Collaborative Affordances of Hybrid Patient Record Technologies in Medical Work

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ABSTRACT
The medical record is a central artifact used to organize, communicate and coordinate information related to patient care. Despite recent deployments of electronic health records (EHR), paper medical records are still widely used because of the affordances of paper. Although a number of approaches explored the integration of paper and digital technology, there are still a wide range of open issues in the design of technologies that integrate digital and paper-based medical records. This paper studies the use of one such novel technology, called the Hybrid Patient Record (HyPR), that is designed to digitally augment a paper medical record. We report on two studies: a field study in which we describe the benefits and challenges of using a combination of electronic and paper-based medical records in a large university hospital and a deployment study in which we analyze how 8 clinicians used the HyPR in a medical simulation. Based on these empirical studies, this paper introduces and discusses the concept of *collaborative affordances*, which describes a set of properties of the medical record that foster collaborative collocated work.

Author Keywords
Hybrid Patient Record; Collaborative Affordance; Hospitals; Electronic Health Record; EHR; Mixed Reality Interaction

ACM Classification Keywords
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces; J.3 [**Computer Applications**]: Life and Medical Science.

INTRODUCTION
Information management in medical work in hospitals is centered around medical records: a legal document containing detailed information about the patient's treatment. Medical records are organizational and coordinative artifacts that are used to share, communicate and manage complex treatment procedures [7]. To improve efficiency and quality in care, the Western world is investing significant resources in digitizing healthcare with a special focus on creating an integrated Electronic Health Record (EHR) [16]. The EHR offers a number of fundamental advantages over the Paper Medical Record (PMR) related to quality of health care, efficiency in use and a higher level of patient safety [11].

Despite this ongoing trend, hospitals still use PMRs as part of the daily workflow [5, 12, 37]. The significance and affordances of paper have been drawn together in Sellen and Harper's book — *The Myth of the Paperless Office* [36] — and are also highlighted in reflections on PMRs in clinical work [16]. Studies show that paper makes clinicians more efficient at their work [34] and that the use of paper forms increases significantly after the introduction of an EHR [35]. In fact, there is little to no evidence about the actual effectiveness of some of the new digitized workflows [8, 43] or EHRs [19]. Moreover, the EHR often operates as a passive information repository and is therefore often supplemented with a PMR which holds more informal documentation, such as ad hoc notes, as part of a *working record* [15]. Furthermore, PMRs frequently function as *transitional artifacts* [12] that mediate the information flow between day to day work in the hospital and the EHR, while also providing redundancy of information [10, 14]. As a consequence, clinicians *"... continue to maintain a hybrid documentation environment"* [13][p. 160] and a typical setup in many hospitals is that the EHR system does not replace the PMR, but a *double record* consisting of both a paper and electronic part is maintained. This double medical record, however, introduces a number of configuration and coordination problems related to finding, using, updating, communicating and managing both records.

To address the ubiquity of paper in workplaces like hospitals, a number of technologies that integrate paper and digital technology have been proposed. Paperlink [2], or the commercial solution Anoto, provides a digital pen as a synchronization mechanism between written documents and digital storage of that data. Building on this idea, other examples such as the Paper Augmented Digital Documents (PADDs) [20], Paperproof [39] and PapierCraft [27] provide support for digital annotation of paper documents using pen input. Other approaches focus on the medical record. Penbook [40] supports capturing handwritten prescriptions by providing a hybrid setup using a touch screen and projector equipped with a digital pen. NOSTOS [3] supports data capture in emergency

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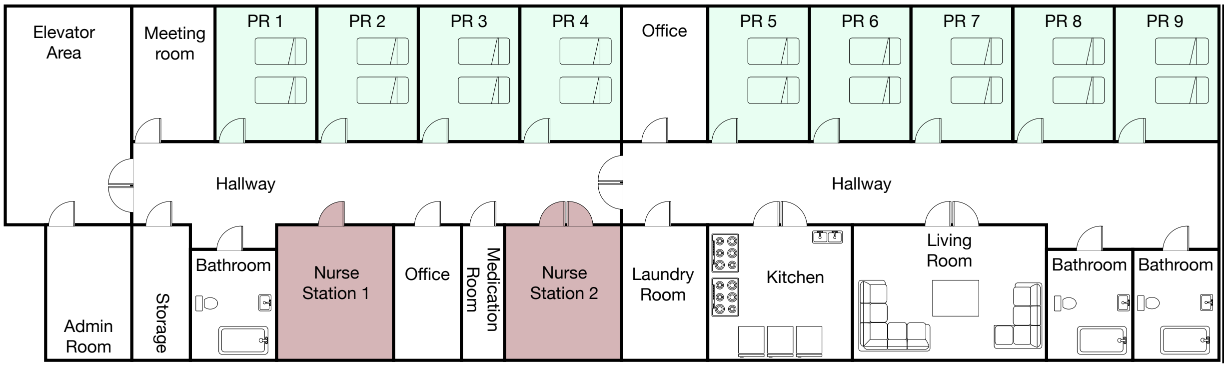

Figure 1. The physical layout of one of the wards from our field study. A typical ward consists of an administration desk, a number of patient rooms (PR), stations for the nurses, offices for the doctors, storage and medication rooms for medical equipment and finally bath- and living rooms for patients.

rooms and combines digital pens, wall displays and a digital desk to augment and enhance the PMR and form with digital patient information. Finally, the Augmented Paper Chart [41] provides seamless integration of paper notes with digital storage by using the Anoto pen.

This paper investigates one specific approach, called the Hybrid Patient Record (HyPR) (Figure 7) [23], for integrating the paper-based and electronic medical record. The HyPR device is attached to the PMR (like a notepad clip) and augments it with a notification system (color and sound), location tracking and ad hoc integration to a tablet that provides access to contextual relevant electronic patient data. By supporting various mechanisms to integrate the PMR and the EHR, the HyPR is designed to be a transitional artifact [12] that helps clinicians to gradually introduce digital tools in their use of medical records.

In this paper we make three contributions. First, we provide results from a detailed field study on the collaborative alignment and integration of PMR and EHR in different medical departments of a university hospital. This study verifies prior findings on collaboration in hospitals, but also contributes to the body of knowledge on the relationship between paper-based and electronic medical records. Second, we describe a study of the HyPR in a clinical simulation environment where 8 clinicians used the HyPR devices over two days performing scenarios originating from the field study. This study provides detailed insights into the use of hybrid or mixed reality technologies in collocated clinical work. Finally, we introduce and discuss the concept of '*collaborative affordances*', which is used to understand what features of a tool (be it paper-based or electronic) foster and support collocated collaboration. We analyze the collaborative affordances of the existing paper-based medical records and describe how they translate to the hybrid technology. Collaborative affordances thus extend the set of paper affordances identified by Sellen & Harper [36].

