An Interaction Approach to Enhance Situational Awareness and the Production of Anticipatory Actions in Emergency Operation Centers

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ABSTRACT

Recent findings from fieldwork conducted at emergency operation centers (EOC) suggest that currently deployed emergency management information systems (EMIS) are not supporting properly the anticipation of individual actions in cooperative work. We present these findings in this paper and introduce joint action theory as an interaction approach to design technologies that explicitly provide for this kind of support. Our main arguments are: (1) contemporary EMIS are affecting negatively cooperative work at EOCs due to their lack of support for the anticipation of individual actions; (2) Available theory that emphasizes the role of anticipation on cooperative work is not impacting on the design of EMIS due to misalignments between the theory and contemporary situations; (3) Joint action theory provides an alternative framework to correct these misalignments; and (4) Joint action theory provides designers of EMIS with guides for an interaction design that supports anticipatory actions in EOCs.

Keywords

Interaction Design; Joint Action Theory; Situational Awareness; Anticipation; Computer-Supported Cooperative Work; Human-Centered Design and Evaluation; Emergency Operation Centers

INTRODUCTION

During the early 1990s, a stream of ethnomethodological studies of cooperative work in collocated coordination centers provided considerable insights and advances for the design of information systems from a human- and interaction-centered perspective. Air traffic control rooms, command and control centers, and public transportation operations rooms provided some of the domains of practices that drew the attention of HCI and CSCW scholars during this period to discover how interaction backchannels (e.g. gaze, body gestures, background sounds, peripheral displays, etc.), the organization of the material environment (e.g. physical layout, lines of sight, technologies, etc.), and the structure of work (e.g. collocated, cooperative, sequential, stable, event-driven, etc.) allowed individuals to anticipate and execute their actions precisely and timely in cooperative lines of actions without explicit requests to do so.

Recent fieldwork conducted in emergency operation centers (EOCs) in Canada and in the United States from June 2011 to March 2012, and detailed later on this paper, suggests that (1) currently deployed technologies at EOCs have systematically ignored findings from early coordination center studies and their implications for interaction design impacting negatively on the production of anticipatory actions in cooperative work; and (2) current organizational and technological conditions of coordination centers, such as EOCs, differ substantively from those that gave rise to coordination center studies. Both findings, the lack of impact of theory on technological design and the changing conditions of coordination centers, suggest that it is time to update the theoretical framework for coordination center studies and recommend appropriate paths for contemporary interaction design and evaluation of technologies in this domain.

This paper starts with a summary of early coordination studies, which focused on anticipatory actions in cooperative work. We then proceed to present EOC fieldwork findings that challenge the assumptions and theory (or lack thereof) behind early coordination center studies and that suggest that current technologies have not incorporated interaction design principles from early coordination center studies. We also discuss the main misalignments between current observed situations and assumptions of early studies, and we propose to conduct joint action theory informed studies to fill in the gaps. Join action theory (Clark, 1996) is a human-centered research framework (i.e. theory and methodology) that we consider appropriate for contemporary interaction design and evaluation studies for the production of anticipatory actions in technologically dense EOCs.

EARLY COORDINATION CENTER STUDIES

At the beginning of the 1990s, Heath and Luff (1992) published a very influential article on the inaugural issue of the Computer-Supported Cooperative Work Journal. In this article, the authors demonstrated that technology-mediated cooperative work in a technologically dense setting, such as the London underground control room, was effective due to the sustaining of a shared perceptual space that allowed coworkers to overhear and oversee what others were doing when acting in their informational environments. The layout of technologies, staff and workspaces in this control room sustained a public display of body postures, speech, gaze, gestures and interactions with artifacts (e.g. radios, computer screens, video screens, etc.) that made individual actions visible to others. Some of these actions were perceived directly when attention was oriented to those actions (e.g. seeing or hearing execution of tasks) and some others were perceived indirectly when individual attention was occupied on ongoing tasks and perception of others' actions was only possible by peripheral monitoring (e.g. overseeing or overhearing) of back channels (i.e. tone, cursing, singing, gazing, volume, repetition, snapping fingers, etc.). Heath and Luff understood the visibility of individual actions to others in a public cooperative space as a necessary condition for the production of individual anticipatory actions and for the alignment of individual and cooperative lines of action (Heath and Luff, 1992). The authors warned that individualized digital technologies would alter the production of anticipatory actions and reduce the effectiveness of collaboration by reducing the visibility of individual actions to others (Heath and Luff, 1992).

