Collaborative Affordances of Medical Records

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Abstract. This article[1] proposes the concept of *Collaborative Affordances* to describe physical and digital properties (i.e., affordances) of an artifact, which affords coordination and collaboration in work. Collaborative Affordances build directly on Gibson (1977)'s affordance concept and extends the work by Sellen and Harper (2003) on the affordances of physical paper. Sellen and Harper describe how the physical properties of paper affords easy reading, navigation, mark-up, and writing, but focuses, we argue, mainly on *individual* use of paper and digital technology. As an extension to this, Collaborative Affordances focusses on the properties of physical and digital artifacts that affords *collaborative* activities. We apply the concept of Collaborative Affordances to the study of paper-based and electronic patient records in hospitals and detail how they afford collaboration through four types of Collaborative Affordances; being *portable* across patient wards and the entire hospital, by providing *collocated access*, by providing a *shared overview* of medical data, and by giving clinicians ways to maintain *mutual awareness*. We then discuss how the concept of Collaborative Affordances can be used in the design of new technology by providing a design study of a 'Hybrid Patient Record' (HyPR), which is designed to seamlessly blend and integrate paper-based with electronic patient records.

Keywords: Collaborative Affordances, Paper Records, Electronic Health Records, Hybrid Patient Record, Clinical Work

1. Introduction

Gibson (1977)'s concept of affordances has been widely used to understand and design human-computer interaction (Norman, 1988; Gaver, 1991) as well as understand the role of paper in different work settings, such as an office (Sellen and Harper, 2003) or a hospital (Harper et al., 1997). An affordance is often taken as a relation between an object or an environment and an organism, that affords the opportunity for that organism to perform an action. In this ecological approach to perception and cognition, people perceive objects in the environment directly in terms of their potential for action. For example, a person perceives a chair in terms of its 'sitability', i.e. how stable, comfortable, and useful a chair is for a particular person and a particular activity this person want to do. Hence, the 'sitability' of an armchair for an adult wanting to read a book might be high, whereas it is low for a kid wanting to play with LEGO.

Extensive ethnographic studies by Sellen and Harper (2003) have described the role of paper in different organizations, and has revealed how the role of paper in office life has to be understood as having coevolved with work practices. Based on Gibson's theory of affordances, Sellen and Harper argue that paper in general possesses a set of 'interactional affordances', that makes paper and paper-based artifacts especially efficient in use. These affordances allow us to quickly navigate through documents in a flexible way, to read across several documents simultaneously, to mark up and annotate documents while reading, and to interweave reading and writing.

With a few exceptions, the use and theoretical development of the affordance concept in human-computer interaction have been entirely focusing on the affordance of physical and digital artifacts for *individual* activity. This is not surprising since the original concept from Gibson focused entirely on individual perception (including animals), and the use of the concept in human-computer interaction has been entirely focused on the design of personal computing technology trying to explain the design and use of windows-icons-menus-pointer (WIMP) interfaces.

However, physical and digital properties of an artifact can also afford *collaborative* activity. For instance, if two kids wants to build LEGO, a table with two chairs have the affordance for this collaborative activity. And in a professional setting, physical artifacts may be used to signal status information to others. For example, in a flight control room, paper-based 'flight progress strips' can be annotated and positioned in a manner that they reveal status information amongst collaborating flight controllers (Mackay et al., 1998). Such flight progress strips thus possess physical properties that affords mutual awareness amongst collaborating actors (i.e., the flight controllers) in a specific context (i.e., the working environment of the control room).

In this article, we introduce the concept of Collaborative Affordances in order to describe the properties of physical and digital artifacts that afford collaborative activity in a specific context. Collaborative Affordances are to be seen as a direct extension and addition to the existing use of the term 'Affordance' in human-computer interaction and is, as such, a supplement to the 'perceived affordance' of computer technology as introduced by Norman (1988) and the 'interactional affordances' of paper, introduced by Sellen and Harper (2003). The concept of Collaborative Affordances is derived from empirical studies of the use of paper-based and electronic medical records in hospitals. The studies of the use of paper-based and electronic in a hospital setting reveal how the physical properties of such records not only support individual use of the record, but also enable close coordination, communication, and cooperation amongst collaborating clinicians. For example, the ability to carry the record around inside the hospital helps facilitate planned conferences and ad-hoc meetings; the ability to position and move the physical records on a table or in a patient bed signals status information from

one clinician to another; and the possibility of 'breaking open' the record and distribute parts of it amongst collaborating clinicians help them achieve a shared overview of the treatment of a patient. However, some of these Collaborative Affordances are 'broken' in the design of technology. For example, the Electronic Health Record (EHR) supports the ability to 'move' a record around inside the hospital, but it cannot be positioned on a table or in a bed.

