 and –1 standard deviation) of the independent variable and for medium and low levels (+1.97 and –1.97 standard deviation) of the moderator variable in Figure 4. Simple slopes tests indicate that the use of synchronous media can exacerbate the negative effect of spatial separation on knowledge sharing ($\beta=-1.11, p<0.01$), while the use of asynchronous media might reverse it ($\beta=0.64$, $p<0.05$). With an f^2 effect size value of 0.10, the additional impact of this interaction measure on knowledge sharing can be classified as small to medium (Cohen, 1988). Next, temporal separation (rather than spatial separation) from colleagues negatively influences knowledge sharing through reduced knowledge awareness, providing credence to Hypotheses 4 and 5. The non-significant relation between temporal separation and knowledge sharing in combination with a significant Sobel test indicates full mediation for the combined model ($z=-1.97, p<0.05$) and the heterogeneous knowledge model ($z=-2.10, p<0.05$). Reduced awareness is thus especially detrimental when it concerns the knowledge awareness of colleagues outside of one's own area(s) of expertise, as this awareness accounts for approximately half of the explained variance in heterogeneous knowledge sharing (i.e. removing it from the model would reduce R^2 from 0.67 to 0.34). For homogeneous knowledge networks, however, we have found that the relationship between temporal separation and knowledge awareness is contingent on the use of synchronous communication media—refuting Hypothesis 6a. To illustrate this interaction effect, we plotted simple slopes for high and low levels (+1 and –1 standard deviation) of the independent variable and for medium and low levels (+1.97 and –1.97 standard deviation) of the moderator variable in Figure 5. Simple slopes tests indicate that the use of asynchronous media can exacerbate the negative effect of temporal separation on knowledge awareness ($\beta=-1.09$, $p<0.01$), while the use of synchronous media

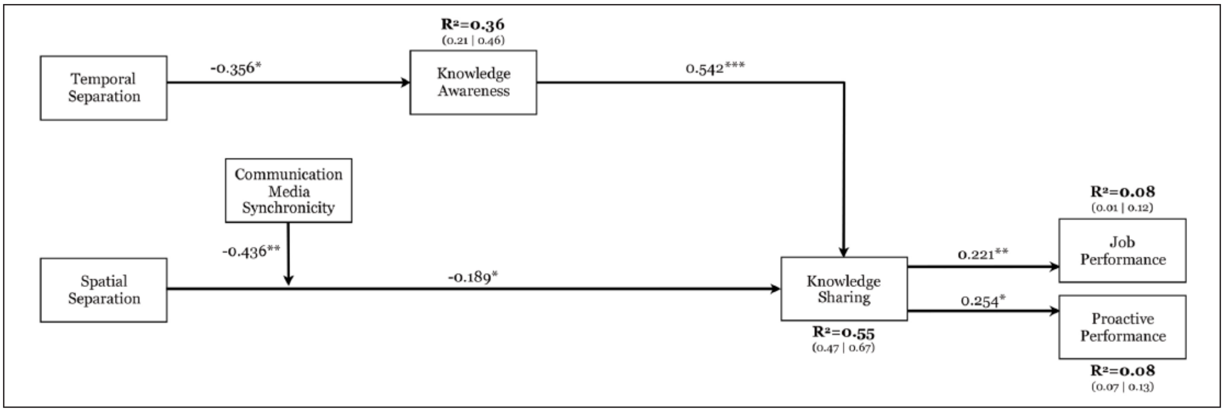

Figure 6. Tested model results.
Numbers represent standardized coefficients. R^2 scores in parentheses, respectively, apply to the homogeneous and heterogeneous knowledge sharing models.
**Significance at 1%; ***significance at 0.1%.

does not seem to significantly reverse this negative effect (β=0.46, non-significant). With an f^2 effect size value of 0.17, the additional impact of this interaction measure on knowledge sharing can be classified as "medium" (Cohen, 1988). Figure 6 graphically summarizes the significant results obtained from our analyses and provides an overview of the variance explained across our three structural models.