Following Heath and Luff's study, Harper and Hughes studied the use of radars, radio transmission, and flight strips by air traffic operators in control towers (Harper and Hughes, 1993). Their study pointed out to the relevance of back channels and shared perceptual spaces in cooperative work. The physical layout of the control tower provided a perceptual space that was shared among operators. Overhearing an operator's communication with pilots using radio transmission, overseeing the structure of paper-based flight progress strips displaying the dynamic position of a flight on a sector, and accessing the same view provided by radar, allowed non-engaged operators to monitor peripherally the actions of other engaged operators. Sectors were connected and flights were moving from one sector to another, which required passing the monitoring of a flight to another operator once it was ready to move to the next sector. The authors demonstrated that by peripherally monitoring the organization of flight progress strips of the previous operator, along with the use of radar and the overhearing of radio, the next operator was able to anticipate her entry and expected actions, taking up on the monitoring of a flight entering in her sector without being explicitly asked to do so. Thus, effective anticipation of individual actions in cooperative lines of work in this setting relied on the existence of a shared perceptual space that made individual interactions with technology visible to others (i.e. witnesseable) and on the peripheral monitoring of cues on back channels provided by an arrangement of audio-visual technologies such as radars, radio, and flight strips (Harper and Hughes, 1993).

Along these lines, in the second half of the 1990s, Lucy Suchman and the Goodwins conducted similar fieldwork studies in airport operations rooms, where the main task was to direct aircrafts to gates after landing in a busy airport. The Goodwins found that monitoring other people's body orientations as well as their interactions with tools (i.e. computers, radios, docs, video screens, etc.) was critical to sustaining cooperative work in airport operations rooms (Goodwin and Goodwin, 1996). They documented a scenario in which a worker at one operations room received a radio call reporting a problem with a jet bridge. The operations room's physical layout allowed a team of five workers to overhear the radio call and direct their attention to one of the video screens displaying the referred gate. This specific situation required the intervention of two of the other workers in the room who, without being asked by the original recipient of the call, started participating in the unfolding of collaborative sequences of actions to establish the origin of the problem and to proceed with a course of action. The "witnesseable" character of individual interactions with tools, such as the radio and the video screen, provided the team with the opportunity to anticipate their individual actions and to intervene exactly when they were suppose to, according to their responsibilities, without being explicitly asked to do so. Here again, the peripheral monitoring of back channels of communication, both by overhearing the talk and by overseeing the work of others, was a fundamental condition to maintain situational awareness and execute anticipatory actions in cooperative lines of work (Goodwin and Goodwin, 1996). Lucy Suchman, who also worked with the Goodwins on this research, conceptualized the technologically dense site of operation rooms as a "coordination center." She defined "coordination centers" as sites to which people, distributed in time and space, can orient to and which they know how to find to when support and coordination was needed (Suchman, 1997). Personnel at a coordination center have also the technological means to access the situation of events and personnel in remote locations, which provides to them with what we referred to as situational awareness. Following up on the Goodwins' work, Suchman also referred to the public display of witnesseable and accountable actions and interactions with technology required for anticipation mentioned, but she also added the critical observation that "*a typified action sequence*," "*division of labor*," and an "*accountable reproduction of normative order*," were necessary conditions to make sense of perceived actions of other individuals in order to produce anticipatory actions (Suchman, 1997). In other words, Suchman shifted her attention from the cognitive to the social factors that structure the sense making process of witnesseable actions being perceived in coordination centers. It was in these social factors that Suchman found the ultimate rationale that triggers the anticipation of actions in cooperative work.

All of these ethnomethodological studies were valuable to point out to the critical role of technological, cognitive, and social factors in creating and sustaining situational awareness in cooperative work. Concepts such as "coordination centers" and "witnesseable" and "accountable" technologies were derived from these studies and still today provide guidelines for human-computer interaction, computer-supported cooperative work, and interaction design. However, findings from fieldwork recently conducted in Emergency Operations Centers in Canada and the United Stated have indicated that these early studies of coordination centers seem to be misaligned from contemporary situations.