STUDY OF DOUBLE RECORD KEEPING

To thoroughly understand the nature of double record keeping, we conducted a field study on the use of the PMR and EHR in a large university hospital. The objective of the study was twofold; first, to obtain insights into the mechanisms clinicians adopt to collaboratively align and configure the two medical records in daily work and second, to prepare for the clinical simulation study of the HyPR technology.

Setting

The study took place in a university teaching hospital with about 3,000 employees providing care for a municipality of about 400,000 people in greater Copenhagen, Denmark. The study involved five connected medical departments, covering two patient bed wards, two surgical departments and the emergency department. All five departments are located in the same building and work in close collaboration with each other. Patients treated in the surgical or emergency departments are sent to the bed wards for recovery and post-op care. Each of the bed wards admit 20 to 30 patients and employ about 15 staff members including doctors, nurses and administrative personnel. The bed wards share the same architecture and consist of a set of patient-related rooms, including patient rooms, living area, bathrooms and a set of rooms used by doctors, nurses and secretaries including the meeting room, nurses stations, medication room, ward offices and the administrative room (Figure 1).

Method

The field study applied participant observations, contextual inquiries and interviews. Observations included task-centric, artifact-centric, place-centric and person-centric observations of work in all the wards and departments. Task-centric observations provided an understanding of the tasks and activities performed in the different wards and departments. Artifact-centric observations studied the use of paper-based artifacts including the PMRs; the different medical information systems used including the EHR; other computing devices, such as digital whiteboards, mobile PDA devices, traditional desktop computers; specialized medical equipment and monitors; and other physical artifacts like whiteboards, carts and medical equipment. Place-centric observations studied the flow of work in and between departments, wards, meeting rooms and patient rooms. Person-centric observation comprised of contextual inquiries of nurses and doctors for one day followed by a post-hoc interview to get a more detailed understanding of the work in each department. In total there were 7 shadowing sessions, 5 follow-up interviews and 10 days of observation material (images and notes). The data were collected and recorded using photographs, audio tapes and extensive note taking, and were analyzed into reports, diagrams and workflow charts. To conclude the study, we conducted a follow-up workshop after the observations in which our findings were presented and verified.

The Medical Record Workflow

At the hospital, the medical record consists of a unique PMR. It is a legal requirement that this record is at all times present at the ward that is currently treating the patient. Although the content of the PMR varies between different departments, the record itself is standardized within the entire hospital. The record consists of a plastic cover that is marked with color-coded sections for different types of documentation (Figure 2). Documentation includes basic patient data, the narrative treatment record (called the 'continuation'), nursing documentation, various schemes and forms, observations, test results (e.g., radiology examinations) and messages from other medical professionals. Each record carries a label that uniquely identifies the patient by stating name and social security number both in text and encoded in a barcode. This label is attached to the front of the record. Normally, the PMR is between 2 and 3 cm thick, but the size of a record can take extreme proportions. In one case, the record of a cancer patient had to be distributed over several physical folders because of the large amount of documents accumulated over a long treatment period. At a patient ward, there are typically up to 25 active PMRs in use.

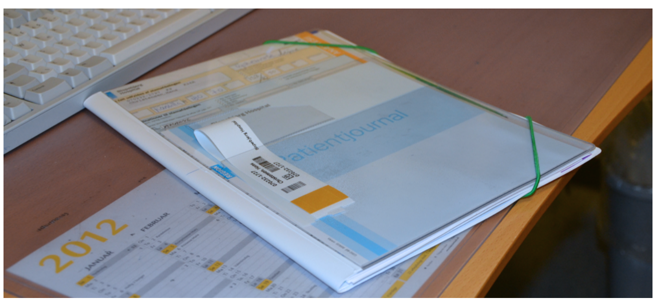

Figure 2. The standard PMR consists of a plastic folder that is labeled with the name and ID of the patient. The record holds all patient documentation and provides separate color-coded sections, e.g., for nurse notes, treatment history or other forms and observations.

Next to the PMR, the hospital provides a set of Health Information Systems (HISs), such as a Radiology Information System (RIS), an Electronic Medication System (EMS), a Patient Administration System (PAS), a Blood Bank System (BBS) and many others. Clinicians can access these applications through a system portal, which collates all applications into one interface, that is referred to as the EHR. Both the paper and digital information are often used simultaneously and are of equal importance. But in order to have electronically stored information 'ready-at-hand', information like lab results and radiology examinations are printed and added to the physical PMR.

Figure 3 shows the four main processes involving the medical record. The color code indicates whether only the PMR (blue), only the EHR (green) or both records (red) are used for that part of the process. The patient is referred to the hospital (e.g., for surgery) by the general practitioner (GP), who fills in an online form. This form is printed by the administration of the hospital when setting up an appointment for the patient. The form is stamped and approved by a doctor and sent

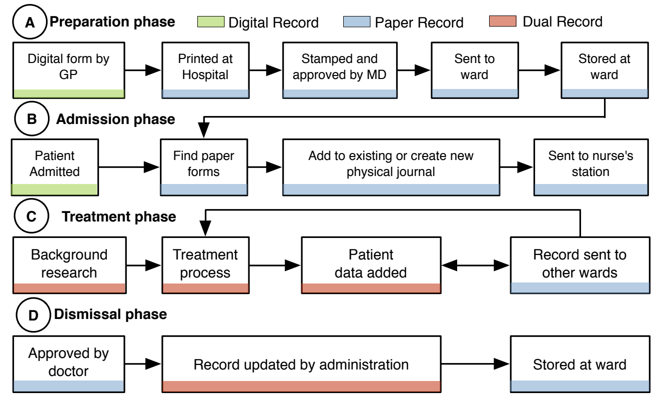

Figure 3. The life cycle of the PMR consists of a (A) preparation phase, (B) admission phase, (C) treatment phase and (D) dismissal phase (GP: general practitioner; MD: medical doctor).

to the ward responsible for the patient (Figure 3A – *preparation phase*). In the hospital, the general workflow surrounding the PMR is primarily managed by the ward secretaries and the nurses. When a patient is admitted to the hospital, the ward secretary locates the PMR. Most patients are readmitted to the same department and this 'home' department hence physically stores the PMR in the storage room. However, if a patient was previously treated at another department, locating the PMR can be a rather cumbersome process. Once located, the referral letter (e.g., from the GP) is added to the PMR. If a new patient with no PMR is admitted to the ward, one is created. The record is then sent to the nursing station the day before (or on the morning) the patient arrives. During the morning conference between the doctors and nurses, the record is used to prepare the arrival of the patient and to plan the treatment (Figure 3B – *admission phase*). Once the daily treatment and care of the patient has ended (Figure 3C – *treatment phase*), the medical continuation is updated by a ward secretary while nurses update the nursing record, the medicine scheme and add relevant examination results to the record (Figure 3D – *dismissal phase*). Once the patient is discharged from the department, the PMR is finalized and stored at the ward. This implies that hundreds of archived records are at the department.