Based on the studies of the use of paper-based and electronic medical records, this article identifies and discusses four types of Collaborative Affordances; mobility, collated access, shared overview, and mutual awareness. These collaborative affordances supplement the individual interactional affordances of paper and other physical and digital artifacts as identified by Sellen and Harper (2003).

In the design of computer systems, the concept of Collaborative Affordances can be used to design interactive systems that afford collaboration. We illustrate this by a design case study of a so-called Hybrid Patient Record (HyPR) (Houben et al., 2014a). Hybrid patient records are designed to seamlessly blend and integrate paper-based with electronic patient records. A clinical evaluation of the HyPR showed that this combined physical and digital device embeds many of the same collaborative affordances as identified in the paper-based patient record, while at the same time exploiting the benefits of digital technology. For example, the HyPR device allows a clinician to place the device in a certain manner in a patient bed, in order to signal to another clinicians to take over the care of the patient.

The article starts by presenting related work on affordance in HCI and CSCW research. Section 2 discusses the theoretical underpinning of Collaborative Affordances in light of previous definitions of Affordances and Social Affordances. We continued by introducing the empirical background of the paper, which consists of a study of the use of paper-based and electronic medical records in a large hospital in Section 3. Based on this empirical work, we exemplify the concept of Collaborative Affordances and presents concrete examples of collaborative affordances. Section 4 then analyzes how these different medical records exhibit different collaborative affordances, and in particular how some collaborative affordances of the paper-based record are deprived in the electronic record. We discuss how collaborative affordances can help design new future technologies for the medication domain in Section 5. This leads to a discussion of the use of the concept of Collaborative Affordances in the design of digital technology in Section 6. By using the case of designing and evaluating the HyPR, we show how the device was able to incorporate collaborative affordances from the paper-based patient record, while at the same time exploit digital technology. Section 7 concludes the paper.

2. Collaborative Affordances

Before discussing the practical implications of using Collaborative Affordances as a unit of analysis and design for medical records in clinical work, we first provide a theoretical account of the relation between Collaborative Affordances, and the classic Gibsonian Affordances (Gibson, 1977), as introduced in Human-Computer Interaction by Norman (Norman, 1988), and more recent extensions and reinterpretations (McGrenere and Ho, 2000), such as Social Affordances (Bradner et al., 1999) or Technology Affordances (Gaver, 1991; Kaptelinin and Nardi, 2012). In contrast to these prior interpretations of social or mediating affordance, we discuss how Collaborative Affordances are a set of physical and digital properties that enable collaborative action, workflow or cooperation.

2.1. AFFORDANCE

Gibson (1977) introduced the concept of *affordances* as part of his Ecological approach to visual perception. In this concept, he described how animal agency interacts with the physical world. He delineated affordances as the actual perceived properties of an object, or the fundamental properties that determine how an object can be used or interacted with. This original affordances concept stemmed from an observation that there exists an intrinsic and naturalistic relation between animal agency and the physical world. Affordances in this context conceptualizes the animal perception, thus, describing action possibilities offered by the environment to the animal. Affordances describe what the environment "offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1977). In his work, Gibson describes that despite the fact that affordances exist independent from the organism, they do exist relative to the action capabilities of the organism. As summarized by McGrenere and Ho (McGrenere and Ho, 2000): Gibson posed that *"an affordance does not change as the needs and goals of the actor change."* Similarly, Torenvliet (Torenvliet, 2003) posed that *"affordances exist independently of perception and only as a relationship between an organism and an object."* The original definition of affordances was primarily aimed at describing the directly perceivable world through raw sensory data that emerges from interaction between animal and environment, thus, implying that it is not defined, influenced or shaped by individual interpretation or socio-cultural setting, or goals.