Discussion

In this study, we examined how daily schedule and location differences between colleagues, in conjunction with communication synchronicity, influence (the social underpinnings of) knowledge sharing networks. Despite the fact that the cross-sectional nature of our study prevents us from inferring true causality between measures, we have made three important contributions to existing literature. First, to the literature on telework, we introduced a new (extent of) telework measure that distinguishes between temporal and spatial separation from colleagues. With this measure, we were able to carve out the individual effects of both types of separation, showing that each influences a knowledge network through distinct causal paths. Second, these findings also have important implications for scholars with an interest in knowledge sharing within and across specific knowledge areas. Instead of focusing on within-unit and cross-unit sharing as proxies, we provide insight into how temporal and spatial separation can constrict homogeneous and heterogeneous knowledge flows and how it might affect the development of metaknowledge. Third, we applied media synchronicity theory in a quantitative context, showing that media use interacts with temporal and spatial separation to affect knowledge awareness as well as the frequency of knowledge sharing. We will further elaborate on these contributions as well as our limitations and recommendations for further research in the following paragraphs.

In line with telework-specific expectations (e.g. Taskin & Bridoux, 2010) and previous studies on spatial separation (e.g. Allen & Henn, 2007), we found that spatial separation directly harms the frequency of sharing in a knowledge network. We posit that this has mostly to do with exposure: the more an individual's working locations deviate from those of his or her colleagues, the less likely he or she is to (serendipitously) interact and subsequently share knowledge with them. Participants illustrated this point by indicating that colleagues at the office will first try to obtain knowledge from physically proximate colleagues; if they at first cannot obtain the knowledge they need this way, only then will they turn to their more distant colleagues. Their subsequent choice of communication medium is primarily determined by immediacy of the knowledge inquiry; interactions that would normally take place face to face are therefore not automatically substituted by relatively synchronous media. Teleworkers adhere to much the same "immediacy" logic and typically replace the partial loss of face-to-face interaction with e-mail or instant messages, as this allows them to structure their knowledge sharing activities and devote more time to focus work. Figure 4 clearly illustrates this behavior and supports exploratory findings by Leonardi et al. (2010). Part-time teleworkers in particular (the average participant worked out of the office approximately 40% of his or her time) can afford such a communication repertoire, as they can still arrange for—and reap the benefits of—regular face time when they are at the office. Anecdotal evidence from an exploratory study by Bélanger and Allport (2008) has shown that such a change in teleworkers' technology use could lead to an increased focus on explicit knowledge and a decrease in tacit knowledge flow. Yet from discussions with our own participants we learned that teleworkers are more likely to reconfigure their various knowledge sharing activities across time, space, and communication media instead. These notions support Watson-Manheim and

Belanger's (2007) work on communication media repertoires, which states that the use of media repertoires is influenced by institutional conditions (e.g. spatial separation) and situational conditions (e.g. urgency and tasks).

Contrasting the effect of spatial separation, we found that temporal separation did not directly influence sharing in a knowledge network. Instead, it works negatively through knowledge awareness, and this is most notably the case for heterogeneous knowledge networks. This means that the more an individual's chosen working times deviate from those of his or her colleagues, the less he or she will be aware of the knowledge these colleagues have to offer—especially if their areas of expertise are different. Working in locations that are different from one's colleagues, however, does not seem to influence one's level of knowledge awareness. This means that not the lack of direct physical proximity, but rather the lack of working time synchronicity, results in reduced awareness in a knowledge network. Concerns regarding teleworkers' increased risk of professional isolation (e.g. Nicklin et al., 2016) are thus partly justified, as there is a certain risk that they (or at least: the knowledge that they could share) become "invisible" to their colleagues. Our expectation was that asynchronous communication media could help mitigate this negative effect, and although we found no such moderating effect in case of heterogeneous knowledge networks, we found the exact opposite for homogeneous knowledge sharing. In that case, the use of asynchronous communication media in combination with greater temporal distance results in reduced knowledge awareness. Participants clarified these findings by stating that they rather not use the communication media at their disposal for signaling or discovering expertise. They prefer to do this in person (at presentations or during shared office interactions) or with the help of unilateral technological solutions (e.g. through searching shared documents or by consulting expert yellow pages). Our findings thus do not rule out the possibility that knowledge awareness can be developed with the help of technology (as suggested by Moreland (1999)), but they do oppose earlier experimental findings in which e-mail (Kanawattanachai & Yoo, 2007) and telephone (He et al., 2007) interactions played a vital role in developing knowledge awareness among separated colleagues (albeit in the context of virtual teams). As such, we posit that different technological capabilities might be required when it comes to developing the knowledge awareness of (part-time) teleworkers.

