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FEATURE Case Study

Increasing Interactions in Healthcare Teams through Architectural Interventions and Interpersonal Communication Analysis

A Case Study

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A critical component of successful care delivery for healthcare teams is efficient, effective rounding, which is a key component of any successful healthcare delivery. Rounds offer an innovative opportunity to improve interdisciplinary practice, specifically to leverage each member's area of expertise and scope of practice.

Optimal rounding depends on effective communication that leverages the knowledge and wisdom of the team members to achieve accurate, efficient, and family-centered care. The quality of communication is determined by the actors, the technology and tools they use to aid information exchange, and the built environment within which they operate. Healthcare staff stress levels, error frequency, and effectiveness have been shown to be influenced by the design of their workspace.[1]

Our overall aim is to decrease environmental distractions and promote collaborative thinking by optimizing the built environment to improve team function. The assumption of this study is that the team will show improved communication as assessed by standard sociometric metrics. The goal of our research is to use design interventions to modify the space to make it more conducive to communication as a means of improving team effectiveness.

LITERATURE BACKGROUND

For chronic conditions, the best care requires effective interdisciplinary teams with diverse competencies who work in a coordinated fashion toward a common goal, as described in the Chronic Care Model proposed by Wagner.[2] In this article, we focus on exploring the characteristics of human interaction and communication to improve of effectiveness of interdisciplinary teams.

An important component of care delivery and communication is the built environ-

ABSTRACT

This study assessed the effect of interventions to existing architectural space to remove environmental distractions, improve communication processes, and promote team effectiveness. The goal of this research is to define a framework that optimizes the development and delivery of care in patients with complex and chronic health conditions by improving communication among members of an interdisciplinary care team. The unit of analysis was an inpatient interdisciplinary care team in a specialized unit at Cincinnati Children's Hospital Medical Center (CCHMC). Sociometric badges were worn by team members during pre-rounds and rounds. The sociometric badges collect data using tools such as microphone, accelerometer, Bluetooth, and RFID. Experiment data were also collected through participant observation, photos, videos, and formatted surveys. Fewer external interruptions during rounds were correlated to an increase in dialog and to a less hierarchical communication pattern. Team members who interacted more with others were able to make a better use of the working space, moving more within its boundaries. This study provided empirical evidence that clearly marked rounding spaces outside of each room act as effective visual indicators, resulting in noticeably more compact and consistent team interaction.

KEYWORDS

Communication, teamwork, chronic disease management, patient-centered care, social network analysis, quality improvement methodologies, architectural intervention.

ment. The field of Evidence Based Design (EBD) has emerged to observe and quantify relationships among the built environment and the individuals and populations that inhabit the designed space. Specifically in relation to healthcare architecture, EBD has the goal of using "rigorous research linking hospitals' physical environments to healthcare outcomes."[1] The setting in which they build and act can influence how team members interact with one another and with patients. Environmental factors that affect communication include the building's layout, visibility, room proximities, noise levels, lighting, and privacy.[1]

An emerging, innovative way to assess and improve team function is to use findings from the science of Social Network Analysis (SNA), an interdisciplinary field that offers methods and tools to dynamically assess the growth of value derived by social interactions.[3] Recently researchers have been using SNA methods to analyze data extracted from sociometric badges that measure various aspects of interactions between people when they are face-to-face or in close proximity.[4,5] The sociometric badge is a wearable electronic device with multiple sensors capable of capturing information on body movement, speech, and interaction patterns. Past analyses using these badges have demonstrated that different patterns of communication emerge for different types of teams.[6,7]

Sociometric badges have been used to predict the length of stay associated with patients in a Post-anesthesia Care Unit.[8] A group of 67 nurses wore badges over a span of 27 days. The researchers were able to predict the daily average value of length of stay using accelerometer data, the amount of face-to-face interaction time among the nurses, and the amount of time nurses spent near a phone. Their work supports the importance of integrating behavioral data into the systems used by healthcare professionals.

Here, we propose to use SNA to understand interactions among the interdisciplinary team members of the liver transplant team while on rounds.