Rather than applying the original definition of affordance provided by Gibson, we rely on Norman (1988)'s re-interpretation for human-computer interaction[2], in which an affordance refers to those action possibilities that are *readily perceivable* by an actor. 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. At its core, Norman argued that affordances provide humans with clues or signs on how to operate and use objects as a well designed object clearly 'affords' its operation. Norman introduced this re-conceptualized definition of affordance in an attempt to couple explicit perceivability and knowledge on the environment to the affordability of objects. Later, Norman (1999) differentiated his interpretation of an affordance from the original Gibsonean definition by calling them 'perceived affordances'. Norman describes that perceivable affordances have three types of distinguishable constraints: (i) physical, (ii) logical and (iii) cultural. Real affordances are closely related to physical constraints of objects while logical and cultural constraints are embedded and intrinsically related to perceived affordances. Norman essentially reframed affordances with an important emphasis on its perceived properties. Although the conceptual difference between real affordances, as described by Gibson, and perceived affordances are not crystallized in literature (McGrenere and Ho, 2000) and often misinterpret by designers and researchers (Norman, 2008), Norman does emphasize the important interplay as *design* is concerned with both real and perceived affordances (Norman, 1999).

Moving beyond the desktop metaphor into intrinsic mobile, nomadic and ubiquitous systems, this interplay between real physical affordances that shape human interaction in the world, and perceived affordances that shape usability of those interactions with the world, become intrinsically more important and difficult. In his definition of 'Technology Affordance', Gaver (1991) described that the perception of affordances is *"embedded in the observer's culture, social setting, experience and intentions"*. Affordances do not need to be visual but can be embedded in other types of information exchange, such as sound, vibration or combinations of sensory information. He makes a distinction between four combinations of affordances: (i) perceivable affordance, (ii) false affordance, (iii) hidden affordance, and (iv) correct rejection. These types of affordances refer to whether the affordance is present or absent and whether the affordance provides perceptible information. Gaver also pointed to the fact that affordances can exist in complex actions, thus, proposing the existence of sequential and nested affordance. Sequential affordances are affordances that reveal new action possibilities onces a person acts on an perceptible affordance. Similarly, an affordance can act as a context for another affordance, thus nesting several affordances into the properties of an object.

The application of this 'classic' view on affordances has been very successful within CSCW and HCI research as a way to discuss and even design new ways of interactions. Notably, interaction with paper documents has been scrutinized heavily in context of affordances. Prior studies (Bardram and Bossen, 2005b; Chen, 2010; Tang and Carpendale, 2008) but this paper as well 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 is independent from the degree to which EHRs are integrated as paper simply makes clinicians more efficient in parts of their work (Saleem et al., 2009). Based on Gibson (1977)'s theory of affordances, Sellen and Harper (2003) have argued that paper in general possesses a set of affordances, that makes it especially efficient in use. 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. (1997) 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. The focus of these affordances, however, are set on the action possibilities with the paper artifact, with limited implications for the social context in which they are being used. In this paper, we extend the ideas by Sellen and Harper (2003) to explicate how such technology affordance can produce, steer and even coordinate collaborative work.

2.2. Social Affordances

Going back to the original definition by Gibson, it seems that the powerful intrinsic relation between the animal and environment is not clearly translated to the modern perceived affordances that are used within Human-Computer Interaction. 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. In the application of affordances to computer-mediated interaction, learning and design, there is often an implied socio-cultural framing around affordances that is linked to the actors' perception. Many HCI studies demonstrate how affordance can lead to social interactions (Laarni et al., 2007). This socio-cultural framing of affordance can be examined from different theoretical perspective. For example, using Activity Theory, Bødker (1991) describes three complementary distinctions in human-tool interaction that exist at a physical artifact level, the subject/object level where humans are acting through the artifact, and handling of interfaces of the artifact. Similar, Bærentsen and Trettvik (2002) argued that using Activity as a unit of analysis for Human-Computer Interaction can greatly help to understand affordances as within the context of their socio-cultural influence and perceive them not as fixed instances of reality but as dynamic evolving properties of artifacts that are embedded in context and environment. Through learning and the use of signs and symbols, human agency can adopt, use and appropriate artifacts through their culturally-specific affordances. Kaptelinin and Nardi (2012) further reconceptualize affordances in a social-culture background describing them

