Close to Me: The Impact of the Interplay of Physical and Social Proximity on Dyadic Collaboration Effectiveness

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Previous organizational studies have independently documented the roles played by physical proximity and by intra-organizational social networks in inter-personal collaboration at work but have rarely – if ever – theorized or empirically examined their joint impact. Our goal, therefore, is to explore the impact of the interplay between physical and social proximity on the effectiveness of inter-personal collaboration. Taking advantage of a quasi-natural experiment where a global pharmaceutical firm relocated two regional offices to two new sites, we measured both the interpersonal physical distances and social networks before and after the moves. Beyond the expected positive effects on collaboration effectiveness, we discovered that the effects of the physical and social dimensions were not independent. Social proximity (in the form of inter-personal affective closeness) mediated the effect of physical proximity on dyadic collaboration, while inter-personal physical distance amplified the positive effect of social proximity (in the form of dyadic closure or ties linked by common third parties) on dyadic collaboration. In other words, physical proximity and dyadic closure had substitutive effects on collaboration performance.

Keywords: Physical Proximity, Social Networks; Collaboration; Empirical, Quantitative

Electronic copy available at: https://ssrn.com/abstract=4498777

Acknowledgement: We appreciate the support of Martin Gargiulo when designing and implementing the social capital (web-based) questionnair used during the data collection phase of this research project. We also appreciate the collaboration of the company in which we collected the data analysed in this paper. We are grateful to Martin Gargiulo, Quy Huy, and Andrew Shipilov for their feedback on early versions of this work.
INTRODUCTION

Organizational scholars have a longstanding interest in how inter-personal physical distance affects collaboration at work. Allen and colleagues’ (1977) seminal work on the exponential relationship between physical proximity and the probability of daily communication initiated a long stream of research on analyzing the drivers and barriers of inter-personal communication patterns, an important determinant of collaboration effectiveness often measured in terms of successful innovation and R&D performance (Brown and Eisenhardt 1995; Van den Bulte and Moenaert 1998; Sosa et al. 2002, Cummings 2004, Kabo et al. 2014, Catalini 2017). However, studies on physical proximity largely overlooked the impact of social networks on collaboration; instead, a contiguous literature developed in parallel focused on explaining the social network drivers of successful inter-personal collaboration. Indeed, previous work on intra-organizational networks show the crucial role they play in collaboration, for instance analyzing the impact of those networks on ease of knowledge transfer, the generation of potentially creative ideas, and the tendency to coordinate innovation efforts (e.g., Burt 2004; Reagans and McEvily 2003; Sosa 2011; Sosa et al. 2015; Tortoriello et al. 2012; Tortoriello 2014).

Yet despite their common interest in explaining similar outcomes, most (if not all) organizational network studies ignore the literature on physical space – particularly the role of physical proximity at work – in determining the effectiveness of inter-personal collaboration. The two streams that independently focus on the effects of physical proximity and social networks on collaboration are like “ships passing in the night”,¹ generating internally consistent bodies of knowledge but rarely considering the joint effect on collaboration (a notable exception being an exploratory architectural study by Wineman and colleagues; 2014).

¹ For a similar criticism on the lack of joint studies of formal and informal structures, see McEvily, Soda and Tortoriello (2014; see also Maoret, Iubatti and Tortoriello, 2020).
The objective of this paper is to shed light on whether and how the interplay of physical proximity and inter-personal networks affects collaboration effectiveness at work, weaving together these two largely disconnected bodies of knowledge. We believe our effort to be important for theoretical and practical reasons. Theoretically, it is vital to develop new models that jointly assess the effects of physical proximity and social networks on relevant organizational outcomes such as inter-personal collaboration. Existing theory does not clarify whether the physical and social dimensions operate additively and independently, or interactively. If actors’ positions in the physical and social spaces are not independent – which is likely given the strong relationship between physical distance and dyadic communication (Allen 1977) – current theories could be confounding the effects of physical proximity and social networks. Going further, these two dimensions may amplify, substitute, or mediate each other’s effects, requiring a more fine-grained understanding of the relationship between them. This clearly has practical and managerial implications, as novel ways of organizing increasingly involve shifting to new physical space arrangements, experimenting with new desk-assignment policies, and allowing colleagues to work from distinct locations (e.g., office, home, co-working spaces, or a mixed of all of these) to overcome external constraints such as those imposed by COVID-19 (Waber et al., 2014, Mortensen and Gardner 2021). Such changes not only directly impact collaboration effectiveness among colleagues but may change the way social networks contribute to effective collaboration, requiring a more holistic understanding of the joint implications of physical proximity and social networks for organizational performance.

To further our understanding of the interplay between physical distance and intra-organizational social networks we took advantage of a quasi-natural experiment in which a global pharmaceutical firm relocated two of their regional offices to two new sites. We had the
opportunity to measure both the inter-personal physical distances and the social networks among co-workers before and after the relocation to examine how changes in social proximity – defined in terms of strong ties (which exhibit high communication frequency and are affectively close) and socially cohesive ties (which experience dyadic closure due to the presence of common third parties) – may relate to changes in dyadic collaboration effectiveness vis-à-vis changes in interpersonal physical proximity. We not only found evidence of the positive effects expected on collaboration effectiveness associated with physical and social proximity, but also tested mediation and moderation effects between the two dimensions. More specifically, we found that dyadic affective closeness mediated the effect of inter-personal physical proximity, and that inter-personal physical distance amplified the positive effect of dyadic closure on dyadic collaboration effectiveness.