The negative effect of temporal and spatial separation on knowledge awareness and knowledge sharing (respectively) will also affect teleworkers' performance. Our findings underwrite the importance of heterogeneous knowledge sharing for job performance, clearly showing that "certain ties might yield better or more relevant information than others" (Cross & Cummings, 2004, p. 929), while both homogeneous and heterogeneous knowledge sharing are important to proactive (or innovator-based) performance. This not only means that sharing knowledge with others from a diverse background enables innovation (as, for instance, shown by Tortoriello et al., 2015), but also that colleagues with similar knowledge might serve as an equally important sounding board that can help them to associate newly acquired knowledge with what they already know (Tortoriello et al., 2012).

Limitations and recommendations for further research

With respect to our study's limitations, we should first point out that our research context and operationalization of constructs place substantial boundaries on our ability to generalize our findings across various organizations and technologies. For instance, our focal organization has long fostered a knowledge-intensive culture in which excellence, transparency, and sharing are the norm. Prior research has shown that such organizations are more likely to approach teleworking as a long-term investment in employees (Peters & Batenburg, 2015), providing a fertile ground for teleworking to be effective. Furthermore, strong cultural norms generally have a substantial influence on knowledge sharing behaviors (Newell, 2015) and could have partially reduced the knowledge sharing risks and uncertainties that our participants experienced regarding the abilities and intentions of colleagues (as, for instance, shown by Chow & Chan, 2008). Replication of our study across several organizations with the explicit inclusion of cultural norm measures would help address this issue and could also address related (i.e. relational and cognitive) dimensions of social capital in the context of telework. Such studies could draw on prior theoretical (Taskin & Bridoux, 2010) and empirical (Golden & Raghuram, 2010) work in this area and combine it with the new (extent of) telework measure introduced in this article. A particularly interesting study setting could be that of software development units or (IT) departments using agile methodologies, where both autonomy and spatial proximity (for informal, ad hoc interactions) are considered crucial and may thus constitute a minor paradox. Such studies could investigate how teleworkers organize various work activities across time, space, and various communication media, as tasks with distinct knowledge requirements (or levels of tacitness) have been shown to require different ways of organization and coordination (e.g. Kudaravalli, Faraj, & Johnson, 2017; Srikanth & Puranam, 2011).

Next, due to our bounded research context, we only focused on dyadic relationships and the *frequency* of knowledge sharing. Research on communication (Marlow et al., 2017) provides several additional characteristics that might also be important for knowledge sharing, such as the quality and the timeliness of the shared knowledge. Including network measures could also prove worthwhile in this regard (especially in much larger settings), for instance, by examining individual knowledge network size and thus the number of connections that teleworkers form over time. Weber and Kim (2015) have shown that employees of a large multinational organization were likely to form more connections with peers for knowledge-seeking purposes in a spatially distributed environment. This could mean that the network density and distribution of knowledge sharing change from "more knowledge with fewer colleagues" to "less knowledge with more colleagues" as separation increases. The development of knowledge awareness will likely play a crucial role therein. To accurately assess these effects, however, it will be important to take the variance in knowledge sharing due to common work projects or collaboration into account—for instance, by incorporating measures regarding project and/or business unit membership. It is important to point out that in our study we have relied on a single indicator (overlap in areas of expertise) for both shared project membership and homogeneous knowledge exchange; we recommend that future studies use separate measures to ascertain their individual effects.