FIELDWORK IN EMERGENCY OPERATION CENTERS

The fieldwork consisted in a series of non-participant observations conducted at Emergency Operations Centers (EOCs), a kind of coordination center. EOCs are sites to which first responders, decision-makers, and citizens distributed in time and space, can orient to and which they know how to find to when emergency management support and coordination is needed. EOC staff has the technological means to access the situation of events and first responders in remote locations, which provides to them with situational awareness to inform their decisions. EOCs normally adopt a unified command and control structure to coordinate and support the emergency response operations of one or multiple incident command posts located close to sites where a disaster or event strikes.

The observations were conducted in Richmond and Vancouver, British Columbia, between July 2011 and March 2012. Observations in Richmond included: sparse full-day observations of routine operations focused on individual work of staff members, observations of collaborative tasks such as: testing of an emergency notification system, two tabletop Emergency Operation Center (EOC) exercises with other agencies, and regular work meetings. Observations in Vancouver included: one tabletop exercise, and two real activations of the EOC. Three in-depth interviews were conducted in Richmond and three more in Vancouver with EOC staff. To increase the external validity of the observations being made, two additional field trips to EOCs in the cities of Portland, OR and San Diego, CA were also included. In each of these EOCs, two additional interviews were conducted with the EOC directors and with the EOC staff in charge of IT support for the EOC. All of the EOCs included in this study shared similar organizational incident command procedures, and were characterized by having a physical dedicated site, being temporarily activated, and supporting collocated operations of representatives from multiple agencies. The data collected was coded and analyzed using a comparative analysis of all the EOCs under three broad categories: informational environment, information practices and flows, and information technologies. General findings and a more detailed description of the methodology has been published elsewhere (Arias-Hernandez and Fisher, 2013), on this paper we will only comment on findings that challenge the theoretical framework currently used in coordination center studies.

FINDINGS

The Richmond EOC is a highly dynamic site. During tabletop exercises conversations among practitioners, public announcements, and the sounds of radio transmissions and telephone landlines fill the environment. There is continuous movement of artifacts and individuals among functional units, face-to-face interactions among individuals, and interactions between individuals and their informational environments. Although similar procedures and standards apply to the Vancouver EOC, both environments could not be any more different. Fieldwork at the Vancouver EOC showed a contrasting picture of practitioners immersed in their own individual interactions with their computers, scarce public announcements, and a rather quiet environment. Movement of artifacts and individuals among functional units was also limited.

Data collected in EOCs in Portland, OR and in San Diego, CA suggested that this phenomenon was not exclusive to Vancouver, BC, but it was also prevalent at their EOCs. The EOC directors complained about the individual immersion of their staff in their computer workstations, their increasingly reduced face-to-face interactions, and their lack of use of alternative and available communication channels, such as radio transmission and telephone. They referred to this situation as a problem of "deep immersion" or "tunnel vision" being produced in the interaction between practitioners and the EOC information system. In this characterization, communications and interactions among practitioners move to the system level even though practitioners are still collocated in the same physical space. In the process, practitioners narrow their repertoire of communicational acts and their use of available resources while reducing face-to-face interactions with collocated peers.

The observations in Vancouver, and the interviews in Portland and San Diego also pointed out to the fact that these three EOCs were technologically dense. In other words, they made intense use of computer-based emergency management information systems (EMIS) in the form of individual PC stations and large digital displays. On the other hand, the City of Richmond EOC's informational environment, where this situation was absent, relied mostly on a paper-based information system, large whiteboards, and poster maps. This correlation between the presence of the "tunnel vision" phenomenon and the technological make-up of the EOCs suggested that the physical layout of the EOC as well as the specific resources used to represent and communicate data were influencing the structuring of attention that accounted for the production of the "tunnel vision" effect. For example, the physical layout of the Vancouver EOC made possible the peripheral monitoring of large screens on which computer-generated situational data was visualized as a situational map. However, the same layout, which places individual PC stations in front of other individual PC stations made extremely difficult the peripheral monitoring of other individual's actions and the possibility of connecting the status of the situational board with the ongoing actions of collocated peers.

The Richmond EOC, in contrast, lacked a computer-based device, such as the situational map, to make this display publicly available. The lack of this resource was compensated with oral public announcements, more face-to-face interactions, and the distribution of printed material. Thus, the amount of public announcements, interactions, and mobility of artifacts among individuals as well as the peripheral monitoring of other individuals' activities was notably higher in Richmond than in Vancouver.