The automatic measure of behavioral data makes a quantitative assessment of provider-patient interactions possible on a substantially larger scale than has been possible in the past.[9] There are several empirical evidences based on surveys showing that interprofessional collaboration is an essential component of best practice in the healthcare environment.[10,11] Despite this surge of interest, the mechanisms of collaboration and teamwork within interdisciplinary healthcare settings are often difficult to put into practice and require commitment, trust, and willingness to cooperate.

Relationships between nurses and physicians have been extensively studied. A large survey conducted by Stein et al[12] found that poor communication among health professionals was the most important factor causing dissatisfaction with nurse/physician working relationships. Similar results confirm that communication failures among professionals can negatively affect patient outcomes.[13,14] Strategies for change have been proposed by several authors, including empowering nurses so that they feel secure in their knowledge and clinical expertise, and increasing collaboration among nurses and physicians. Regular nursing/medical staff meetings, similar to the preround discussed in this article, have the potential to help move all healthcare providers away from an "us versus them" mindset.

The remaining sections of the article will describe a five-week data collection using Sociometric badges at the Cincinnati Children's Hospital Medical Center (CCHMC) and its subsequent analysis.

PROBLEM IDENTIFICATION

The main research question leading this study is: how can architectural interventions influence interpersonal communication in the context of interdisciplinary healthcare teams? To address this question, we built a basic conceptual model described in Figure 1. In this article, we will focus on phase 1 and not discuss whether distinct patterns of human interaction predict patient outcomes (phase 2).

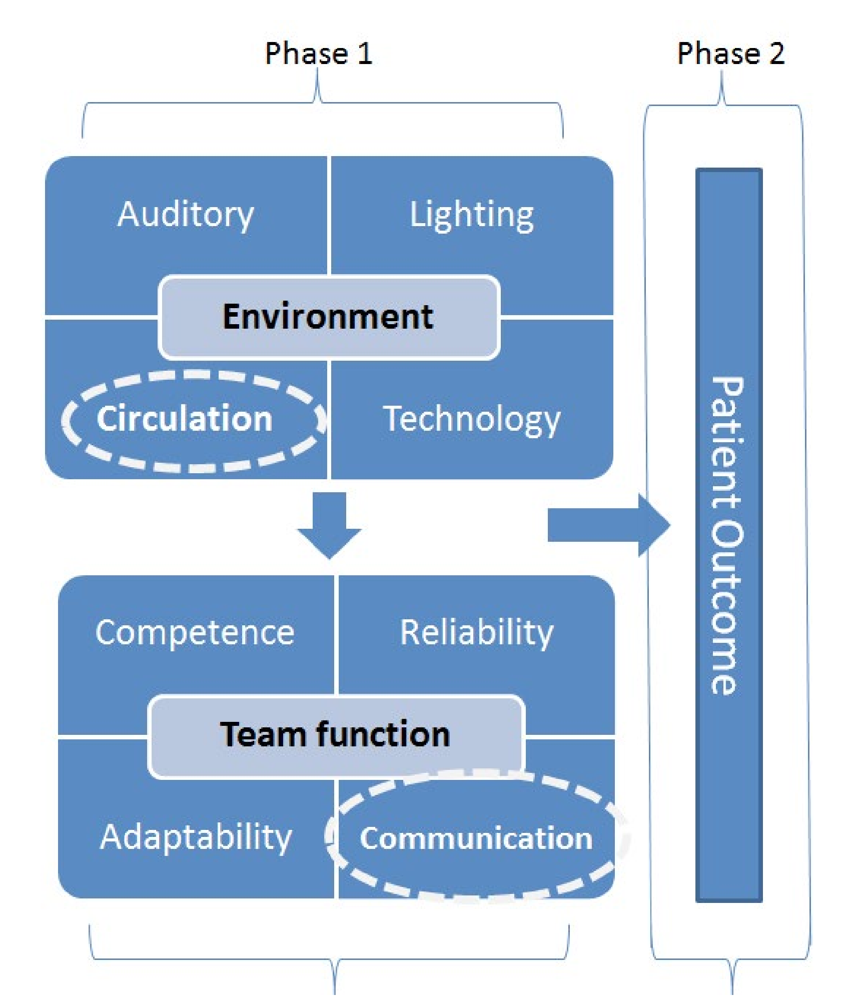
The model illustrates that team function, especially communication, is dependent on environmental drivers such as: auditory factors, lighting, circulation, and technology. The model described in **Figure 1** is based on a definition of team function as composed of competence, reliability, adaptability, and communication. Competence is defined as team members' ability to possess the skills and knowledge to carry out care delivery tasks; reliability is defined as the likelihood that the care professional will do the expected task with desired outcome; adaptability is defined as team members' ability to respond to changing situations with respect to patient needs, the demands of other team members and the situation; and communication is defined as team members' transmission of information on patient status and care plan to one another. The working environment is made up of several components including traffic circulation patterns and interruptions, lighting and glare, sound levels and interruptions (auditory), and information technology and displays.