FINDINGS

The field study on the use of (double) medical records provided three main findings related to: (i) establishing workflows, awareness and coordination; (ii) micro- and macro-mobility of medical records; and (iii) how medical record sub-artifacts are collated and aligned. These findings relate well to those from other studies of the use of (electronic) medical records in hospital environments, but also add a detailed insight into how medical professionals handle such double record keeping.

Workflow, Awareness and Coordination

Several studies (e.g., [12, 33, 37]) have shown that the PMR serves as a key coordination mechanism between clinicians, which is confirmed in our study. The PMR is used as a coordination mechanism between nurses and doctors inside the patient ward where the doctor can give orders concerning the patient via the PMR and in turn, the nurses note information in the record that helps the physician decide what to do next for the patient. In our study, we found that the PMR is actively used during coordination of patient treatment and care during the morning conference. The content of the record including the latest examination results is key in deciding on treatment and care as well as the allocation of doctors and nurses to the patient. As such, the record is essential in coordinating treatment within and between departments, which is reflected in the fact that the record is always required by law to follow the patient to other departments.

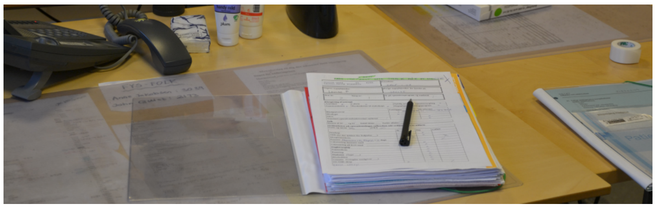

Figure 4. The placement of a PMR (e.g., spatial orientation or opening the record) is used to signal information to other clinicians.

The PMR is also key in a more subtle coordination inside the ward as its physical form helps to achieve local coordination and awareness. The physical placement of records often reveals status information and can be used for signaling and for drawing attention to important matters. For example, the PMRs shown in figure 4 are deliberately placed on the desk by a nurse to signal to the doctor that the paper forms in the record should be inspected and validated. Similarly, the PMR would often be placed in the bed of the patient inside a patient room, visible from the hallway. This is a signal to the porter that this patient is ready for pick-up and can be moved, e.g., to surgery. This phenomenon of signaling through document placement was also observed by Bång et al. [3] who noted that if, e.g., a physician wanted a laboratory test, the request was attached to the folder that was then placed at a designated spot on the desk. Hence, our study confirms that the processes of signaling and monitoring are used in medical work to constitute mutual workplace awareness [6]. However, an interesting addition to prior research is that in this case, not only humans but also computational devices work as active signaling actors. For example, printing lab results directly on the ward's printer is a signal from the lab to the ward. In general, the spatial arrangement of documents bestows local importance on the workplace and provides an overview and deposition of information that facilitates memory recall and the tracking of work processes. The placement of a record inside the ward, the nurses station, the filing cabinet or storage room convey information about their role in the overall workflow.

Micro- and Macro-mobility

Medical work in hospitals is inherently nomadic [4], which implies that clinicians and the tools they use move around inside wards, departments and the entire hospital. This mobility includes the PMR, which moves between different departments, wards and locations within the ward [32]. As such, the mobility affordance of PMRs fits medical work well, as they are easy to move around inside a hospital. Our study showed that the PMR is primarily moved around inside the patient ward and is mostly used in the ward offices, nursing stations, doctor's offices and at the bedside of the patient. However, since it is a legal requirement that the record is present during medical treatment, the record always 'travels with the patient'. For example, when patients are sent to other departments (e.g., for x-ray or surgery), the record is mounted in a special container on the side of the patient's bed and travels with the patient to the receiving department. This flexible mobility affordance of the PMR, however, also introduced significant challenges since it often was lost or misplaced both inside the ward and in other departments. Significant time was spent looking for records, especially by the ward secretaries. Hence, a core challenge to a paper-based workflow is that sometimes the physical record is misplaced or not available. As one of the nurses explained:

> *"Doing background research on a patient can be difficult when the patient does not belong to our ward. Then the PMR is elsewhere and the digital data might not be up to date. All we can do is wait for the patient and improvise."*

But also finding records inside the ward offers its own set of challenges. Finding the right PMR is difficult because there is no visual differentiation between different records; they are all stacked upon each other and scattered all over the ward in the nurses station, the secretary offices and in the storage room.

In addition to mobility on a macro level, micro-mobility of a PMR plays a central role in medical work [28]. Micro-mobility is *the way in which an artifact can by mobilized and manipulated for various purposes around a relatively circumscribed, or 'at hand', domain*. For example, during the ward round a physician and nurse jointly worked on a PMR by standing next to each other reading the record. They handed over parts of the record to each other, pointing out specific results. Furthermore, the record was often broken open and the individual records, results, forms and graphs were spread out on, e.g., a desk for better overview. This micro-mobility affordance of a PMR hence supports clinicians in achieving an overview of the medical situation at hand [9].

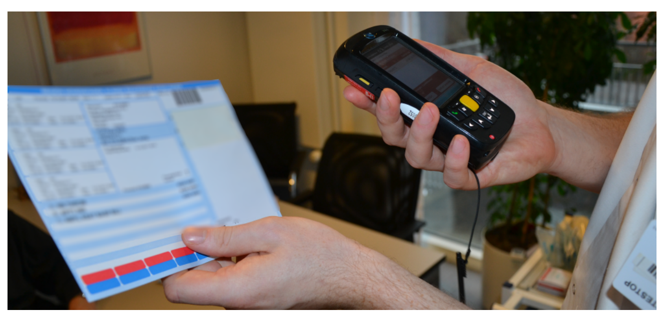

Figure 5. A nurse completing a form while using a PDA to scan the vacutainer after taking a blood sample.