Also, individual access to specialized applications and individual computer stations at the Vancouver EOC promoted individualized and compartmentalized work that was hard to be peripherally monitored by others. In contrast, at the Richmond EOC, the witnesseable character of individual interactions with radio, telephone and large printed maps provided a different structuring of attention for an easier peripheral monitoring of other individual lines of activity, strengthening the hypothesis that computer-intensive environments have altered the structuring of attention and the production of anticipatory actions in contemporary coordination centers, such as EOCs, as warned by early coordination center studies.

From a social point of view, the fieldwork also provided findings that reinforced the hypothesis that anticipatory actions were systematically affected at the Vancouver EOC. As mentioned in the previous section "typified action sequences," "division of labor," and an "accountable reproduction of normative order" are necessary social conditions to make sense of perceived actions of other individuals and to produce anticipation. Even though, operation procedures by roles and functions (i.e. division of labor) are explicitly established on manuals in Richmond and Vancouver EOCs, two factors impeded the establishment of routine typified action sequences and an effective reproduction of normative social order. First, the temporary and sporadic character of the EOCs as a social organization impact negatively on the sustaining of a history of interactions and on the tacit learning of operational procedures derived from constant, stable, and routine repetitions of cooperative tasks. This situation affects both EOCs analyzed: Richmond's and Vancouver's. Second, due to the size of the Vancouver EOC, the turn over of multiagency personnel is considerably higher in Vancouver than in Richmond. Thus it is more evident in the Vancouver EOC the lack of a shared history of interactions and a shared participatory framework of event-specific expectations. Absence of this shared knowledge affects expectations of action since there is no strong foundation for tacit normative orders of what people should or should not do and when they should do it.

In summary, the existence of the "tunnel vision" phenomenon in technologically dense EOCs suggests that technological and organizational considerations suggested by early coordination center studies have not been incorporated in the design of these socio-technical systems. Some of the characteristics observed in contemporary EOCs, such as technical and social factors, deviate from what it was expected and assumed by early coordination center studies making it necessary to highlight the misalignments between early studies and contemporary conditions. This will be the basis to determine the need for a theoretical and methodological approach that updates and restores the interaction emphasis on anticipation of individual actions for the design and evaluation of information technologies in contemporary coordination centers.

MISALIGNMENTS

The first argument of misalignment between early studies and contemporary conditions of coordination centers is technological. Visual displays, user interfaces, and interaction technologies from the 1990s are different than those deployed in contemporary coordination centers. The technologies mentioned during early studies included radars, paper flight strips, electromechanical sensors, and video feeds. From a visual and perceptual point of view all these technologies were treated by researchers of early studies as discrete and monolithic units of analysis. For example, the researcher would observe interactions of operators with monitors displaying video feeds, or positions of aircrafts on a radar, and assume a one-to-one relation between the visual information being provided and the representation device. In other words, a representation device or artifact would provide one and only one kind of visual information that it was necessary to conduct the task at hand. If the task at hand required additional information then the information needed had to be fetched from a different representation device. In these scenarios, putting together multiple pieces of information to create situational awareness required operators to direct their attention to the state of individual devices, capture the relevant visual information from them, and move on to the next device if required. Once all the relevant information was captured, operators proceeded to make sense of it in a mental schema relevant to the effective completion of the task at hand.

Technologies deployed and used in contemporary coordination centers, such as EOCs, cannot be treated as discrete and monolithic units of analysis anymore. Take for example dashboards, one of the most popular metaphors for representation of information for EMIS. Digital dashboards, displayed on a single computer monitor, represent a multiplicity of visual data of different kinds: a geographic information system with plotted events, CCTV video feeds, sensor gauges, instant messages services, mass media news feeds, lists of time-stamped events, etc. Visual information that previously was displayed in different physical artifacts is now integrated within a single device. Thus the structuring of visual attention has shifted from a macro level, of multiple monolithic displays at coordination centers, to a micro level of resolution where one single display is itself a container for multiple other displays. Even when talking about a single representational device such as a communication tool, technologies such as radio transmission are now evolving towards media that presents not only audio but also video (i.e. video conference, video calls, etc.), providing access to multiple stimuli (e.g. speech, face gestures, body gestures, etc.) that it was impossible or impractical to have during the 1990s.