Participant observations, interviews, photos, and surveys were used to gather a diverse dataset representing inputs that impact communication quality. Review of these datasets supported the inclusion of the five environmental factors in **Figure 1** (audibility, visibility, circulation, glare, and ergonomic quality) that determine the effectiveness of the rounding space. Additionally, we identified communication practices and networks within the team, and spatial impediments to team function.

An initial on-site visit was made to identify communication gaps and how they relate to the built space. To model the communication patterns within the team, we used data extracted from the sociometric badges that created digital traces of the physical activity within the team, speech activity, face-to-face interactions, proximity, and social network metrics such as betweenness centrality and degree centrality.[15,4,5]

We identified existing conditions of the corridor that did not support effective team communication. Uniform lighting, limited formal workspaces, lack of natural light, an undifferentiated corridor, and barriers to patient visibility are all marks of a space of compression. Encouraging expediency, the corridor in its current configuration was detrimental to the interdisciplinary team and their goals to deliver high-quality, effective, family-centered care.

FIGURE 1: Conceptual Model



This model is the result of the interdisciplinary contribution of our research team composed of a physician, computer research scientist, business school professor, PhD student in Engineering and a team of designers.

RESEARCH DESIGN

The experiment was set up as a two-stage process. In the first stage, which lasted five days, all team members working in prerounds and rounds were asked to wear sociometric badges that collected data on their communication practices. Additionally, participant observation and photos were used to record circulation, formation, interruption, location, and duration patterns.

In the second stage, we installed design interventions to alter the space and informed the team of how they were to use the newly altered space. Each of these interventions was chosen based on specific architectural impediments, specifically corridor traffic and audibility. There were three interventions designed to address these barriers. A large yellow tape was placed on the hallway floor to delineate a path for corridor circulation. This separated regular hallway traffic from the team and was intended to reduce interruptions. A blue tape was also placed on the hallway floor to make boxes to mark where presenters should stand and arcs to mark the team meeting space. The boxes and the arcs were installed to improve audibility between team members. Instructions were passed out to each team member and posted on the workstations on wheels to inform them of the tape's purpose. No interventions were made to modify glare or natural light condition in the corridor, and no interventions were made in the pre-rounding room. Finally, sociometric badges, pictures, video, and written observations were used to collect the same measurements as the previous week.

To further assess the impact of the interventions, each space outside of patient rooms was assigned a score based on the degree of external interruptions, such as hallway traffic and ambient sound volume. These scores were determined based on room placement along the hall because they could be exposed to more hallway traffic, certain pieces of architecture that influence audibility, or other hall uses, such as work stations or reception desks.

HYPOTHESES

The expectation was that the intervention on the physical space would lead to unconstrained communication, allowing for conversations to develop, resulting in more opportunities for all members to contribute.