Our results expand – conceptually and empirically – the way the performance consequences of co-workers’ positions in both social and physical spaces at work are regarded. For organizational designers it is not only important to be aware of the positive correlation between physical proximity and collaboration effectiveness but also of the possible mechanisms by which being physically closer (or more distant) to colleagues may affect collaborative relationships. Confirming empirically that physical proximity accelerates the formation of inter-personal affect which in turn positively impacts collaboration is important when considering the implications of measures that may significantly change inter-personal distances in organizations. And even more novel finding is the substitutional effect of inter-personal proximity and dyadic closure. The fact that such a substitutional effect has not been explicitly studied theoretically or empirically opens a wide set of questions for organizational scholars and organizational designers which must consider their joint effect on collaboration effectiveness.
THEORY

The interplay between physical proximity, organizational networks, and collaboration: A gap in the literature

Collaboration is broadly defined as “the act of working together with other people or organizations to create or achieve something” (Cambridge Business English Dictionary). It therefore requires coordination between interdependent organizational actors. Inter-personal communication is one of the most widely accepted mechanisms to effectively coordinate coupled tasks (Thompson 1967, Galbraith 1973, Adler 1995, Sosa et al. 2015). While communication patterns at work depend on the nature of the task and the formal and informal organizational structures underpinning its execution, physical proximity also plays an important role (Sosa et al. 2002). The barriers to inter-personal communication imposed by physical distance have been extensively studied, becoming “accepted as an axiom in social theory” (Van den Bulte and Moenaert 1998, p. S3). Allen’s (1977) research describing how increasing distance between team members reduced the chances of two members communicating to address task interdependence is probably the best known in the R&D context. Several subsequent studies supported and extended Allen’s findings (Keller and Holland 1983, Jaffe et al. 1993, Van den Bulte and Moenaert 1998, Sosa et al. 2002, Kabo et al. 2014, Crescenzi et al. 2016, Catalini 2017, Lee 2019).

The emergence of electronic media that enable geographically distributed organizations prompted many studies on the effect of distance on collaboration (Kiesler and Cummings 2002). Sosa et al. (2002) explored the effect of distance on technical communication in globally distributed teams and found that its hindering effect was contingent upon the communication media used; distance exhibited the expected exponential decay of face-to-face communication but increased telephone and electronic-based communications. Kabo et al. (2014) analyzed the effect
of physical space on the formation and success of scientific collaborations. Crescenzi et al. (2016) showed how the effect of geographic proximity on co-patenting and the success of patents was contingent upon other forms of proximity such as organizational, cognitive, and cultural proximity. More recently, Catalini (2017) took advantage of a “natural” experiment sparked by relocation of various labs in Paris, finding that colocation increased joint research, while separation did not affect previously collocated labs. The outcome of research collaboration, however, was affected by distance between labs after the move. Lee (2019) also took advantage of a natural experiment to study the effect of relocating the headquarters; they found that individuals who got closer to each other after the move (but were separated prior to the move) engaged in more exploratory activities than those whose physical proximity to their colleagues did not change.

Absent from all these studies of physical proximity is the role of the social networks that form among co-workers at work and their influence on the effect on collaboration of inter-personal physical distance. Inter-disciplinary studies involving researchers in architecture, urban planning and the social sciences have started to consider the potential role that social network patterns and physical spaces play in organizational processes, particularly in innovation (Wineman et al. 2009, Wineman et al. 2014). Although they find that both position in the physical space and in the social network (at work) is likely to influence innovation outcomes, they are largely exploratory studies whose main conclusion is that “innovation is a process that occurs at the intersection of social and physical space” (Wineman et al. p. 2014).

A similar shortcoming is evident among social network researchers who have probed the role that physical proximity plays in network formation only from a methodological viewpoint. For instance, Sailer and McCulloh (2012) modeled physical distances between people in an organization in various ways and used these specifications as explanatory variables in exponential
random graph models (which control for various network structures) that predict tie formation. Doreian and Conti (2012) similarly showed through various social network analytical approaches (including network visualizations, quadric assignment procedure regressions, and a combination of exponential random graphs models and blockmodeling) that both the social and physical dimensions mattered in influencing the emergence of a social network in an organizational setting. Along the same lines, Daraganova et al. (2012) extended exponential random graph models to account for the geographic proximity of network actors, and found that physical distance had an exponentially decaying effect on tie formation – yet did not jointly consider the impact played by social network and physical proximity on key organizational outcomes such as inter-personal collaboration effectiveness. This is the conceptual and empirical gap that our paper seeks to fill.

To develop a theory of the interplay between the social and physical dimensions, we first review the mechanisms through which physical proximity and social networks have a direct effect on collaboration performance. Then, we develop mediation and moderation effects that capture how physical and social proximity jointly influence dyadic collaboration effectiveness.

The direct effect of inter-personal physical proximity on dyadic collaboration effectiveness

To understand the effect of physical proximity on collaborative performance, we start by reviewing the mechanisms – i.e. visual presence, ease of access, tacit coordination, and control – through which the physical space may influence inter-personal relationships at work above and beyond communication frequency. Indeed, getting physically closer not only increases the chances of inter-personal communication (Allen 1977) but also the physical and visual presence, which may contribute to improved collaboration performance even in the absence of communication (Kabo et al. 2014, Wineman et al 2009).
We posit that physical proximity is likely to bring easier and richer access to potentially interdependent actors. A co-worker who is physically closer is more available for in-person interactions, which enables the use of richer communication media (such as face-to-face exchanges) with more ‘bandwidth’ than other media (such as telephone or email exchanges) to share information (see Daft and Lengel 1986 for a discussion on media richness theory on organizational communication). When collaborators are more accessible due to collocation, more frequent task-related interactions take place, which facilitates the resolution of uncertainty even in complex tasks that need to be reworked before converging to a consensus solution (Sosa 2014, Mihm et al. 2003).

More frequent and richer in-person interactions also help develop positive affect and familiarity between collaborators, which in turn increase the tendency to collaborate and the performance of such collaborations. Indeed, Casciaro and Lobo (2009) found that instrumental ties at work were more likely to form between actors that shared positive affect. Huckman et al. (2009) and Fonti and Maoret (2016) found that teams that shared a higher level of familiarity were more likely to perform better in terms of being less likely to deviate from quality, effort, and schedule expectations. If proximity facilitates the development of positive affect and team familiarity, therefore, it is logical to expect better collaborative outcomes from physically closer co-workers.

Physical proximity at work can facilitate collaboration even in the absence of frequent communication. Since closeness increases visual contact, it is likely to trigger monitoring mechanisms that increase collaboration effectiveness. This is because when others are close, they can more easily see what one does and how one does it, hence one is more likely to work harder with colleagues that are physically closer. A physical co-presence “makes it easier for individuals to monitor each other’s signals, get into a rhythm, and develop a common focus of attention”
(Christensen and Foss 2021, p. 88); when others are around, it is difficult to discriminate some collaborative efforts against others. In other words, physical and visual proximity make it harder to make “excuses”, refuse or delay the exchange of information or give help to others. Conversely, when colleagues who are physically closer “see” (i.e., monitor) how one engages at work and collaborates with others, trust and reputation are reinforced, and access to resources and support is forthcoming, enhancing the effectiveness of the collaboration. It also enables tacit coordination between organizational actors by allowing them to adjust their behavior to develop shared expectations and understanding of their mutual availability and capabilities (Trefalt, 2013). Physical presence is also essential to develop a sense of belonging (to a group) and convey participation in addressing a task that is critical to create the “emotional energy” that provides enthusiasm and strength of working together (Collins 2004; Maoret, Marchesini and Ertug, 2022).