From an interactional point of view, interactivity with computers and with representations of data has also changed dramatically. Computer visualizations of data do not present stable displays of data anymore, such as those previously provided by radar or early non-interactive computer graphics. Interactive techniques such as zooming and filtering, panning, hyperlinking, and details on demand have allowed users to re-create representations dynamically (Schneiderman, 1996; Yi et al., 2007). Therefore researchers studying human-information interaction or human-computer interaction now need to go beyond speech and body gestures to incorporate data such as mouse clicks, interaction logs, eye-tracking, and screen capture, in order to determine what exactly operators are doing or attending to within the perceptual space of one single screen (Arias-Hernandez et al., 2011). In other words, every representational artifact (e.g. computer display) at a coordination center is now rarely a discrete and stable unit in a perceptual space and it should be better conceptualized as an integration of multiple and dynamic representational devices (e.g. multiple views or windows).

The second argument of misalignment is organizational and it is related to Suchman's social argument. Something common to all of the coordination center studies reviewed for this paper is that the work sites chosen by researchers shared certain tacit characteristics that influence considerably the way operators interact with technology. First, tower controls, airport operation rooms, and underground control rooms are all social organizations with clear "participation frameworks" (Goffman, 1981). A participation framework is a structure of social practices, individual positions, and the respective normative expectations of appropriate conduct in a position (Goffman, 1981). This framework is a necessary condition for phenomena like anticipation to occur, since it establishes what is expected from agents in response to specific situations or events. For example, one normative expectation of an airport operator discovering that a gate that should be available for a flight to use is not is to inform pilots of the anomaly and divert the aircraft to another available gate. Participation frameworks also determine routine and expected interactions with technology. For example, in the underground case presented by Harper and Hughes, novices were expected to learn how to read cues while overhearing radio transmissions that would allow them to anticipate their own actions (Harper and Hughes, 1993). Participation frameworks in coordination centers define expectations for cooperative work. Operators working in collocated operations rooms are expected to align their individual actions to those of other individuals and to do so with a minimum of interruption. Thus knowledge of sequences of actions, prompt reading of verbal and non-verbal cues from other operators, and timely alignment of individual lines of actions with cooperative lines of action are considered critical skills in these coordination centers. Second, and consistent with the previous point, all of these social organizations observed in early studies were stable and permanent. The stability of personnel and the permanent character of these coordination centers is a necessary condition for routine practices and participatory frameworks to establish in practice. Repetitive actions and the stability of personnel reproduce the social order of the coordination center and creates obdurate participation frameworks for people to sustain their expectations of practice.

As made clear by the previous section on EOCs, clear participation frameworks and stable social organizations are challenged in contemporary coordination centers. Even though, EOCs comply with the general definition of coordination centers proposed by Suchman (1997), EOCs do not comply with the stable and routine social structure that Suchman considered necessary for the production of anticipatory actions. EOCs are temporary and their participation frameworks lack a stable history of interactions that can be used by individuals to anticipate effectively their individual actions (Arias and Fisher, In Press).

The third and last argument is cognitive. All of the authors of early coordination center studies relied on ethnographic and conversation approaches to HCI and CSCW that highlighted the relevance of peripheral monitoring of back channels, such as overhearing and overseeing for the individual anticipation of actions in cooperative work. However, none of them connected their results to broader theoretical frameworks of either human interaction or cognitive behavior. It is the proposal of the authors of this paper that Herbert H. Clark's theory of joint action (Clark, 1996) can organize these concepts and phenomena in an integrated sociocognitive framework, which addresses directly and emphasizes the production of anticipation in cooperative work while providing guidelines for the design and evaluation of technologies.

JOINT ACTION THEORY FOR AN INTERACTION DESIGN THAT SUPPORTS ANTICIPATION

Joint Action Theory (JAT) is a structured, sociocognitive, theory of "language in use" developed by Herbert H. Clark (1996). For Clark, language use is an instantiation of a broader class of human practices: joint actions. In joint actions, individual participatory actions have to be coordinated to produce their intended effect. This implies coordinating content –what the participants intend to do- and processes –the physical and mental systems they recruit in carrying out their intentions-. Joint actions, the fundamental units of analysis in Clark's theory, have several properties and characteristics. They can be coordinated because they divide into phases. A phase is "a stretch of joint action with a unified function and identifiable entry and exit times" (Clark, 1996). Entry and exit times are what actually participants of the joint action coordinate.