The interdisciplinary work of Tom Allen[16,17] combining architecture, psychology and information technology has been the foundation for our hypothesis development. Allen's work demonstrated how failure to communicate is often the result of not seeing other member on a regular basis, which leads to lack of understanding what others are doing with negative consequences on the organizational performance. By investigating the physical distance between people and how frequently they communicate, Allen demonstrates that "the probability of a pair of people in an organization communicating with each other declines rapidly as the distance between them increases."[16] Allen found that people tend to communicate more with others that they are sitting close to, regardless of the method of communication, proposing the existence of a "50-meter barrier": if people sit outside this barrier, then the communication between them will likely never occur. Based on these studies, we developed the first two hypotheses:

H1. A working space with fewer external interruptions leads to an increase in dialog and a less hierarchical communication.

H2. An architectural intervention designed to suggest people's position leads to an increase in dialog and a less hierarchical communication.

To test H1 and H2 we relied on data extracted from the sociometric badges and from the direct observations during the rounds. The badges allowed us to measure how frequently each team member was speaking and whether the team member successfully interrupted the others (turn taking). We expect that the intervention to mark huddle spaces to reduce external circulation interruptions will lead to an increase in turns taken for all team members and to a more evenly distributed communication behavior. We anticipate that delineated, circular huddle spaces will cause less physical movement and improve team member visibility.

We also expect that the intervention that creates a consistent space for presenters to stand will lead to an increased number of turns taken at every patient room. By having presenters deliver information to the rest of the team from a consistent position, our third hypothesis assumes a more cohesive knowledge base, and thus a more developed conversation.

H3. An architectural intervention designed to suggest people's position leads to an increase in dialog when dealing with patients.

Here the intensity of dialog is extracted once again from the information provided by the badges, with a specific focus on the number of communication turns each badge-wearer is taking on average, per each patient.

H4. People who interact more with others also succeed in making a better use of the working space, moving more within its boundaries.

Team members who position their bodies to engage other team members take more turns, move more, and are more dominant in rounds conversations. We expected to see those who actively engage other team members by positioning their body to have similarly high metrics associated with verbal communication.

RESEARCH SETTING

We designed an experiment to investigate how the built environment at a major pediatric inpatient unit impacted the communication practices of an interdisciplinary healthcare team. Care for this population is complex and requires working knowledge of an interdisciplinary team with competences in fields such as transplant hepatology, transplant surgery, immunology, infectious disease, pharmacology, and nutrition.

An initial on-site observation period provided data for problem identification. A subsequent visit was made to gather primary data using sociometric badges worn by team members, to collect photos of the space and videos to assess space conditions and team communication patterns. In the second visit, we introduced interventions to alter the space as a means of effecting team communication.

In this environment, rounds function as the only time for all team members to meet face-to-face. During rounds, the team walks through the hall and meets at each patient's doorway for approximately 10 minutes to discuss the most recent updates on patient condition and care plan. Because the patients are immunosuppressed, the team is forced to round in the hallway, rather than in the patient's room, as they do in other wards. This separation makes it more difficult to connect with the patients and forces the team to meet in the disruptive corridor environment.

The rounding area—as currently used—is foremost designed as a space for circulation rather than decision making, care delivery, and communication. Functioning as a transitory space, the corridor impacts nearly all of the team's stated goals for care plan development, family-centered care, and decision making. Uniform lighting, limited formal workspaces, barriers to visibility, undifferentiated circulation, and a lack of natural light combine to create a space designed for circulation. **Figure 2** and **Figure 3** [illustrate the space condition before and after the intervention.