When examining the development of knowledge awareness, it might also be interesting to examine the use of enterprise social networks, as these provide increased transparency of directional communication and insights regarding workflows, activities, and physical locations (Leonardi, 2014, 2015) An additional benefit of these media is that they can allow for "planned serendipity" (Majchrzak, Cherbakov, & Ives, 2009) in which potentially valuable but under-explored relationships in the knowledge network can be proactively presented to teleworkers. Since such capabilities of transparency and planned serendipity were largely absent in the media we examined, we highly recommend that future research efforts focus on (part-time) teleworkers' use of enterprise social networks (or other media that offer these capabilities) as a way to maintain knowledge awareness in separated work settings. In doing so, it would be advisable to take a sociomaterial research approach (Orlikowski & Scott, 2008) and focus on the way in which these communication media are entangled with teleworkers and enacted in practice rather than deterministically inferred from functional characteristics (as we did with media synchronicity). A specific focus on how temporal/spatial separation and various knowledge sharing activities influence the appropriation of communication media in specific repertoires could thus prove highly valuable.

Recommendations for management practice

Ultimately, our research shows that working "any time and at any place" with the help of ICT is not without consequences: teleworkers' temporal and spatial separation from colleagues may lead to a workforce which shares less knowledge, performs worse, and has less innovative potential. This is most certainly expected to affect an organization's bottom line, meaning that managers should aim to minimize the negative impacts of telework on the organization's knowledge base. In part, this could be done by limiting extreme instances of telework, as we found that negative effects of spatial separation can be overcome if teleworkers are supported in consciously reconfiguring their various knowledge sharing activities across working locations and various communication media. Regular face-to-face contact with colleagues (e.g. at the office) is an important part of this reconfiguration process, which should be encouraged. Such an approach may also prevent temporal separation from negatively affecting an employee's knowledge awareness of colleagues with identical areas of expertise. In addition, we advise to partially synchronize working times (for instance, by instituting certain "core working hours" during part of the week) within the organization, as this improves knowledge awareness between otherwise separated colleagues who may offer heterogeneous knowledge. Managers themselves play an important role here as well: they should stay on top of the knowledge needs of their employees and serve as boundary spanners between various knowledge groups to connect employees when it is most beneficial. Eventually, new technologies (such as enterprise social networks) might proactively support teleworkers in maintaining their knowledge awareness. We urge organizations to be on the lookout for these technologies and experiment with them, as solving the issue of reduced knowledge awareness would reduce the main (structural) threat to a teleworker's knowledge sharing network.

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Appendix A

Table 7. Correlation between variables for the homogeneous knowledge model.

Measure	Mean	SD	1	2	3	4	5	6	7	8	9
1. Work hours (control)	34.70	7.80	1								
2. Years of tenure (control)	7.14	5.14	−0.002	1							
3. Temporal separation	0.50	0.11	−0.770**	−0.086	1						
4. Spatial separation	0.70	0.14	−0.413**	0.035	0.474**	1					
5. Communication synchronicity	0.67	0.34	−0.052	−0.160	0.022	−0.010	1				
6. Knowledge awareness	3.11	0.69	0.166	0.314*	−0.279*	−0.074	0.065	1			
7. Knowledge sharing	5.68	2.51	0.252*	0.306**	−0.369**	−0.380**	0.121	0.544**	1		
8. Job performance	3.90	0.77	0.246	−0.024	−0.200	−0.019	0.099	−0.002	0.105	0.841	
9. Proactive performance	3.49	0.92	0.229	0.090	−0.141	−0.260*	0.016	0.066	0.260*	0.511**	0.910

SD: standard deviation.
*Significance at 5%; **significance at 1%.

Table 8. Correlation between variables for the heterogeneous knowledge model.