In sum, proximity to others facilitates collaboration by increasing the frequency and richness of work-related communication that is crucial to resolve task interdependencies. We assume that the mere presence of others promotes collaboration by augmenting affective closeness and trust, increasing the opportunity to become positively familiar with others and thus increasing the collaboration performance. Despite not having been empirically tested in any previous study, the association between inter-personal physical proximity and dyadic collaboration effectiveness are broadly thought to be positive. Put more formally into a first baseline hypothesis:

*Baseline Hypothesis 1: Physical proximity between co-workers is positively related to their collaboration effectiveness.*

**The direct effect of social proximity on collaboration effectiveness**

When two actors work together to achieve a shared goal, a social network that brings them socially closer – i.e., into proximity – can facilitate reciprocal cooperative behavior characterized by trust,
knowledge transfer and learning, thus promoting inter-personal collaboration effectiveness (Coleman 1990). Consistent with Burt (1992, 2005) and Granovetter (1992), we view the effects of social proximity along two dimensions: a direct, “relational” component (*tie strength*), which is a function of the amount of time and affective closeness invested in the dyadic relationship; and an indirect, “structural” component (*dyadic closure*) which is a function of the time and affective closeness invested in their relationships with common contacts (i.e., third parties).

Existing studies support the view that both dimensions of social proximity facilitate the mobilization and coordination of resources to implement ideas and monitor collaborators’ behavior (Coleman 1990, Burt 2005). Moreover, there is ample conceptual and empirical evidence that strong ties and cohesive social networks are positively associated with effective inter-personal collaboration. Reagans and McEvily (2003), for example, found that both tie strength and social cohesion (or dyadic closure) eased collaboration in the form of knowledge transfer. Gargiulo et al. (2009) found that network closure was associated with positive performance by the requester of information but not the provider of information. Tortoriello et al. (2012) found that cohesive network structures increased the provider’s willingness to share knowledge with others across organizational boundaries. Highly cohesive social networks also influence innovation by enabling individuals to be more supportive of colleagues’ innovation endeavors (Obstfeld 2005, Tortoriello et al. 2015). Liu et al. (2018) found that cohesive networks facilitated collaboration with creative stars as such structures enforced trust, closeness and cooperation to support creative synthesis.

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2 We use the term *dyadic closure* to refer to the presence of common third parties between two interacting actors. Although the term *network cohesion* has been used to refer to such a construct in other dyadic social network studies (e.g. Reagans and McEvily 2003, Sosa 2011, Tortoriello et al. 2012), the same term has also been used in other studies in which the individual (instead of the dyad) is the unit of analysis (e.g., Gargiulo and Benassi 2000, Liu et al. 2018). Dyadic closure emphasizes both the dyadic nature of our construct as well as the trust development and control reinforcing effects that common third parties pose on the focal dyad (Burt 2005).
These findings are consistent with the argument that dyadic closure accelerates the emergence of trust between interacting actors which in turns favors their collaborative efforts (Burt 2005).

In sum, people with a strong tie are intrinsically motivated to work effectively together and willing to devote a larger share of their time and energy to enhance the quality of communication and interaction (Reagans and McEvily 2003). The positive effect of the strong tie is reinforced by the presence of common contacts (dyadic closure). Such network closure at the dyadic level can induce extrinsic (to the dyad) social pressure to enforce cooperative behavior, as cohesive ties rich in common third parties are characterized by cooperative norms and the corresponding reputational penalties for not abiding by such norms (Coleman 1990, Obstfeld 2005, Reagans and McEvily 2003, Gargiulo et al. 2009). They also provide the social ground to develop the trust upon which relationships can build better collaboration. Hence, a second baseline hypothesis states that:

*Baseline Hypothesis 2: (a) tie strength and (b) dyadic closure between co-workers are positively related to their dyadic collaboration effectiveness.*

**The interplay of physical and social proximity: Mediation effects**

Having discussed the fundamental mechanisms by which physical and social proximity relate to dyadic collaboration effectiveness, we now theorize the interplay of physical and social distance in the form of mediation and moderating effects. First, after considering the importance of physical proximity to accentuate communication frequency and the development of interpersonal affect, we explore whether the latter are (albeit partial) mediators of the relationship between physical space and collaboration effectiveness. Second, given the control mechanism and trust development associated with both physically close dyads who share visual presence and socially cohesive dyads with common third parties, we expect the effects of physical and social proximity on collaboration to be substitutes.
As argued, physical proximity supports richer, more frequent inter-personal communication (Allen 1977) as well as providing control mechanisms that encourage trust and cooperation (Coleman 1990, Burt 2005). However, the interplay with tie strength and dyadic closure differs.

Since physical proximity increases both inter-personal communication frequency and the development of interpersonal affective closeness (the key components of tie strength; Granovetter 1972, Marsden and Campbell 1984), while tie strength is positively related to dyadic collaboration effectiveness (Reagans and McEvily 2003, Sosa 2011), then it could plausibly be expected that the positive effect of physical proximity on dyadic collaboration effectiveness will be mediated by tie strength. However, on further examination of both components of tie strength, we realize that communication frequency is less susceptible to physical proximity than affective closeness. That is, for more physically distant interdependent dyads face-to-face communication is likely to decay, but interactions through other media such as telephone and email is likely to compensate for the absence of personal interaction (Sosa et al. 2002). Given the increasing use of technology for communication between interdependent actors, communication frequency (regardless of the media used) is less likely to be associated with physical proximity (Sosa et al. 2002), making communication frequency (across all media) less likely to have a mediating effect.