Moreover, as seen in figure 5, nurses often 'break open' the record by only taking parts of the record with them, while interacting with patients. In this specific case, a nurse has brought the record and placed it on the table before taking a blood test from the patient, scanning the tube with the PDA and adding the form to the PMR. In current work practices, this kind of micro-mobility alignment between paper and digital information is often cumbersome. Additionally, since the

PDA only provides limited access to the patient data (in this case only the blood work), the clinician will have to return to the nurses station to manually add any data to the electronic record. The mobile device as such is only used to ensure the blood test was taken from the correct patient.

Artifact Collation and Alignment

Core to medical overview and decision making is the collation and alignment of information from many sources. This includes both the many different paper forms and records in the PMR, as well as the information located in the EHR. Hence, significant effort was put into collation and alignment of medical information for several sources to get a comprehensive overview of a patient's medical state. As seen in figure 6, both the paper and digital information are of equal importance and are thus often used simultaneous. This implies that while some information is duplicated in both records, other information only exists in one of both.

Figure 6. Clinicians are using both the PMR and EHR to coordinate information.

Managing the dual record introduces a number of configuration challenges related to managing, synchronizing, communicating and cross-referencing both versions of the record. Current work practices still include printing a significant amount of information, which is then stored in the PMR. Furthermore, most of the digital applications can only be used to request or add new medical data (such as blood test or MRI). The results of these requested tests are often still sent by paper trough internal mail or by sending the results to the printer located at the requesting ward. This places a large and important coordinative role on the printer, which essentially operates as a communication and awareness mechanism. It also implies that although a lot of time and effort is invested in printing, often these printouts are quickly outdated compared to the digital record, or even get lost throughout the printing process. There was a general recognition that aiming for a completely 'paperless hospital' would be naive. Moreover, information on large whiteboards were also constantly updated to align information across several records and other coordinative artifacts. The need for collation and alignment of information across such a 'web of coordinative artifacts' is known to be essential for the general flow and coordination of medical work [5].

HYBRID MEDICAL RECORD TECHNOLOGY

As argued above, there is a significant set of configuration challenges related to managing, synchronizing, communicating and cross-referencing both versions of the medical record.

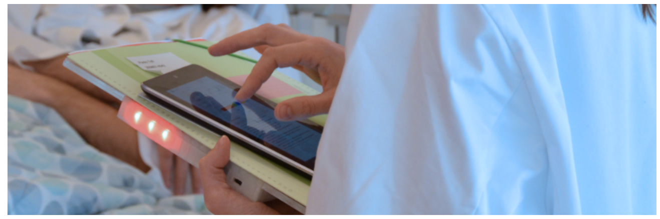

Figure 7. The HyPR device augments the PMR with a notification system (color and sound), location tracking and near-field communication that uniquely identify the medical record, which allows clinicians to pair a tablet with the HyPR to display the digital information associated with the present PMR.

In order to provide a technical design to mitigate these problems, we have previously proposed an augmented hybrid patient record or HyPR device (Figure 7) [23]. The HyPR device is a small sensing and computing platform that supports notification through colored light and sound, location tracking and unique identification using near-field communication (NFC). The HyPR device is designed to be 'clipped on' to the paper-based record as an augmentation of the plastic folder used now. Hence, one HyPR device should be deployed for each PMR in use in a hospital department.

As shown in Figure 7, the HyPR device is attached to the PMR and, by placing a mobile device like a tablet computer or a smart phone on top of the record, relevant electronic information from the EHR is loaded and displayed. The HyPR embeds a unique id, which is communicated to the mobile device using NFC and Wifi and is used to retrieve relevant patient information in the EHR. On the side of the HyPR device, an array of LED lights can be used for signaling purposes and the device also has a small buzzer for sound notifications. These notification features can be used to convey status information about a patient, such as when the patient is ready for the ward round or should be prepared for surgery. The HyPR also embeds a location tracking tag that allows for tracking the location of the physical paper record. This allows clinicians to retrieve the location of a record when missing. Additionally, they can turn on the buzzer or set the colored lights to blink, to visually or auditory locate the HyPR.

The overall design goal of the HyPR approach is to create a transitional artifact allowing clinicians to easily move between paper-based and digital records. Clinicians thus benefit from both the portability and flexibility of paper-based records as well as the easy access and information processing capabilities of electronic medical records. As such, the goal is to reduce the amount of configuration work required to use and setup this dual record. Specifically, the HyPR approach supports: easy and fast *configuration* of the dual record by allowing clinicians to connect the paper and digital information, *coordination* by providing a notification system equipped with dynamic colored lights and sound and *mobility* by including location tracking capabilities to the portable device. The HyPR approach supports flexible and dynamic configuration of paper and digital information, which allow for a gradual transition between paper and digital. For example, paper-based forms can be digitized and stored in the EHR or digital material can be printed and stored in the PMR, all of which can be handled by the HyPR approach.

HYBRID MEDICAL RECORD STUDY

Previous studies of the HyPR device have only provided preliminary insights into its overall usability and usefulness [23]. Therefore, there is a need to understand the details of how this technology supports collaborative work in hospital departments, in particular, how it helps alleviating configuration challenges related to managing, synchronizing, communicating and cross-referencing both versions of the medical record. The study investigated to what degree the HyPR supports and potentially enhances existing clinical practices.

Since doing a field deployment of this type of technology is technically, legally and organizationally unfeasible, we conducted a clinical simulation in a separate 1:1 simulation environment. In the medical domain, a clinical simulation is a methodology frequently applied to train and educate clinicians in critical clinical scenarios, such as surgery, medicine prescription and administration and emergency cases. It has proved very efficient and reliable for the initial phase of training and assessment of clinical staff [1]. However, since the clinical simulation approach attempts to bring the dimension of clinical context into stronger focus, the method has lately been used also as a method for testing clinical systems with representative users doing representative tasks, in an ecologically valid setting [24]. The main source for this medical simulation was the data and insights obtained from the original hospital field study, which provided input for the physical setup, the scenarios and the configuration of the technology.

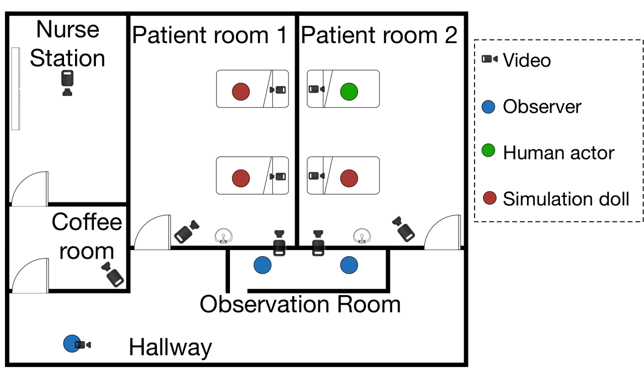

Figure 8. The simulation setup was comprised of a medical ward with five zones including two patient rooms, a nurse station, a coffee room and a hallway. The simulation facility is equipped with hidden cameras and an observation room behind a one-way mirror. The simulation included three simulation dolls (patients) and one human acting as a real patient.