as *mediating actions*. By explicitly adopting the original approach of Gibson (1977), but reconceptualizing it through the socio-cultural approach of Vygotsky (1980), they re-shift the focus from animalistic interaction with the world to purposeful activities where minds are mediated by culturally developed tools. Similarly, Vyas et al. (2006) describe that *affordances in interaction* exist between the user and environment, emerges from activities and practices and are therefore socially and culturally constructed. They propose to move away from the one-to-one relationship in current definitions and analyze affordances in a broader socio-cultural contex'. In another theoretical perspective, Zhang and Patel (2006) used the distributed cognition framework to define affordance as distributed representations that are extended across internal representations in the organism and external representations in the environment. Using this definition they define five types of affordances: (i) biological, (ii) physical, (iii) perceptual, (iv) cognitive and (v) mixed affordances. These 5 categorizations describe different levels of affordance, that begin at the biological level (instinct), move to the physical and perceptual level (Gibson's real affordance) up to the cognitive and mixed affordances, which are distributed perceived affordances that combine perceptual affordances with cultural significance and learning. However, although this drastic re-framing of the classic Gibsonian interpretation can lead to new interpretations of phenomena from different theoretical perspectives, McGrenere and Ho (2000) argue that *"returning to a definition close to that of Gibson's would solidify the concept and would also recognize that designing the utility or functional purpose is a worthwhile endeavor in its own right"*. There is, thus, an opportunity to explore how the classic view of affordances (and by derivation perceived affordances) can be extended to include clearer concepts that can be leveraged to analyze human interaction in the world, and even guide design.

From a Gibsonian perspective, the recent work by Davis et al. (2010) explored how the basic notion of affordance, which by definition describes individual perception, could be extended to *joint actions*. In a set of well-described experiments, Davis et al. found that *"individuals are sensitive to the affordances related to a joint action, and that this process may not entirely reduce to the perception of the affordances for each individual."* There, thus, exists a set of affordances that enables social interactions or collaborative actions: behavior only portrayed when multiple actors act in the world. In their experiments, they provide the example of a doorway, which when multiple people walk through it side-by-side, is no longer fully defined purely by the anthropometric features of the observing actor, but by dynamic and functional features that emerge from the goals and perception of individual, causing them to adapt their behavior to fit the dynamics of the social setup. This social character of affordances was also recognized by Bradner et al. (1999), who proposed the notion of 'Social Affordance' to delineate a working relation

between *"the properties of an object and the social characteristics of a group that enable particular kinds of interaction among the members of that group"*. There are social rules in culture that mediate how humans act in the world. The rules are social affordances. Going back to the example of a doorway, Bradner et al. (1999) give the example of a glass door in a busy corridor that affords opening (like any door), but also enables actors to perceive people on both side of the door in order to create a shared knowledge and accountability about who will enter first without obstructing the others. Furthermore, since social rules in culture develop over time, social affordances are dynamic changing properties that can be appropriated by groups depending on practices or purpose.

Similarly, Kreijns and Kirschner (2001) describe *Social Affordances* as properties of collaborative environments *"which act as social-contextual facilitators relevant for the learner's social interactions.´´* For example, although a couch affords sitting down for someone who wants to watch television, it simultaneous affords lying down for people who just returned home after a night shift. This is not only true for social setting, but even for different cultures. In their experimental study Oshlyansky et al. (2004) showed clear cultural differences in how basic physical affordances (like a light switch) are perceived differently in different countries, leading to a breakdown of the affordance. This relationship between affordances and the context in which they are perceived are underlined by the theoretical examination of Turner (2005), who states that *"from a holistic or phenomenological perspective, affordance, use and context are one"*. A concrete, yet conceptual, example of social affordances are the 10 'Motivation Affordances' by Zhang (2008), that describe how learning can be facilitated through a number of social, psychological and emotional affordances. In this work, Zhang (2008) discuss how motivational affordances *"comprise the properties of an object that determine whether and how it can support one's motivational needs"*. A final concrete example of how social affordances can be applied to design is Affordance Table (Laarni et al., 2007), an interface for supporting collaborative workflow management, designed specifically around the notion of affordances that enable collaboration among operations. In summary, affordances are perceived by actors based on their training, experience, role, motive and social position. The social but also cultural context of actors directly influence how affordances are perceived and what kind of social interactions they enable. Going back to Norman (2008)'s revision of perceived affordances into broader signifiers, it is clear that affordances do not only exist as physical properties in the world, but are socio-cultural concepts that can be created, developed and appropriated within a social context. They are physical properties of artifacts that enable and mediate human action. However, the focus of the prior extensions of affordances are primarily on the social setting in which they are

perceived, and not on the *joint action* that is achieved within a socio-cultural setting.