In contrast, the development of affective closeness is clearly enhanced when interactions occur in person and visual presence allows for body language and richer communication that increases relational energy, trust, familiarity and closeness between interdependent actors (Collins 2004, Trefalt 2013, Casciaro and Lobo 2015). Moreover, the opposite is also true; if there were cases in which physical proximity failed to accelerate the development of affective closeness, then we should expect the link between physical proximity and dyadic collaboration effectiveness to
wane. Therefore, affective closeness is more likely to give inter-personal physical proximity a strong mediating effect on collaboration effectiveness. Hence, our mediation hypothesis:

\[ H1: \text{Dyadic affective closeness mediates the positive effect of physical proximity on dyadic collaboration effectiveness.} \]

The Interplay of Physical and Social Proximity: Moderation Effects

Existing studies suggest that social control and monitoring mechanisms facilitate the functioning of work-related relations as monitoring makes the collaborating parties more likely to fulfill their part of the task in a timely manner and with the desired outcome (Burt 2005). That is, they facilitate the emergence and enforcement of cooperative norms. As argued, both physical and social proximity serve to control and monitor; the former is a direct effect as it occurs in visual co-presence, the latter more indirect stemming from the norms expected of collaboration and corresponding sanctions for defectors in the form of the reputational penalties embedded in socially cohesive relationships (i.e. relationships characterized by a high number of common third parties).

We contend that the direct monitoring effect of physical proximity and the indirect effect of social proximity (in the form of dyadic closure) are not additive, but rather operate as substitutes of each other. That is, when the physical inter-personal distance is small, co-workers are able to monitor each other directly, hence the effect of dyadic closure via group norms and common third parties will be weaker. Conversely, when the distance increases, the control mechanisms of physical proximity are likely to disappear (as visual presence dwindles), leaving dyadic closure as the main control and monitoring mechanism operating between the collaborators. In this context, the effect of dyadic closure will be much stronger. Hence, our moderation hypothesis:
**H2: The effects of physical proximity and dyadic closure on dyadic collaboration effectiveness are substitutive; that is, the effect of dyadic closure on collaboration effectiveness increases as physical proximity between co-workers decreases.**

**METHODS**

**Data Setting**

We collected data from all the personal of two regional offices (in Singapore and in Kuala Lumpur, Malaysia) of a large and global pharmaceutical firm that were scheduled to move to a new site (in the same city). The moves followed the same format as previous moves in other regional offices of the same firm in other major cities worldwide. They were part of a company-wide policy which involved relocating the entire regional office personnel to a new site in the same city with a more “modern-look”, open-floor layout and ‘hot desk’ policy (i.e., no members of the organization had a pre-assigned desk/office in the new site - anyone could sit at any desk). We obtained social network data as well as physical location data between active members of the organization at the old site (prior to the move) and the new site (after the move) for both regional offices.

**Social Network Data**

The social network data were collected in the previous two months prior to the move (Time 1 of data collection) and within the following three months after the move (Time 2 of data collection). Network data were collected using a customized version of the Social Capital Questionnaire (a web-based survey specially designed to collect inter-personal social network data in organizations) developed by Gargiulo (2012). Survey questions were customized to the organizational context and conceptual framework of our study. All members of the organization were sent an introductory email, signed by the managing director and human resources director of each regional office, explaining the nature of the study (i.e., to understand the effects of the move on the social network...
patterns at work). The communication emphasized that the collected data would be confidential and only seen by the academic researchers conducting the study. Each respondent received an email sent from the Social Capital Questionnaire server with her/his login and password credentials (to guarantee confidential access to the survey). Respondents could complete the survey in one go or ‘save and return’ to it later for completion. The survey used a combination of typical sociometric techniques to collect the network data (Wasserman and Faust 1994, pp. 43-54). It had three sections: (i) “Contacts” to identify the main contacts at work of each respondent; (ii) “Relationships”, to capture the nature of each dyadic relationship identified; (iii) “About you” (at Time 2 only) to capture background information and work style of each respondent.

(i) Contacts: Respondents identified the people they had “engaged in work-related or social exchanges” over the last six months (at Time 1) or since the move to the new site (at Time 2). Respondents were asked to identify contacts based on four types of inter-personal communication (discuss-type, help-seeking, help-giving, and social-type). For each type, they were provided with a fixed roster comprised by the people working in their regional office. (For Time 2 these rosters were revised with new additions and departures from the respective sites.) The full name of each possible contact was clearly specified, and respondents were asked to select contacts based on the type of interaction, as follows. Discuss-type contacts “with whom [the respondent] has discussed important aspects of her/his work [at the company]”. Help-seeking contacts that the respondent “has gone to for advice or to seek help on matter regarding her/his work”. Help-giving contacts that “have come to [the respondent] for advice or to seek help on matters regarding their work”. Social-type contacts with whom the respondent “usually get together for informal activities such as going for lunch, coffee breaks, dinners, drinks, movies, visiting one another’s homes, and so
on”. On average, respondents selected 15 and 18 contacts at Time 1 in Singapore and Malaysia, respectively, and 16 and 19 contacts at Time 2 in Singapore and Malaysia, respectively.

(ii) Relationships: Respondents reported the nature of their relationship with each of the people selected in the Contacts section. For each contact, the respondent was asked nine questions about various aspects of the relationship. For each question the full name of the contact was displayed. Questions captured the duration of the relationship, communication frequency per media (face-to-face, telephone or videoconferencing, electronic media such as email or messenger), affective closeness, and four dyadic performance indicators (see later discussion of the dependent variable). Questions were based on the “the last six months” of interactions at Time 1 (pre move) and “since the move to [the new site] took place” at Time 2 (post move).

(iii) About you: This section captured data concerning the respondent’s background and work style, including gender, age, nationality, level of formal education, main area of study, job title, duration in current job position, and tenure at the company. These data allowed us to define basic controls (based on observable data) for each active dyad in our analysis. Respondents were asked to indicate their top three most-used desks at the new site (at Time 2) and shown the office layout of the new site, each desk clearly marked with a unique identifier. In both locations (Singapore and Malaysia), the new site was divided into three (in Singapore) or four (in Malaysia) distinct (colored) zones with unique identifiers for each desk location.