Setting and Participants

The study was conducted at a 1:1 clinical simulation and training facility in a large hospital. This simulation facility supports the simulation of different hospital departments ranging from patient wards to surgical department and emergency ones. For our study, we set up the facility to be identical to a fully equipped patient ward with two patient bed rooms. Figure 8 shows the layout of the setup consisting of five zones: two patient rooms, a nurse station, a coffee room and the hallway. One human actor performed as a patient in a bed in room 2 (Figure 7, green dot). The other patient beds were equipped with simulation dolls, each connected to a monitor displaying the vital signs of the 'patient' (such as heart rate, saturation, blood pressure, temperature, etc). The setup included artifacts such as a traditional whiteboard with patients' data, desks in the nursing station with a stationary computer and nursing carts with medical equipment.

During the two-day simulation, 8 senior clinicians with different specialties (such as surgery, psychiatry and intensive care) participated in the experiment. Participants included 5 doctors, 2 nurses and a psychologist. The entire simulation was recorded using video and audio as well as extensive note taking and observations from inside the observation room through a one-way mirror.

Method

The study applied a scenario-based evaluation of the HyPR approach. The scenarios were drawn directly from the initial field study and revolved around interacting with the patients (both the actor and simulation dolls) to assess the patient case, update the status in the EHR and add or remove all necessary documents to the PMR. Scenarios included:

S1 *Ward Round* – Clinicians were asked to perform a ward round to assess the situation of four patients. By examining the patients and monitoring vitals signs on the monitor, they had to calculate an Early Warning Score (EWS) to describe their current status.

S2 *Blood Result* – Clinicians were asked to order a blood test result while working on the case of patient P1. After receiving the results they had to visit the patient, re-calculate the EWS and discuss the situation with the patient.

S3 *Lost Record* – Clinicians were asked to find a number of PMR, which, after a shift change, were not at their usual place. For this scenario, they could employ information on the patient's location, the last treating doctor, the current treatment procedure and the location of the HyPR.

After welcoming the participants, a brief introduction was delivered on the concept, the system and the physical layout of the ward. Participants were then asked to perform the three scenarios above. We did not provide any detailed instructions on how to perform the scenarios, which patients to look at first or how to use the system. Because we were interested in how clinicians would leverage their existing practices while using the HyPR setup, the scenarios were deliberately open ended: no explicit instructions or training on the system was given to them and the facilitator only intervened to solve technical issues. Because the initial field study showed that most medical work is highly collaborative, involving both doctors and nurses, the scenarios were conducted in pairs of two clinicians from the same department.

Artifact and Technology Setup

A list of patient cases with realistic names, backgrounds, social security number and medical background was compiled for the study. The PMRs used in the simulation contained real blood tests, EWS forms, admission forms, doctor and nurse notes and other medical information. The whiteboard placed in the nurse station listed all the patients with room number, treatment plan, responsible doctor and nurse and admission date. Four HyPR devices and three Nexus 7 tablet computers were used. We equiped the simulation facility with the Sonitor[1] ultrasound location tracking system in all rooms, excluding the hallway.

Since there was no open access to the medical information system in the hospital, we implemented a simple Activity-Centric EHR application to be used in the simulation. This application contained all patient cases with a set of medical entries such as blood test results, continuation records and nursing notes. The adaptable web application runs on phones, tablets and desktop computer and supports two views: (i) an overview screen and (ii) a patient details screen. The overview screen lists all patients currently active on the ward and provides basic information, such as name, assigned color, room number and ongoing medical procedures on each patient (Figure 9A). Using the 'Blink' button causes the colored lights of the HyPR to start blinking (Figure 7), asking for attention until a tablet is paired. The 'Buzz' button can be used to turn on a buzzing sound to quickly find a record. The buzzing sound is automatically stopped after 15 seconds.

Figure 9. The details of the patient record.

By placing the tablet on the HyPR device, the patient information (Figure 9B) is displayed. This screen allows clinicians to inspect prior observations and update medical information (e.g., EWS), add a message, or change the status color of the patient. Changing this color in the EHR will cause the color of the HyPR device to change accordingly (see Figure 7). The EHR on the tablet computer can also be used while not paired with an HyPR device. In this case, if new data (medical observations or a message) for a patient is entered into the EHR application, the patient's HyPR device (attached to the patient's PMR) will start to blink. In this way, the physical record signals changes in the digital record. Once a tablet is paired with the HyPR record, the patient information is displayed and the device stops blinking. All patient information is thus organized in 'patient activities' which are visualized in the overview screen and can be quickly and easily accessed through physical or remote interaction.

FINDINGS

The objective of the simulation was to study how work practices observed in the field study would translate to the HyPR. As such, we were interested in relating the observations of the HyPR approach to current work practices at a medical ward. The discussion of the simulation findings are therefore framed in the three main findings from the field study on the use of medical records in the hospital; (i) establishing workflows, awareness and coordination; (ii) micro- and macro-mobility of medical records; and, (iii) how medical record sub-artifacts are collated and aligned.

Workflow, Awareness and Coordination

Since the HyPR encloses the PMR, it was used as a coordination mechanism in exactly the same way as seen during the field studies. Clinicians would use the record for information sharing, during clinical conferences and as the key coordination mechanisms between doctors and nurses during, e.g., the ward round. It was, however, interesting to observe how the features and functionality of the HyPR sparked new workflows, awareness and coordination practices.

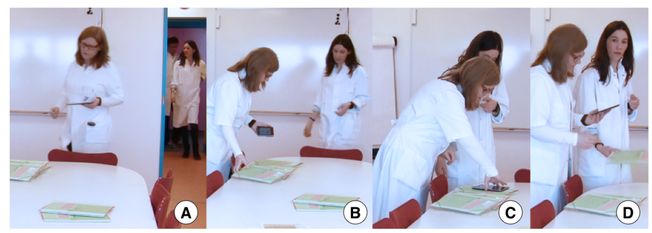

Figure 10. Clinicians glance at the PMRs (A) and notice that a colored light is blinking, indicating a new message (B). They pair a tablet computer with the record to read the message on the tablet (C) and finally consult the paper forms for more details (D).