FIGURE 2A-D: Existing Conditions – Before Intervention

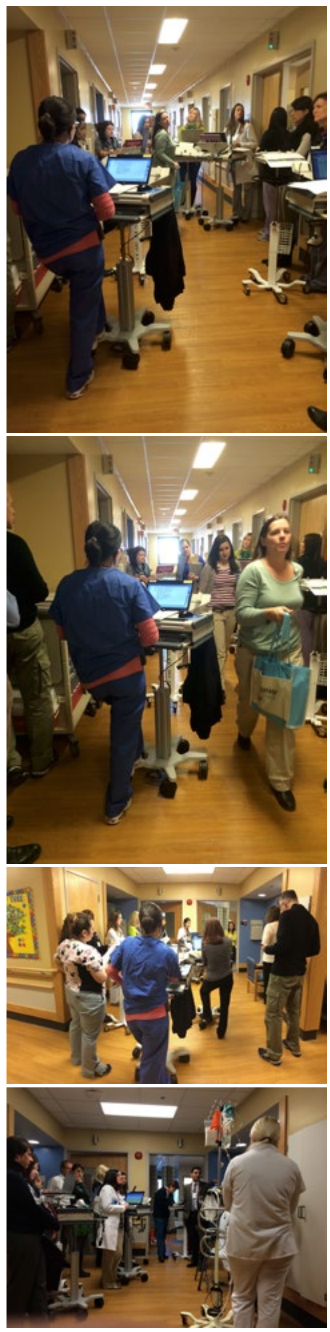


FIGURE 3A-D: Conditions after Intervention

Research was conducted in the spaces where the team prerounds and rounds occurred. During rounds, the core team, fellows, attending physicians and residents meet to discuss the patient condition in a more formal, sit-down setting. These pre-rounds sessions offer an alternative space for team members to develop patient plans of care; however, they do not include the family and other team specialists. It is essential to include all of these parties in treatment development to achieve the best outcomes for the floor's complex patients.

RESEARCH POPULATION

The liver transplant interdisciplinary team varies in size from 8 to 14 members from diverse specialties and experience levels. This team works to offer the best outcomes for populations of children with severe liver disease or those who have undergone liver or small bowel transplantation. During the observation period, the team had a varying composition depending on schedule. In all, it included one attending hepatologist, one transplant surgeon, one to two hepatology fellows, three advanced practice nurses (APNs), one fellow, two residents, one pharmacist, one dietitian, one care manager, and one charge nurse. Rounds and pre-rounds were enriched by a diversity of professional languages, which could potentially pose a challenge to effective communication and team function.[18]

An essential part of the liver team's communication practices is the divided organizational structure of the core team and the rotating team. Team structure varies widely as different combinations of surgeons, attending doctors, fellows, and residents rotate onto the team from day to day. The variation in team structure stunts the development of a consistent culture and practices that are essential to effectively exchanging information.

DATA COLLECTION

Experimental data was collected through participant observation, photos, videos, formatted surveys, and sociometric badges. Together, all of these data sources informed our hypothesis generation. Photos were taken approximately once every 30 seconds to provide evidence of interruptions and to mark the spatial location of each team member as they rounded. Time lapse videos were used on the final two days of the second week and provided a more comprehensive representation of how the design interventions impacted team behavior. Formatted surveys were used to record room number, rounds duration, interruption occurrence, and team presenter. Together, these datasets provided an accurate record of what part of the physical space the team was rounding in, their duration, and general trends in movement and interruptions.

Ten sociometric badges were handed out to team members prior to prerounds and rounds. The sociometric badges collect data using tools such as microphone, accelerometer, Bluetooth, and RFID. The infrared sensor serves as a substitute for face-to-face interaction that occurs when two badges are within line of sight of one another at a distance of less than 1 m. The microphone collects information on speech features such as volume, tone of voice, and speaking time, while the accelerometer provides measurements on body movement such as energy, posture angle, and consistency.[4,5]

DESCRIPTION OF VARIABLES

Applying a social network approach and using data extracted from the sociometric badges, we focused on the interaction flows occurring in each meeting and on the evolution of these ties over time. The networks maps we created are directed graphs, in which each actor (team member) is a node; nodes are connected by arcs that in our case represent the physical proximity interactions among team members. Accordingly, if actor a is interacting with actor b there will be an arc from actor a to actor b. Each arc is then weighted by the duration of the interaction, measured in seconds. If two actors are interacting, there is always a reciprocated relationship among them, so we will always have two arcs, one from actor a to actor b and one in the opposite direction. Because all the arcs in the networks are reciprocated, we can study a directed graph as if it were undirected; we assigned a weight to each edge, corresponding to the sum of the values reported on the arcs that form each dyadic relation in the directed graph.