From the Singapore site, we had 60 (out of 67) complete respondents at Time 1 and 61 (out of 78) respondents at Time 2 with 90% and 78% respondent rates, respectively. From the Malaysia site, we had 131 (out of 142) complete respondents at Time 1 and 104 (out of 138) respondents at Time 2 with 92% and 75% respondent rates, respectively. In total, we had complete network data for 136 active employees in both rounds 1 and 2 in both sites (44 in Singapore and 92 in Malaysia).
Physical Location Data

We obtained (from the corresponding HR departments) the offices layout for both sites (at both Time 1 and 2) as well as the seating plans with the assigned desks/offices of all respondents at Time 1 (in both regional offices). As mentioned, we asked respondents to report their three most-used desks at Time 2. With this location data we then estimated inter-personal distances between actors of active dyads in both Times 1 and 2.

Variables Description

Dependent variable: Collaboration Effectiveness. For each active dyad in either Time 1 or 2, we captured four different dyadic performance metrics from the respondent’s viewpoint with respect to their relationship with each contact identified: (i) timeliness of the contact’s support regarding the respondent’s work at the company; (ii) value added by the contact to the respondent’s work at the company; (iii) significance of the contact’s contribution to the respondent’s professional development; (iv) respondent’s desire to interact more with the contact to enhance the respondent’s professional development. These four performance metrics loaded onto a single factor at both Time 1 and 2, averaged to build our main dependent variable (Cronbach’s Alpha 0.78 and 0.80 for Times 1 and 2, respectively). Hence, we measured Time 1 and Time 2 collaborative effectiveness for active dyads in both rounds.

Independent variables. We had two sets of independent variables: dyadic social network variables and dyadic physical distance variables. Our dyadic social network variables (tie strength and dyadic closure) were calculated based on the communication frequency and affective closeness reported by each respondent on each active dyad at Time 1 and 2.

Tie strength is a complex construct formed by a combination of tie-related factors that include duration, communication frequency, and emotional closeness (Granovetter 1973, Marsden
and Campbell 1984). As per the network literature, we measure tie strength based on the latter two indicators (e.g., Hansen 1999, Reagans and McEvily 2003, Sosa 2011). First, respondents were asked to indicate their *average communication frequency* (“outside regular team meetings”) with each identified contact “during the last six months” at Time 1 and “since the move to [the new site] took place” at Time 2 (daily, weekly, once or twice a month, less often) based on the communication media used (in person face-to-face, telephone or videoconference, electronic media such as email or messenger). Respondents were also asked about their *affective closeness* by choosing the “statement that best represent their relationship” with each of the identified contact: Very close—the contact “is a close friend”; Close—the respondent “feels close to [the contact] but you would not call him/her a close friend”; Acquaintance—“[the contact] is OK to work with, but you have no personal relationship with him or her”; Distant—“this [the contact] is a person you will seek out only if necessary.” To calculate tie strength, we followed Burt (1992), measuring interaction intensity as the average of affective closeness and average communication frequency ($z_{ij}$). Then, we measured tie strength ($p_{ij}$) as the proportion of the respondent’s total interactions invested in the relationship with contact $j$, both as a result of $i$’s seeking out $j$ and of being sought out by $j$. This was consistent with previous network studies that transform tie intensity into a proportional measure of tie strength (Burt 1992, Gargiulo and Benassi 2000, Reagans and McEvily 2003, Sosa 2011). Hence:

$$p_{ij} = \frac{z_{ij} + z_{ji}}{\sum_{q}(z_{iq} + z_{qi})}, \text{ for } i \neq j.$$ 

This proportional measure of tie strength allows us to capture how respondent $i$ allocates time and attention to the different people with whom she interacted at work (“during the last six months” at Time 1 and “since the move to the new site” at Time 2). It is worth noting that the tie strength measure is based on all communications in which the respondents were involved as either
seeker or provider of information. In this way, tie strength takes into account the proportional amount of energy and attention that respondent $i$ spent with contact $j$ relative to all the interactions in which respondent $i$ was involved (Burt 1992, Gargiulo and Benassi 2000).

_Dyadic network closure_ is a function that depends on the number and strength of third-party connections surrounding the focal relationship $(ij)$. Following Burt (1992, pp. 54-56) and Reagans and McEvily (2003, p. 255), the involvement of respondent $i$ on common third parties ($q$) with source $j$ was assessed using a measure of indirect constraint ($c_{ij}$):

$$c_{ij} = \sum_{q} p_{iq} p_{qj} \text{ for } q \neq i, j$$

This measure captures the strength of the relations surrounding the focal interaction between actors $i$ and $j$. A relation with a common third party ($q$) is strong to the extent that the respondent has a strong relationship with the third party ($p_{iq}$) and the third party also has a strong relation with the respondent’s contact ($p_{qj}$).

To assess the overall strength of these indirect connections surrounding the focal connection between respondent and the contact, we need to sum over all their common contacts. Note that as $p_{ij}$ measures the proportion of the respondent’s total interactions invested in the relationship with contact $j$ (as a result of $i$’s seeking out $j$ and of being sought out by $j$), our measure of dyadic closure captures the presence of common third parties even if respondent $i$ did not seek out $q$ but was sought out by $q$ ($z_{iq} = 0$ and $z_{qi} > 0$).

_Dyadic physical distance_ was calculated between actors of each active dyad at Time 1 and 2. We first estimated inter-desk distances on each office layout by calculating the shortest step distance among each unique pair of employees. This is the most natural measure of distance in a building, i.e. the actual distance one person covers to reach the other party. To calculate step distances, we overlaid a graph on the office maps, to capture the available pathways among all the working desks, and calculated the shortest path (geodesic distance) among each unique dyad. In
one site where employees were sitting on two different floors, we calculated cross-floor distances using the closest elevator as a mid-point. This allowed us to assume the same distance unit (or step, of about one meter) on each office layout so that inter-desk distances could be compared across sites. After estimating inter-desk distances, we determined inter-personal distance for any given dyad (at either Time 1 or 2). For the location of people at Time 2, we calculated inter-personal distance between the “most used desk” locations and controlled for the tendency of either member of the dyad to change desk location at Time 2.

Control variables. We control for dyadic homophily indicators based on the age, gender, education, professional experience, nationality and tenure in the firm of the respondent and the contact in each active dyad. We also created contextual controls related to the location of the actors in a dyad, that is, indicator variables to control for the tendency of the members of any dyad to change desk locations at Time 2, and an indicator variable to control for the fact that some dyads were located in two different floors at Time 1.