Another characteristic of joint actions is the participant's use of common ground and coordination devices to advance the joint activity. Common ground is shared awareness between participants of a joint action (Clark and Brennan, 1991). This shared awareness may correspond to culturally shared knowledge, beliefs and assumptions but also to situated and more locally relevant knowledge. Common ground can be perceptual, procedural, content specific, individual specific, and cultural. Perceptual common ground corresponds to the shared knowledge of the existence of physical stimuli generated in a shared perceptual space (a.k.a. "joint salience"). For example, when in a collocated environment an unexpected loud alarm is heard, participants may assume that everybody heard it, that is now part of the perceptual common ground and anticipate consequential joint actions. Procedural common ground corresponds to the knowledge of operational tasks that I am aware that you know (shared task representations) about how our interaction should proceed. Content specific common ground is the knowledge that I am aware that you know about the topic we are discussing. Individual specific common ground is the knowledge associated to an individual as a result of historic interactions or assumptions associated with that individual. Cultural common ground includes all of the social knowledge, beliefs, and assumptions that we share with the many different social groups to which we belong (Clark, 1996). Failure in coordinating joint actions commonly occurs due to failures in creating or sustaining this common ground.

Coordination devices are discursive and material artifacts (e.g. verbal and non-verbal cues, gestures, and technologies), elements of the common ground, which give participants of a joint action expectations and rationales for believing they and their partners will converge on the same joint action. Coordination devices generate physical cues read by participants to time and synchronize their actions in a pertinent and effective way that advances their joint action (Clark, 1996, 2005). The ring bell at school, the traffic light, the gun shot at a race, the music script, a song theme in a dancing competition, hand signals used by soldiers during a coordinated team attack, a fire alarm at a fire station, plans, etc. are some of the examples of such coordination devices. The most effective coordination devices are integrated in routine cooperative interactions in order to offload communicational and coordination processes to interactions with the coordination device. Failure in using coordination devices also results in failed joint actions.

Joint action relies on several assumptions and expectations about interaction. The most relevant for this paper is the fact that participants in a joint action commit to a sustained state of joint attention. In short, joint or mutual attention of what others are saying or doing is a pre-requisite for joint action. Since in joint actions participants continuously propose joint projects to each other, attention of participants has to be placed on the continuous stream of signals presented to them by other participants (Arias-Hernandez et al. 2011). If attention is not focused on the signal being presented, then the intention behind the signal will not be communicated and the joint action will fail. The effective use of coordination devices also relies on the assumption that all of the participants responsible for individual tasks are attending to (1) the cues provided by the coordination devices and to (2) the actions of the other participants in response to the cues of the coordination device. Take for example a musical performance in a duet. The music script acts as a coordination device. From this coordination device to be effective, joint attention needs to be directed to the music script as well as to signals generated by the other participants. Every participant is aware of what the current state of actions is and she is able to locate herself in an ongoing cooperative line of activity. By monitoring directly the music script and indirectly monitoring the activities of the other participant, she is able to respond to expectations of her performance and anticipate her future entry and exit points. The concept of joint attention is directly related to that of situation awareness but it specifically points out to the perception of salient phenomena, directly or indirectly, whose main function is to allow people to respond to expectations and anticipate their own individual actions in a joint activity.

According to Clark's theory, joint attention focuses on the continuous monitoring of signals being transmitted by participants on front channels and back channels (Clark, 1996). Front channels transmit signals whose pragmatic purpose is to communicate some explicit intention and content from a speaker to a listener, such as when speech is used to ask a question (i.e. content). Back channels on the other hand transmit signals created by the listener whose pragmatic purpose is to facilitate the coordination of joint action per-se by providing ad-hoc feedback to the speaker (i.e. process). For example, verbal fillers such as "yeah" and "uhuh" and non-verbal cues such as gaze and nodding are use to communicate that there is an ongoing understanding and that the listener is attending to the speaker signals. Face gestures by listeners during speech indicate misunderstandings and prompt speakers to repair their communicative acts ad-hoc without an explicit request to do so (i.e. anticipation and effectiveness). Therefore back channels and their signals are critical for anticipation to occur. If back channels are not supported and attention cannot monitor them, then feedback is lost affecting negatively situational awareness and anticipation of actions. Another characteristic of back channels is that individuals are not normally aware that they are monitoring these signals and that they respond to them by adjusting their own behaviors. Back channels are peripherally monitored due to their opportunistic and contingent character.