The aim of our investigation is to understand whether or not the spatial intervention has positively affected the sociometric variables described in Table 1. We used the sociometric metrics as a dependent set of variables, while the spatial intervention represented the independent variable.

TABLE 1: Sociometric Variables

Variable	Description
Turns (T)	This variable represents the number of times the badge-wearer spoke after someone else. To compare human interactions between different meetings, we assumed that the intensity of communication is influenced by the number of participants and by the meetings' duration. We controlled for these two additional factors that might have otherwise biased our results. To this aim, we defined the variable Turns by dividing its value by the meeting duration and by the number of participants.
Successful interruptions (S)	This variable represents the number of successful interruptions made by the badge wearer. The variable is affected by the duration of the meeting and the number of participants, so we divided its absolute value by these two factors.
Body movement (BM)	This variable represents the magnitude of movement of the team members in the working space. It measures the absolute value of the first derivative of the energy magnitude over the three spatial axes, reported by the accelerometer. Also in this case, we controlled for the meeting duration and the number of participants.
Turns per patient (TP)	This variable represents the number of times the badge-wearer spoke after someone else, per each patient in the round. In this case, we controlled for the number of participants.
Weighted all-degree proximity (WAP)	This is a new variable we created to measure the total amount of interaction of each member in each meeting. WAP derives from the analysis of the proximity networks and is consistent with the measure of degree centrality discussed by Freeman (1979). Accordingly, we consider the weighted all-degree of a vertex as the sum of the weights of its incident edges. As we are doing with all the other variables in our investigation, we control the weighted all-degree centrality values, dividing them by the number of people in each meeting and by the meeting's duration, so as to compare values of this metric across different networks.

FINDINGS

In our study, we approached the interaction networks emerging from the sociometric badges' data, and we compared node level measures, so as to test our hypotheses. **Table 2** reports the descriptive statistics for the analyzed variables. For the sake of representation, we multiplied the value of the body movement (BM) metric by a constant number $k = 10000$. This had no impact on the outcomes.

From the correlation analysis presented in **Table 3**, we find support for H1 and H4. In support to H1, we found that external interruptions are negatively correlated ($\rho s = -0.264$, $p<0.050$) with the number of turns taken by the badges' wearers during the rounds. Also, successful interruptions are positively correlated with the number of turns ($\rho s = 0.886$, $p<0.001$) and negatively with external interruptions ($\rho s = -0.334$, $p<0.010$); this seems to imply that fewer external interruptions during rounds lead to a more fluid and efficient way of communicating. Team members, when less interrupted, showed a more dynamic dialog (higher number of turns) and a less hierarchic approach to communication, being more successful in rapidly interrupting others and in bringing their ideas into conversation. We also maintain that those who speak more dynamically are also more dominant i.e., more confident in successfully interrupting others. Consistently, Table 3 shows that fewer external interruptions are associated with a higher number of turns per patient ($\rho s = -0.439$, $p<0.001$). Not surprisingly, a higher number of external interruptions seemed to suggest an increase in BM ($\rho s = 0.311$, $p<0.050$), which is also confirmed by the direct obser-

TABLE 2: Descriptive Statistics (data refers only to rounds)

	Turns (T)	Successful interruptions (S)	Body movement (BM)	Turns per patient (TP)	External interruptions	Weighted all-degree proximity
Description	*=turns/sec/# of people*	*=successful interruptions/sec/# of people*	*=energy magnitude /sec/# of people*	*=turns/sec/# of patients*	*1=low, 3=high*	*=weighted all-degree/sec/# of people*
Max	1.690	1.580	0.350	19.400	2.930	178.040
Min	0.120	0.050	0.060	1.060	2.110	6.940
Mean	0.926	0.791	0.149	9.208	2.456	57.391
Standard Deviation	0.313	0.281	0.060	3.545	0.240	48.800