First, the colored lights of the HyPR triggered a number of novel workflow coordination mechanisms. The color was quickly appropriated as part of the externalization of the EWS. This meant that clinicians would use the color to organize and structure their ward round. One doctor, for example, mentioned that the colors helped him prioritize his patients during the ward round by using blue, green and red colors to indicate low, normal and acute patient cases. Colors were also used to reveal workflow status information. For example, during one of the ward round scenarios, a nurse had already appropriated the use of colored light as a method to keep track of the workflow:

> *"This [patient record] is green and it is not blinking, so he is fine." – P7*

Colors were also used for revealing if new content was added to the PMR. Figure 10 shows a video fragment of two nurses picking up a new message via the HyPR. First, the two nurses pass by the nurse station and glance at a number of PMRs in active use (Figure 10A). One nurse notices a blinking colored light indicating that new content has been added to the record (such as a new observation, message, or lab test result) (Figure 10B). The clinicians approach the record and, by placing the tablet on top of the record, they are able to read the updates (Figure 10C). They realize that they need more detailed information and align it with the paper documentation (Figure 10D) to construct a shared overview of all patient data.

Second, placement of the HyPR combined with the color light was also used for deliberately signaling status information.

[1]http://www.sonitor.com

Placing PMRs in the patient's bed was a signaling mechanism often observed during the field study. The simulation study showed that this work practice was continued and enhanced using the HyPR. We observed that clinicians carefully considered location and orientation when placing the HyPR. In the patient rooms, for example, clinicians would often position the records in such a way that the lights were visible from the hallway. This mechanism was adopted so that clinicians could easily glance inside the room and check if the colored light was changed or if a new message was received. They considered the colored lights to be an important collaborative affordance that helped them share and externalize the status of the patient in a fast and efficient way.

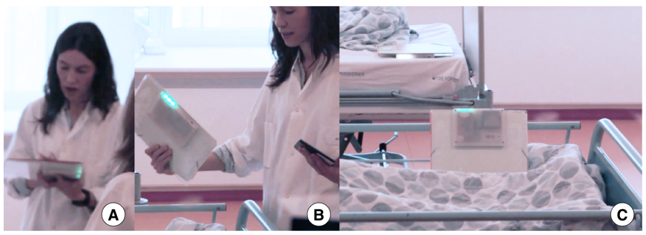

Figure 11. The clinician uses the record (A), checks if the colored light matches her assessment (B) and places both records in such a way that they are visible from the hallway (C).

Figure 11 shows a video fragment of a nurse using the HyPR for signaling. After finishing assessing the patient case (Figure 11A), the clinician double checks the color to see if it matches her assessment color (Figure 11B) and then positions the record to allow for visibility from the hallway (Figure 11C). Interestingly, this positioning was done differently depending on the location of the bed in the patient room:

> *"Then I should place it so one can see the light.. now it lies across his legs, then I should probably move it.. there!" – P8*

As seen in Figure 11C, the record on the second bed in the background is positioned differently than the one on the bed in the foreground. This was done because the bed in the foreground was close to the wall, implying it would not be visible from the hallway if it were flat on the bed. With the current positioning both records where visible from the hallway.

Micro- and Macro-mobility

The HyPR device is designed to maintain the macro-mobility affordance of regular PMRs. The medical simulation study clearly showed that a HyPR was carried around in the simulation facility just like regular PMRs are carried around. This can be seen in the video fragments in Figures 11, 14 and 16. However, as observed during the field studies, there are a number of problems related to mobility in clinical work, including the problem of lost PMRs and the lack of support for accessing the EHR while roaming the ward or hospital. The HyPR was designed to mitigate these problems by supporting location tracking of the HyPR and by allowing access to the EHR via a tablet that is paired with the PMR.

During the simulation, clinicians very quickly appropriated these features and we observed a number of recurring patterns in the mobile use of the HyPR. Figure 12 shows a video fragment of two clinicians searching for a lost PMR. The search strategy was very similar for most clinicians. First, they use the tablet computer to look up the location of the HyPR PMR. Since location tracking is room-based, they enter the room and look for the record. If it is not immediately visible, they use the tablet to turn on a blinking pattern on the record (Figure 12A). This approach only works if the PMR is in plain sight, e.g., on a desk or on a stack of other records, but not if the record is in a cupboard or drawer. Clinicians therefore turn on the buzzing sound and divide the mobility work between both of them. One clinician holds the tablet and repeatedly presses the buzz button while the other clinician tries to identify the location of the record with the instructions of the clinician that is holding the tablet and who has a better idea on where the sound is coming from (Figure 12B). After finding the tablet, it is still blinking from the initial search attempt, thus helping them verify that they have found the correct PMR (Figure 12C).

Figure 12. Clinicians use the color blinking (A) and buzzing feature (B) to identity the location of the record (C).

Figure 13. Clinicians inspect a pile of PMRs (A), select the one that they need (B) and position it strategically on the table while discussing it (C). Afterwards the doctor takes it (D) and places it in the out-tray with the colored lights clearly visible (E)

The field study also revealed extensive micro-mobility of PMRs; the spatial orientation and positioning of the record often carry a meaning as it symbolizes and reflects work processes. During the simulation, we observed similar micro-mobility use patterns with the HyPR as depicted in the video fragment in Figure 13. Clinicians inspect a pile of records and spatially categorize them based on their importance (Figure 13A). After selecting and inspecting a particular PMR (Figure 13B), the doctor places the record on the corner of the table (Figure 13C) to indicate that this is the record they are currently using. After discussing the patient case, they realize that this patient is no longer at the ward and the record is therefore no longer needed at the ward, but has to be sent to another ward (Figure 13D). The doctor then places the record in the out-tray with the colored lights facing upwards and clearly visible (Figure 13E).

Artifact Collation and Alignment

The original field study revealed significant work associated with aligning and collating PMR with EHR. A first observation from the simulation study reveals that record alignment and collation no longer takes place at the desk in the nurses station (as seen in Figure 6), but can be done by clinicians while roaming around inside the entire ward. All clinicians followed a very similar strategy in aligning the PMR and EHR. Figure 14 shows a video fragment showcasing the new approach available through the HyPR, performed by the patient's bedside. The clinicians first pair the paper and digital record to get an overview on the patient case (Figure 14A). They then jointly inspect both the paper and digital information and explicitly check if any new observations were added to the digital or PMR (Figure 14B). After discussing the case with the patient, they add a new observation to the digital record and place the paper forms back in the record (Figure 14C).