Estimation Procedures
Since our dependent variables are dyadic, we tested our hypotheses using the Social Relations Model (SRM; cf. Kenny and La Voie 1984, Snijders and Kenny, 1999), a commonly used multilevel method for analyzing data at the dyadic level (Koster, Leckie and Aven, 2020; Dorff and Ward, 2013). The logic of SRM is to break down variance in social network data at three levels of analysis: ego (rater), alter (rated), and dyad (ego-alter relationship). Ego variance is the proportion that derives from the tendency of an actor to rate others, on average, in a specific way. Alter variance refers to the proportion arising from the tendency of a target to induce ratings from average others. Dyadic variance arises from the specific relationship between the actor and the target. This method allows us to examine how much of the dyadic variance in collaboration
efficiency is due to characteristics of the relationship between ego and alter, controlling for random variance of at the individual levels.

To fully utilize the longitudinal nature of our data (composed by pre and post move measurements, or Time 1 and Time 2), we employ a model specification based on change scores (Allison 1990). The basic premise is to regress Time 2 collaboration effectiveness on change in our predictors, while controlling for baseline (Time 1) levels of the predictors, allowing us to estimate the effect of whether getting physically closer to someone (calculated as Time 2 minus Time 1 difference in inter-personal physical distance) is positively related to dyadic collaboration effectiveness in Time 2. In order words, we examine why some dyads show better collaborative effectiveness than others after the move, estimating whether the variation in collaboration effectiveness is related to changes in physical and social distance between interacting dyads.

RESULTS

Table 1 reports bivariate correlations and descriptive statistics of change in the main variables included in our analysis. Basic bivariate correlations provide some preliminary support for our theoretical model. Change in physical distance is negatively related to change in collaboration effectiveness ($b = -0.06; p < 0.05$), while change in both tie strength and dyadic closure are positively related to our outcome variable ($b = 0.09; b = 0.06; p < 0.05$). Next, we move to testing our hypotheses more rigorously using our multivariate specifications.

--- INSERT TABLE 1 ABOUT HERE ---

Testing baseline hypotheses 1 and 2. Models 1 to 5, reported in Table 2, test the differential impact of changes in physical and social distance (Time 2 – Time 1) on collaboration effectiveness at Time 2, while controlling for the baseline levels of physical and social distance at Time 1. Model 1 focuses on change in physical distance. While we did not explicitly hypothesize the directionality
of the effect of physical distance, we expected a reduction in physical distance to have a positive impact on collaboration between two employees. Consistent with this, Model 1 reports a negative and statistically significant effect of change in physical distance \((p < 0.001)\) on collaboration effectiveness, confirming that physical closeness to a colleague favors dyadic collaboration effectiveness. Model 2 examines the impact of change in tie strength on collaboration, finding – consistent with the literature – that an increase in tie strength corresponds to an increase in collaboration effectiveness \((p < 0.001)\). Model 3 again reports a positive and statistically coefficient for change in dyadic closure \((p < 0.001)\), again suggesting that dyadic closure via common third parties improves collaboration performance. Model 4 includes both the effects of change in tie strength and change in dyadic closure, and shows that while the former stays positive and statistically significant \((p < 0.001)\), the latter becomes much smaller and non-significant. This may be partially attributable to the positive correlation between tie strength and dyadic closure \((r = 0.27)\). A preliminary interpretation of this is that tie strength is simply a much stronger and direct predictor of dyadic collaboration performance than dyadic closure (Reagans and McEvilly 2003), but to be conclusive we need to examine the possible confounding effects of physical proximity and social network structure. To that end, Model 5 jointly tests the effects of changes of physical and social distance. The fundamental finding here is that while change in physical distance and change in tie strength remain negative/positive (respectively) and statistically significant at the 95% level, the same cannot be said of the coefficient of change in dyadic closure, which continues to be non-significant.

--- INSERT TABLE 2 ABOUT HERE ---

**Testing hypothesis 1.** The inclusion of change in tie strength in Model 5 (Table 2) corresponds to a 66% decrease in magnitude of the coefficient of change in physical distance (in comparison to
Model 1, Table 2). This result hints at how tie strength may mediate the effect of physical distance; in other words, getting physically closer might increase tie strength, which may then have an impact on collaborative performance. To further explore this potential mediation effect, regression models in Table 3 split tie strength into its two basic components, *frequency of dyadic communication* and *dyadic affective closeness*, to test H1 and understand which one underlies the potential mediation mechanism.

--- INSERT TABLE 3 ABOUT HERE ---

All models in Table 3 substitute *change in tie strength* for *change in dyadic communication frequency* and *change in dyadic affective closeness*. Consistent with the previous results, Model 7 shows how an increase in both dyadic communication frequency and affective closeness boost collaboration effectiveness (*p* < 0.001). Moreover, the inclusion of the two components of tie strength again reduces the effect of *change in physical distance* (compared with Model 6), suggesting the presence of mediation. To statistically test H1, we perform a multiple mediation test to understand the degree to which the effect of change in physical distance on collaboration effectiveness is mediated by either an increase in dyadic affective closeness or frequency of dyadic communication. Four conditions need to hold to statistically prove the presence of a mediator (Hayes, 2013). First, the independent variable (IV) needs to be statistically related to the dependent variable (DV). Second, the IV needs to statistically predict the mediation variable (MV). Third, the MV needs to statistically predict the DV while controlling for the IV. Finally, a Preacher-Hayes bootstrap test is needed to test for significance of the mediation (Preacher and Hayes, 2004).

The first condition for a significant mediation was satisfied by Model 6, which found a statistically significant negative coefficient for *change in physical distance* (*p* < 0.05). The second condition was supported by regressing *change in physical distance* on our two moderators,
showing that an increase in physical distance affects negatively both the change in affective closeness \((p < 0.01)\) and change in frequency of communication \((p < 0.05)\). The third condition was supported by Model 7, which showed a positive and statistically significant relationship between change in dyadic affective closeness, change in frequency in dyadic communication and our dependent variable \((p < 0.001)\) while accounting for the effect of change in physical distance.

The magnitude of the indirect effects is noteworthy. Change in dyadic affective closeness mediates 71% of the effect of change in physical distance on collaboration effectiveness, while change in communication frequency mediates another 16%. Thus, communication and affect combined mediate about 87% of the effect of physical proximity on collaboration performance. To test the statistical significance of these indirect effects, we calculated them based on bootstrapping with 5,000 iterations (Preacher and Hayes, 2004): the indirect effect of communication frequency was marginally significant \((p < 0.10)\), while the effect of affective closeness was strongly significant \((p < 0.001)\), lending support to our first hypothesis.