TABLE 3: Pearson's Correlation

Variables	Turns (T)	Successful interruptions (S)	Body movement (BM)	Turns per patient (TP)	External interruptions	Weighted all-degree proximity
Turns	1.000					
Successful interruptions	0.886**	1.000				
Body movement (x10000)	0.071	-0.066	1.000			
Turns per Patient	0.959**	0.880**	-0.096	1.000		
External Interruptions	-0.264*	-0.334**	0.311*	-0.439**	1.000	
Weighted all-degree proximity	0.077	-0.010	0.592**	-0.058	0.214	1.000
*p<0.05; **p<0.01						

vations during the rounding sessions (i.e., photo, video, report). This seems to imply that when people walk in the middle of the rounding space, team members tend to move at a higher pace.

H4 is supported by the strong positive correlation of BM with weighted all-degree proximity ($\rho s = 0.592$, $p<0.001$). The reason for this might be that the more team members interact with each other, the more they need to change their position and to move within the boundaries of the working space.

H2 and H3 originate from our main research question: did the spatial intervention during the second week favor intrateam interaction and communication? To answer this question, we formulated H2 and H3 and tested them by means of the independent t-tests we present in Table 4.

We also checked, by means of Levene's test, if we could assume equal variances of the population from which different groups were drawn. Results show full support for H2 and H3. In fact, the number of turns and successful interruptions is significantly higher in week 2: we find support for H2 and expect the increase in dialog and informal communication to be mainly due to the hallway circulation division. This is also reinforced by interviews to team members stating that no other significant changes in the experiment conditions took place during the second week. Similarly, we find support for H3, observing that turn per patient is significantly higher in week 2.

DISCUSSION

This article describes the application of a framework that aims to optimize the delivery of care in patients with complex and chronic health conditions by improving communication among members of an interdisciplinary care team. The complexity of the care, as well as the interdependency between the healthcare system and the environment, often preclude a linear relationship between targeted improvement and metrics. This article illustrated a new method to support interdisciplinary team effectiveness by redesigning the architectural space.

Qualitative observations were made that showed marked difference in team huddle formations and interruptions before and after the design interventions were installed.

Currently, the corridor does not support effective team communication. Encouraging expediency, the corridor in its current

TABLE 4. T-TESTS (ROUNDS)

Variable	Group	N	Mean	Standard deviation	Levene's Test (F)	T-test (t)	Mean difference
Turns	Week 1	33	0.850	0.305	.196	-2.211*	-0.166
	Week 2	31	1.016	0.295			
Successful interruptions	Week 1	33	0.712	0.247	1.730	-2.446*	-0.163
	Week 2	31	0.875	0.285			
Turns per patient	Week 1	33	7.731	2.980	0.763	-4.120**	-3.249
	Week 2	31	10.980	3.328			
*p<0.05; **p<0.01							

configuration is detrimental to the rounds and their efforts to deliver high-quality, effective, family-centered care.

Our study confirms the validity of capturing face-to-face communication via wearable badges to identify behaviors of successful teams. Our findings support Pentland's description of high-performing teams which are characterized by high energy, creativity, and shared commitment.[19] Although the wearable sensors are quite unobtrusive, as they do not record a complete conversation between actors, a person's movements and interactions can still be tracked. This implies that researchers are advised to design experiments able to minimize the impact on people's privacy. At the same time, they need to control for possible changes in human behaviors due to the awareness of being observed to avoid the Hawthorne effect.[20]

In conclusion, this study provided empirical evidence that clearly marked rounding spaces outside of each room act as effective visual indicators, resulting in noticeably more cohesive and consistent team interaction.

Coordinating the flow of information among team members has the potential to create a more sustainable, accountable care network that delivers optimal value across all stages of treatment. Reaching this potential requires coordinating interaction among the three key communication components: technology, actors, and environment. Successful coordination creates a comprehensive knowledge base that all team members can use to make informed decisions on treatment development and delivery.

Our research agenda includes conducting other studies in which photo and video coding will be implemented to quantify the impact of these interventions and compare these data with the sociometric variables.

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