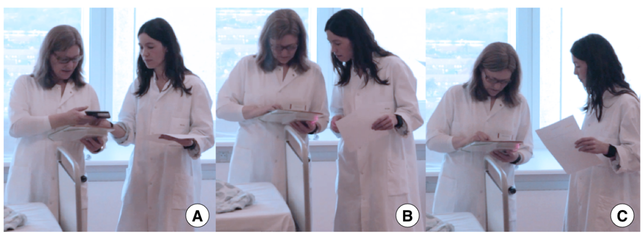

Figure 14. Clinicians first align the paper and digital record (A), then inspect both types of documentation (B) and finally update the documentation in both records (C).

While interacting with a patient, clinicians would divide the PMR between both of them. One clinicians would thus hold the PMR and inspect all the printed blood tests and paper forms, while the other clinicians would consult the paired tablet for the EHR. However, while moving to another patient or room, one clinician would carry both the HyPR and tablet, while the other clinician would focus on the patient. One clinician is thus often "left behind". Busy adding information to the electronic record using the tablet, the other clinician moves to the next patient. Interestingly, we also observed that although clinicians had easier access to both records, they sometimes were reluctant to use all its features. At one time a nurse, for example, whispered to the doctor:

> *"I am very much against that we should be writing it in here. We should do this at the nurses station." – P4*

She essentially disliked using the system in front of patients, as she argued that it detached the contact between the clinician and the patient.

During the EWS assessments of patients, we often observed that clinicians would spatially organize information that was needed to better understand the case. The video fragment in Figure 15 shows two clinicians doing a ward round while using the patient bed to organize and collate all the paper forms stored in the PMR and in the tablet computer. They first collate the prior blood results paper, EWS forms and digital messages (Figure 15A). Based on this information, they discuss

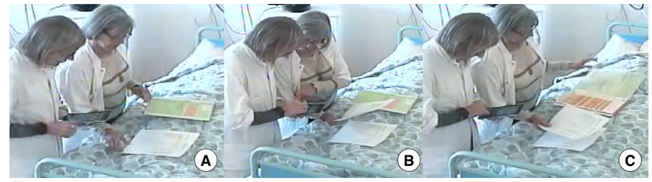

Figure 15. Two clinicians are using the patient bed to spatially organize both the paper and digital record of the patient (A-B), before adding content to the digital record (C).

the patient case and compare the previous data to the live information on the monitor (Figure 15B). Finally, they complete a new EWS form and add the form to the PMR while at the same time recording the EWS score to the digital record (Figure 15C).

When a physical surface was not available for spatial organization, clinicians would perform the collation in a much more mobile setting. The video fragment in Figure 16 depicts two clinicians that are collating medical forms, blood tests and digital record entries. While talking to the patient, the doctor (Figure 16A — on the right) is studying previous data. Based on the vital signs on the monitor, he requests the other clinician (Figure 16B — on the left) to update the electronic record with his assessment. He also asks the other clinician to update the color of the record to match his assessment (Figure 16C). Before leaving the patient room, the doctor checks the HyPR to see if the color has been updated based on his assessment of the patient (Figure 16D).

Figure 16. During the ward round, two clinicians are collating the paper and digital record (A-B) of the patient while standing at the bed assessing the patient case (C-D).

DISCUSSION

Prior studies [5, 12, 37] as well as this paper show that paper documentation remains to play an important central role as it is persistently and pervasively used during medical work in hospitals. This intensive use of paper documentation seems to be independent from the degree to which EHRs are integrated as paper simply makes clinicians more efficient in parts of their work [34]. Based on Gibson's theory of affordances [18], Sellen and Harper have argued that paper in general possesses a set of affordances, that makes it especially efficient in use [36]. These affordances include the ability to quickly navigate through documents, read across multiple documents at once, mark up a document while reading and interweave reading and writing. Looking more specifically to the medical domain, Harper et al. [21] point to the affordances of *flexibility*, *markability*, *portability* and *accessibility* of the anesthesia record that makes it easy to fill out, share and use during surgery.

Collaborative Affordance - *Affords the ability to*
Mobility and Portability *Physically carry, share and use the record in different places*
Collocated Access *Simultaneous and collocated read and update the record*
Shared Overview *Collectively create an overview of the content on the record*
Mutual Awareness *Signal and monitor information between users*

Table 1. The Collaborative Affordances of PMR and HyPR.

Based on the two studies reported in this paper, we argue that the core benefit of a paper-based medical record does not solely lie in its core basic affordances, but that a set of *collaborative affordances* exist that support clinicians in coordinating work. Rather than applying the original definition of affordance provided by Gibson [18], we rely on Norman's interpretation for human-computer interaction[2], in which affordance refers to those action possibilities that are *readily perceivable* by an actor [29]. In this definition, affordances depend not only on the physical capabilities of an actor, but also on the actor's goals, plans, values, beliefs and past experiences. Gaver describes that the perception of affordances is "*embedded in the observer's culture, social setting, experience and intentions*" [17]. Although affordances exist as a configuration of physical properties, its perceptible meaning is often dependent on the social strata and can thus change or differ between environments or social setting. Within the framework of distributed cognition, Zhang and Patel [42] refer to this dependency to culture as *cognitive affordance*. Using Activity Theory, Kaptelinin and Nardi reconceptualize affordances in a social-culture background describing them as *mediating actions* [25]. Similarely, Vyas et al. [38] describe that *affordances in interaction* exist between the user and environment, emerges from activities and practices and are therefore socially and culturally constructed. Finally, Kreijns and Kirschner [26] introduced *social affordances* as properties of collaborative environments "*which act as social-contextual facilitators relevant for the learners social interactions.*"

Based on these prior interpretations of the social role of affordances, we describe *collaborative affordances* as 'physical' properties that afford — make possible different actions for a person perceiving the object — collaborative perceptions and actions within a specific social context. Collaborative affordances do not replace the normal affordances of paper, but rather contextualize them in a social structure. Table 1 lists four basic collaborative affordances of the medical record which were observed in both studies. As technology comes closer to paper (as in the HyPR approach), questions arise on how these collaborative affordances translate to technology. Using the field study and the clinical simulation as case studies, we describe below how the four collaborative affordances described in Table 1 were observed in the initial study and how they translate into the HyPR approach.

[2]Although Norman nowadays prefers the terms perceived affordance [30] or signifier [31] over affordance.