**Testing hypothesis 2.** We start by exploring the interaction effects between social and physical distances. In Model 8 we introduce separate interaction terms multiplying change in physical distance with change in frequency of communication, change in affective closeness and change in dyadic closure, respectively. The effect of change in communication and affect is positive and significant, while the baseline effect of change in dyadic closure remains negative and non-significant, in line with previous models. When analyzing the interaction effects, two results are noteworthy. First, a significant negative interaction between communication frequency and physical distance \((p < 0.05)\) shows that the positive effect of communication frequency on collaboration marginally decreases as physical distance between employees increases. Thus, the effect of communication is amplified by physical proximity. Second, Model 8 shows a positive
and statistically significant coefficient for the interaction between change in physical distance and change in dyadic closure ($p < 0.05$). These results provide support for H2 on the substitution effect between changes in dyadic closure and change in physical distance – a strong increase in dyadic closure seems to mitigate the otherwise negative effects of moving away from colleagues. Alternatively stated, the effect of a change in dyadic closure increases for dyads that increase their physical distance after the move while the effect of dyadic closure is not significant for dyads that become physically closer after the move.

Robustness Tests

Selection bias. Table 3 presents the results of several tests of the robustness of our findings. First, we might be concerned about the reasons why respondents reported dyads at time 1, but not at time 2. Indeed, of the 2762 dyads reported by respondents at Time 1, 1204 dyads (44%) were not reported again in the second data collection round (Time 2). Dyads could have been dropped for exogenous reasons (such as the collaborating employees being assigned to other projects) or endogenous ones. For instance, attrition could be due to poor collaboration performance at Time 1, or a high physical and/or social distance, injecting selection bias in our estimations. However, since we observed performance and distance measures at Time 1, we corrected for potential selection-on-observables by implementing a Heckman-selection procedure (Heckman 1979), by including a first-stage equation in which we estimated the likelihood of respondents to report a dyad at Time 2 - contingent on having reported it at Time 1 – using a probit model. This first stage indeed showed that respondents were more likely to report again a dyad at Time 2 if they rated the collaboration to be effective at Time 1 ($\beta = 0.29, p < 0.001$), if the dyad was in the same department ($\beta = 0.16, p < 0.01$), and if they reported high dyadic closure at Time 1 ($\beta = 4.63, p < 0.05$); conversely, respondents were less likely to report again a dyad that was physically distant at Time
1 (β = -0.09, p < 0.01). Since these results suggest the presence of potential selection bias, we corrected for it by using the first-stage estimations to calculate an inverse-Mills ratio to include in our full model specification. The results, provided in Model 9, show that while the coefficients were indeed affected by the first stage selection process, they also behave in the same direction of the hypotheses, thus confirming our results in the face of potential selection bias. That is, change in dyadic affective closeness substantively mediates of the effect of change in physical distance (consistent with H1) while the positive interaction effect between change in physical distance and change in dyadic closure remains positive and significant (consistent with H2).

**Endogeneity of physical distance.** Another potential threat to our results relates to the endogeneity of changes in physical distance between Time 1 and Time 2. At Time 2 respondents were given the freedom to choose their own workstation, which could be problematic if they did so based on collaboration effectiveness or for other endogenous reasons. To allay concerns about potential endogeneity we thus implemented a control function approach (with two-stage residual inclusion), as it is preferable over two-stage least square (2SLS) estimations in the presence of interaction effects (Terza et al. 2008). We selected two instrumental variables. The first was a dummy that took the value of 1 if the two actors in the dyad have the *same gender*. Our choice was guided by existing research, which shows that while similarity in demographic traits may lead to preferential attachment, it impacts dyadic performance only under very specific conditions (Ertug, Gargiulo, Galunic and Zou, 2018). The second variable is *difference in organizational tenure* between interacting actors; our logic here is that while employees may choose their desk based on difference in tenure (employees might sit together by cohort or junior employees might sit closer to seniors to benefit from status and power spillovers), based on past studies we do not expect
difference in tenure per se to have an impact on the collaboration effectiveness of the dyad (cf. Reagans and McEvily, 2003).

Results of the first stage shows a strong significant effect of difference in organizational tenure on seating choices ($\beta = -0.03$, $p < 0.001$), and a marginally significant effect of same gender ($\beta = 0.12$, $p = 0.07$). As predicted, the bivariate correlations between our instrumental variables and our dependent variable are close to (and statistically indistinguishable from) zero. Note that because our instruments are also correlated with change in dyadic affective closeness, we cannot use this approach to test the robustness of H1. Nonetheless, it allows us to test the robustness of our findings with respect to H2.

Model 10 implements our control function approach by introducing the first stage residuals of change in physical distance in our full model. The expected interaction effect of change in physical distance and change in dyadic closure remains positive and significant ($p < 0.05$), once again confirming our main finding regarding the substitution effects of inter-personal physical distance and dyadic closure. Finally, Model 11 includes both the control function and the correction for selection bias, again confirming this result.

**DISCUSSION**

With the introduction of new ways of organizing, both physical space and the structure of social networks have a role to play in organizational performance, yet existing organizational theories do not consider how moving into new office arrangements might change communication networks and affect patterns of collaboration. Our work provides insight to expand the current view of the role of interpersonal networks in organizational performance to take account of the levers that novel seating arrangements offer to organizational designers. Such insights are increasingly important in the post-pandemic world as firms explore new ways of organizing a workforce that
is no longer collocated, and where the interplay between inter-personal distance and intra-organizational network structures have effects on workplace collaboration.

**Theoretical Contributions**

Our work bridges two streams of literature which examine the determinants of inter-personal collaboration from two distinct perspectives, respectively how physical distance affects the propensity for and effectiveness of collaboration at work (e.g., Allen 1977, Van den Bulte and Moenaert 1998; Sosa et al. 2002, Cummings 2004, Kabo et al. 2014, Catalini 2017, Lee 2019), and how social network structures influence various aspects of collaboration (e.g., Burt, 2005; Reagans and McEvily 2003, Sosa 2011, Tortoriello et al. 2012). Our study shows that connecting these two streams of research both conceptually and empirically is critical to be able to identify the effects of social network patterns beyond the effects of physical separation. And that it is equally important to consider the various underlying mechanisms by which physical proximity affects collaboration. In so doing, we are able to understand how social and physical spaces contribute independently and jointly to intra-organizational collaboration.