We conceptualize cooperative work in coordination centers as another form of joint action. Since effective joint actions rely on anticipation, we consider that Clark's joint action theory (JAT) provides an adequate social and cognitive framework to emphasize the production of anticipatory actions in coordination centers. We also consider that JAT is consistent with the basic assumptions of coordination center studies. First, the strong emphasis placed by JAT on face-to-face interaction is appropriate for the kind of collocated cooperative work commonly found in coordination centers. Second, JAT's concept of common ground addresses directly the social and cognitive dimensions that are relevant for the production of anticipatory action in coordination centers. Perceptual common ground highlights the importance of making "salient" (i.e. visible or "witnesseable") individual actions and interactions with technology in cooperative settings. Operational common ground responds to Suchman's call for shared knowledge of "typified sequential tasks" that allow individuals to locate their actions in cooperative tasks. Cultural common ground allows researchers to determine whether the organizational culture of the coordination center is aligned or not with the reproduction of a normative social order and the establishment of participation frameworks. This concept also suggests social practices that can construct such orders and participation frameworks if they are not in place. Third, JAT's concept of coordination device allows HCI and CSCW researchers to emphasize the role of technology and interactions between humans and technology for the production of anticipatory actions. Fourth, JAT's concept of back channels helps researchers determine whether the physical space and the arrangement of technologies at coordination centers support the creation, transmission, and peripheral monitoring of these signals, which are critical for anticipatory actions to occur. Fifth, JAT' methodology is consistent with coordination studies methods: JAT also relies on conversation analysis and ethnomethods (Arias-Hernandez et al., 2011).

The misalignments between early studies and contemporary conditions of coordination centers such as EOCs can also be corrected by specific adjustments of JAT's methodology. The technological and interactional gaps require that applications of JAT consider digital technologies as an arrangement of multiple coordination devices rather than the computer as a whole monolithic coordination device. Screen capture of human interactions with digital dashboards combined with video recordings of operators interacting with technology allows researchers to refine the level of JAT analysis to specific interactions with singular interactive GUI elements, pieces of data, windows, or views, within the context of one computing artifact. The social gap requires that applications of JAT emphasize the analysis of the cultural and operational common ground and determine whether these kinds of common ground provide participation frameworks and the knowledge of typified action sequences at the coordination center. This can be achieved by conducting individual interviews with the operators to determine their expectations on their own behaviors and the behavior of others and their knowledge of typified action sequences. Finally the cognitive gap requires that applications of JAT restrict their analyses to the peripheral monitoring of back channels that transmit perceptual stimuli that is necessary and sufficient for anticipation of individual actions to occur. This implies video recording of the team activities at the coordination center and conversation analysis of all of the joint actions, determining the range of peripheral monitoring supported by the physical space and the technologies, and determining whether cues on back channels are producing anticipation of actions or not.

CONCLUSION

The proposed approach for using joint action theory provides guidelines for interaction design and evaluation studies in contemporary coordination centers, such as EOCs. The focus of interaction analysis and design from this perspective is on people's capacity to be aware of what others are doing at the EOC in order to anticipate their own individual actions in cooperative lines of work. We have chosen to focus on anticipation for interaction design not only because it creates effective cooperative work in coordination centers, but also because we consider that EOC environments and their current technologies have systematically ignored this factor, as documented by our fieldwork findings.

Thorough applications and evaluations of this methodology are needed to support a stronger claim that joint action theory in fact can provide general interaction design principles for the production of anticipation at EOCs. However, from our own experience with ongoing design projects with EOCs we have found that this approach has the potential to impact on the design and evaluation of EMIS. A current project with the City of Richmond, BC, called the Virtual EOC is already incorporating some design principles derived from this perspective. The prospective of moving the Richmond EOC from a collocated environment to a mobile, non-collocated environment supported by the use of EMIS running on mobile devices, immediately triggered on us concerns about the potential negative impact on the anticipation of individual actions that now occur in the paper-based EOC. Since several visual and auditory cues that allow people to peripherally monitor what others are doing in the current collocated environment will not be present in the non-collocated mobile environments, we have included in the design of the Virtual EOC the requirement that this technology should provide an auditory back channel, based on digital radio, to compensate for the loss of visual and auditory cues from traditional face-to-face back channels. Future work will focus on quantitative and qualitative evaluation of the impact of this design feature on the anticipation of action in order to demonstrate that design features informed by joint action theory are indeed improving the computer supported cooperative work of EOCs.

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