Mobility & Portability

Portability, the ability to carry, maneuver and navigate, is an important affordance of paper [36], hence, also of the PMR [21]. From a collaborative stance, the portability and mobility of PMRs is a central reason for its success in mediating cooperative medical work. As argued by Østerlund [32], a PMR serves as a *portable place* in the sense that it can move across space and time but retain the indexical structure which points out relevant participants, places and times. This collaborative affordance allows several clinicians to use the record on the move as they continuously perform care activities for many patients across multiple locations. Such macro-mobility inside and across patient wards was also found in both of the presented studies: PMR as well as HyPR were carried around and used during care activities (e.g., ward rounds) and this portability of the record helped clinicians to jointly accomplish their work. Although the HyPR in its current state is relatively heavy and bulky due to the sensor platform, the technology essentially incorporates support for mobility as there was less mobility work [4] required to configure the work setup. The mobility and portability affordance of the HyPR is much closer to that of a PMR, specially if compared to other approaches that attempt to include mobility use for the EHR (e.g., Computers on Wheels (COW) [37]). By using the PMR as a contextual surface that auto-configures the paired tablet, HyPR mitigates the high cost of information access [37] and physical [21] challenges of handling digitized medical information at the bedside.

Collocated Access

Paper has a high degree of configurability as it affords simultaneous access through reading and writing [36]. These affordances are key to PMRs, since *working records* [15] and *transitional artifact*s [12] are used by clinicians as a coordinative reflective tool to bridge the gap between day to day work in the hospital and managing the EHR. In the course of the working shift, clinicians keep these documents to continuously gather information on the move and gradually transfer them back to the official record [32]. Our studies of the use of PMRs and the HyPR approach emphasize the collaborative nature of such simultaneous access to medical records. Records were often used in a collocated setting in which typically a pair of a nurse and a doctor would break open the record and simultaneously inspect and access the documents and forms. Examples of situations in which collocated access of the medical record is evident include the ward conference situation and the use of the record at the patient's bedside during a ward round (Figure 14). Such situations are examples of *standard operation configurations* [4] in a hospital, which are spatial setups fostering easy cooperation because of a common knowledge and agreement as to how to use and navigate the artifacts involved. A core requirement for medical records is that they embed this collaborative affordance of collocated access, which enables them to be part of such standard operation configurations. Using HyPR provides clinicians with a high degree of plasticity to import a digital device into standard operation configurations. Furthermore, by using a tablet computer with a size that fits into the clinicians' white coat pockets, the tablet can easily be brought in and out of the configuration. Although the sensors of the HyPR device are clearly visible to the clinicians, the technology was considered to be transparent as clinicians did not mention the mediating hardware at all, but rather talked about the HyPR as a 'smart paper-based medical record'.

Shared Overview

One of the most prominent affordance of paper is that it supports quick and flexible navigation and simultaneous access of multiple documents [36]. This is extensively used in a clinical setting, in which the PMR is key in obtaining an overview of the treatment and care of a patient [9]. Our studies of both the PMR and HyPR showed that this creation of an overview is primarily a collaborative effort, as the records afforded the creation of a shared overview by aligning documents. In the case of the PMR, we observed that clinicians would collate and align medical information from several sources (both PMR and digitally, as shown in Figure 6) to get a comprehensive overview of a patient's medical state. Moreover, during the study of the HyPR record, we often observed that clinicians would spatially organize information that was needed to better understand the case. For example, the video fragment in Figure 15 shows two clinicians doing a ward round while using the patient bed to organize and collate all the paper forms stored in the PMR and in the tablet computer. The micro-mobility associated with this specific operation configuration, thus includes digital devices that can essentially be handled similar to another paper artifact while providing a portal into the EHR. As concluded by Bossen and Jensen:

> *"Collaborative overview requires a display that can be shared by two or more people in the many ad hoc conversations that take place, for example a display that can be carried and handed around like paper (like the printed lists), providing essential overview, but also making it possible to go into specifics"* [9][p. 11].

How the device contextualizes, integrates and visualizes large, complex and specialized EHRs to achieve *seamless integration* remains an important open question [14]. Nevertheless, HyPR can be used as a long term *stable concept* for a gradual movement towards a higher degree of integration and a less paper-centric hospital.

Mutual Awareness

Paper is not only easy to annotate and manipulate, but also provides an intrinsic historical account on these actions or changes [36]. Physical records are extensively used in achieving workplace awareness [6] in a hospital setting, as also evident in our studies of the PMR and HyPR. For example, the PMRs shown in figure 4 are deliberately placed on this desk to signal the hand-over from the nurse to the doctor. And, while using the HyPR record, clinicians positioned the HyPR in various ways (e.g., in the patient bed) to signal a status change, as seen in the video fragment in Figure 11. Similarly, clinicians were able to monitor places to pick up awareness information on status changes. For example, monitoring the printer in the ward office for lab results, as well as the HyPR records in the out-tray for status changes (Figure 13). Mutual awareness is a collaborative affordance as the medical record should allow the creation and perception of awareness information through the physical artifact. The physical properties of a PMR allow for placement in different places and positions — something that the EHR does not. HyPR did not remove any of the original collaborative affordances of the PMR, but rather supports and amplifies existing ones. The colored lights, for example, were used as *signifiers* [31] that allowed clinicians to externalize work practices into signals that helped them to optimize and prioritize interaction with patients. As such, medical records — PMR, EHR or HyPR — should be designed with the affordance of mutual awareness in mind, thus, providing clinicians with tools to *configure awareness* [22].

CONCLUSION

Medical records are key in coordinating treatment and care of patients in modern hospitals. Historically, they were paper-based, but due to the increased digitizing of medical information, more and more patient information is stored in different medical information systems. This creates a situation in which clinicians need to maintain and use a double record consisting of both a paper-based and electronic part. A detailed field study of the use of such a double record in a large university hospital revealed that a paper-based medical record is key in the subtle coordination inside the ward as its physical form helps to both achieve local coordination and awareness, as well as facilitates micro- and macro-mobility. These results echo previous findings, but our study highlighted that these paper-based affordances are not transferred to the electronic medical record used in the hospital. Specifically, our study showed that managing the dual record introduces a number of configuration challenges related to managing, synchronizing, communicating and cross-referencing both versions of the record. Different technologies for bridging the gab between paper-based and digital records have been proposed and we did a detailed study of one particular technology called the HyPR device. The study was conducted in a simulated medical ward environment with 8 clinicians performing a set of scenarios. Although the study was limited to 8 clinicians, it already showed that the HyPR approach has the potential to function as a transitional artifact that helps integrate and synchronize paper-based and digital information while maintaining some of the benefits from both the paper-based and digital records. Based on these two studies we introduced the concept of collaborative affordances, which denotes a set of properties of physical devices and artifacts that supports collaboration. These collaborative affordance include: mobility and portability, collocated access, shared overview and mutual awareness. The concept of collaborative affordances can be used in the analysis and design of collaborative technologies.

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