Measure	Mean	SD	1	2	3	4	5	6	7	8	9
1. Work hours (control)	34.70	7.80	1								
2. Years of tenure (control)	7.14	5.14	−0.002	1							
3. Temporal separation	0.51	0.11	−0.793**	−0.082	1						
4. Spatial separation	0.71	0.14	−0.397**	0.077	0.422**	1					
5. Communication synchronicity	0.67	0.34	−0.052	−0.160	−0.003	−0.042	1				
6. Knowledge awareness	1.10	0.52	0.456**	0.472**	−0.520**	−0.158	−0.128	1			
7. Knowledge sharing	0.43	0.25	0.301*	0.475**	−0.383**	−0.253*	−0.128	0.799**	1		
8. Job performance	3.90	0.77	0.246	−0.024	−0.252*	−0.123	0.099	0.218	0.350**	0.841	
9. Proactive performance	3.49	0.92	0.229	0.090	−0.123	−0.268*	0.016	0.253*	0.364**	0.511**	0.910

SD: standard deviation.
*Significance at 5%; **significance at 1%.

Appendix B

Table 9. Covariance matrix for the combined model.

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Work hours (control)	60.765										
2. Years of tenure (control)	−0.066	26.408									
3. Temporal separation	−0.621	−0.049	0.012								
4. Spatial separation	−0.403	0.040	0.006	0.018							
5. Communication synchronicity	−0.154	−0.332	0.000	−0.002	0.118						
6. Knowledge awareness	1.604	1.363	−0.030	−0.011	−0.011	0.372					
7. Knowledge sharing	1.733	1.706	−0.031	−0.033	0.050	0.324	0.800				
8. Job performance	1.418	−0.097	−0.020	−0.010	0.032	0.102	0.262	0.601			
9. Proactive performance	1.528	0.422	−0.012	−0.033	0.006	0.103	0.273	0.370	0.838		
10. Com. Sync.*Temporal Sep.	−0.475	0.301	0.003	0.006	−0.018	0.044	−0.035	−0.024	−0.003	0.830	
11. Com. Sync.*Spatial Sep.	−0.474	0.828	0.004	0.008	−0.165	0.055	−0.155	0.016	0.006	0.814	1.158

Table 10. Covariance matrix for the homogeneous knowledge model.

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Work hours (control)	60.765										
2. Years of tenure (control)	−0.066	26.408									
3. Temporal separation	−0.626	−0.049	0.012								
4. Spatial separation	−0.426	0.026	0.007	0.020							
5. Communication synchronicity	−0.154	−0.332	0.000	−0.001	0.118						
6. Knowledge awareness	0.842	1.119	−0.022	−0.007	0.018	0.481					
7. Knowledge sharing	4.597	3.936	−0.103	−0.135	0.122	.945	6.279				
8. Job performance	1.418	−0.097	−0.017	−0.002	0.032	−0.001	0.209	0.601			
9. Proactive performance	1.528	0.422	−0.014	−0.034	0.006	0.042	0.596	0.370	0.838		
10. Com. Sync.*Temporal Sep.	−0.520	0.366	0.009	0.010	−0.037	0.035	−0.129	−0.028	−0.005	0.983	
11. Com. Sync.*Spatial Sep.	−0.405	0.758	0.008	0.007	−0.152	−0.033	−0.400	0.004	0.023	0.925	1.186

Table 11. Covariance matrix for the heterogeneous knowledge model.

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Work hours (control)	60.765										
2. Years of tenure (control)	−0.066	26.408									
3. Temporal separation	−0.620	−0.045	0.012								
4. Spatial separation	−0.392	0.054	0.006	0.018							
5. Communication synchronicity	−0.154	−0.332	0.000	−0.002	0.118						
6. Knowledge awareness	2.066	1.511	−0.035	−0.013	−0.032	0.388					
7. Knowledge sharing	0.559	0.622	−0.010	−0.008	−0.013	0.127	0.065				
8. Job performance	1.418	−0.097	−0.021	−0.013	0.032	0.107	0.070	0.601			
9. Proactive performance	1.528	0.422	−0.010	−0.033	0.006	0.144	0.085	0.370	0.838		
10. Com. Sync.*Temporal Sep.	−0.464	0.316	0.001	0.004	−0.010	0.031	0.013	−0.023	−0.011	0.775	
11. Com. Sync.*Spatial Sep.	−0.498	0.878	0.003	0.009	−0.162	0.084	0.024	0.022	−0.008	0.765	1.119