Our findings indicate, first, that although inter-personal proximity indeed correlates with more frequent inter-personal communication at work, the effect of physical proximity is mediated by the stronger positive affect associated with physically closer coworkers. This highlights the role of physical proximity (beyond promoting inter-personal communication) in promoting familiarity, trust, positive affect, and relational energy, which in turn contribute to more effective relationships at work (Casciaro and Lobo 2006, Amabile et al. 2005, Collins 2004).

We also find evidence that physical proximity encompasses a control mechanism due to the visual presence of physically closer colleagues. Visual proximity is likely to facilitate the emergence and enforcing of trust, reciprocation and cooperation in a similar way as third parties
would do. As a result, the effect of dyadic closure, as measured by the presence of common third parties, is accentuated for physically distant dyads as the effect of visual presence disappears. This finding is critical for future research in social networks because it shows the downside of overlooking (as traditionally happens) the role of inter-personal distance when studying how network structures affect organizational performance. Analogously, future studies of how changes in collocation patterns affect performance will not be complete if they do not capture the effect of social network structures.

**Limitations**

Despite the robustness of our findings when estimating the effects on collaborative effectiveness, there are limitations to our study. First, even though having access to both social network and physical space data before and after an exogenous shock (i.e., moving to a new site) provided a unique dataset, it also imposed limitations on our research design. In particular, the fact that the firm implemented a free-seating policy “after the move” allowed people to vary both their social communication and inter-personal distance patterns simultaneously. Such an arrangement differs from the ideal scenario in which the researcher randomly varies one explanatory factor (like the seating arrangements after the move) and observes the effect of other factors on collaboration. Indeed, it is possible that in the setting studied, pairs of collaborators who had worked well together before the move chose to seat closer after the move, which would increase their social connection and the effectiveness of the collaboration. Yet even if that were true in isolated cases, it is unlikely that the entire organization would self-organize into clusters of well-functioning collaborators. Indeed, our data and robustness checks suggest that respondents had effective collaboration with partners at various distances and with various levels of social connection, hence a systematic bias.
towards clustering effective collaboration pairs together in physical and social spaces was unlikely to be at play.

Second, like most of previous intra-organizational social network studies a great deal of our data rely on self-reported network surveys. Although we followed best practice in social network data collection, there is always the possibility that self-reporting errors undermine the veracity of the data gathered. However, there is no specific reason to believe that such measurement errors would not be randomly distributed in our sample. Another data-related issue is the fact that our dependent variable is a combination of self-reported dyadic indicators. However, because our key explanatory variables were not an exclusive function of the respondent, concerns about common methods bias are minimized (Podsakoff and Organ, 1986).

Obviously, inter-personal distance is not a direct function of the respondent because it also depends on where his/her contacts decide to sit. Again, with respect to our main social network predictors we follow previous network studies (Burt 1992, Gargiulo and Bennasi 2002, Reagans and McEvily 2003) by which tie strength and dyadic closure not only depend on the communication frequency and affective closeness reported by the respondent but also the communication frequency and affective closeness reported by all contacts of the respondents. This should reduce concerns about common method biases.

Third, our findings are based on data from South East Asia – the sites of a multinational firm in the pharmaceutical industry. For our results to be generalizable, future work should test our findings in other firms in other industries and other regions.

Conclusions and Future Research

With this work we aim to open new avenues of research for both social network scholars and researchers studying the organizational impact of inter-personal distance (be it in relation to new
seating arrangements, changes in the physical space, or hybrid working policies). Novel research questions emerge as we consider the interplay of both the social and physical domains in a context of collaboration. Is the moderating effect of distance and closure on collaboration non-linear? Is there a distance threshold after which the effects of distance entirely disappear? Do physical spaces affect creativity directly or through changes in social capital, or both? Given the ubiquity of digital technology, how can we collect more granular and longitudinal social network and inter-personal distance data to analyze more precisely the dynamic drivers of inter-personal collaboration?
REFERENCES


### TABLE 1. Correlation table and descriptive statistics

<table>
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<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
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<th>3</th>
<th>4</th>
<th>5</th>
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<td>2. Change in physical distance (Time 2 - Time 1)</td>
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<tr>
<td>3. Change in tie strength (Time 2 - Time 1)</td>
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<td></td>
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<td>0.04</td>
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*N = 1245. Correlations bigger than |0.04| are statistically significant at the 0.05 level (two-tailed tests).*
Table 2. Regression analysis of dyadic collaboration effectiveness at Time 2: Testing baseline hypotheses.

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
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<tr>
<td>Change in physical distance (Time 2-Time 1)</td>
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\(^a\) Robust z-statistics are in parentheses.
\(^b\) Controls include dyadic homophily in age, gender, tenure, education, professional experience, nationality
\(^#\) \(p<0.1, \,*\ p<0.05, \,**\ p<0.01, \,**\!\!\! p<0.001; \) two-tailed tests for hypothesized effects.
Table 3. Regression analysis of dyadic collaboration effectiveness at Time 2: Hypotheses testing.

<table>
<thead>
<tr>
<th></th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
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<th>Model 10</th>
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<td>.07**</td>
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<td>.06**</td>
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<td>.43***</td>
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<td>Change in dyadic affective closeness (Time 2-Time 1)</td>
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<td>.36***</td>
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<td>(12.70)</td>
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<td>(10.60)</td>
<td>(12.53)</td>
<td>(10.71)</td>
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<td>Change in physical distance * change in dyadic communication frequency</td>
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<td>- .03#</td>
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<tr>
<td>Change in physical distance * change in dyadic closure</td>
<td>2.31*</td>
<td>2.06*</td>
<td>2.18#</td>
<td>2.05*</td>
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<td></td>
<td>(1.99)</td>
<td>(2.05)</td>
<td>(1.94)</td>
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<td>-2.66***</td>
<td>-2.54***</td>
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<td>Residuals of change in physical distance</td>
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<tr>
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<td>(8.39)</td>
<td>(2.27)</td>
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*Robust z-statistics are in parentheses.

Controls include dyadic homophily in age, gender, tenure, education, professional experience, nationality

p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001; two-tailed tests for hypothesized effects.

Control variables:

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