2.3. Collaborative Affordances

These extensions of the classic affordance concept (Norman, 1988) into social affordances (Bradner et al., 1999; Kreijns and Kirschner, 2001; Turner, 2005) indicate a need to provide more precise distinctions between physical or perceived affordances, and the social effect of those affordances. Although reconceptualizations of the affordance concept into broader Technology Affordances, that enable mediated actions (Kaptelinin and Nardi, 2012), provides new insights and analytical possibilities, we subscribe to the proposition of McGrenere and Ho (2000) that we can solidify and extend the existing affordances concept. This is strengthened by empirical studies that experimentally demonstrate cultural differences in the perception of affordances (Oshlyansky et al., 2004) as well as the existence of affordances that are only perceived in social settings (Davis et al., 2010). The central purpose of social affordances are to support articulation work (Schmidt and Bannon, 1992), as they enable recurring communicative practices within a group practice. Collaborative affordance extend social affordances to not only communicative practices but also recurring collaborative and cooperative practices within a group. Based on these prior interpretations of the concept of affordance in HCI and CSCW, we define *Collaborative Affordances* as;

> "a relation between a [physical and/or digital] artifact and a set of human actors, that affords the opportunity for these actors to perform a collaborative action within a specific social context."

In the original definition by Gibson, an affordance is the perceived possibility of action for an individual person (or 'organism'). As a relation, an affordance exhibits the possibility of some action, and is not a property of either an organism or its environment alone (Neisser, 1987). The definition of Collaborative Affordances does not replace the existing use of the concept of affordance, but similar to 'Social Affordances' rather extends it to collaborative activities and contextualizes them in a social structure in which they are perceived. The extension takes place in two main aspects.

First, rather than focusing on the individual, a collaborative affordance suggests possible actions to *several collaborating human actors*. Collaborative Affordances are a direct extension of Social Affordances (Bradner, 2001) as they are only perceivable by a group of people within a social setting. Although affordances are perceivable by individuals, only collaborative affordances foster direct collaboration with the social setting. [3] Hence, the perception of possible actions is tied to a collective perception shared amongst collaborating actors who have a shared practice, accountability and knowledge

domain. The intrinsic collaborative aspect, however, does not necessarily imply that the perception happens synchronously. Collaborative affordances can be perceived within wider socio-cultural context that is embedded in work practice, group dynamics and social rules. For example, although a whiteboard has both perceived affordances (one can write on the whiteboard), and social affordances (multiple people can share the board), an example of a collaborative affordances is a whiteboard that is specifically setup for operation scheduling in a surgical department which affords multiple clinicians to continuously update the schedule itself, the status information about each operation, and the whereabouts of patients (Bardram, 2000; Xiao et al., 2001), thus coordinating direct action defined within the practices of the group. And updates can be made by collaborating clinicians both concurrently in front of the board, as well as asynchronously as they go to and from the board. As such, it provides a spatially and collaboratively stable environment for joint actions that enables work. Coordination of work in a surgical department using a whiteboard is a highly collaborative action, which is mediated – and afforded – by the properties of a whiteboard being highly visible, public, and easy to annotate. Second, collaborative affordances are perceived in a specific *social context*. As such, collaborative affordances emerge, are developed and maintained in a specific socio-cultural context, in which they are shared and taught amongst collaborating actors. In contrast to social affordances, which can be perceived in any social context, collaborative affordances are more deeply rooted in coordinative work practices within such as socio-cultural context. For example, the collaborative use of annotations, symbols, and writings on a surgical whiteboard is something that has been evolving over many years in a hospital. It takes significant training for newcomers to learn the subtle cues used, and is something that primarily trained nurses engage in. Moreover, such collaborative affordances emerge and evolve over time, and are, hence, dynamic. Collaborative affordances are strongly determined by experience through work practices, and workflows through training. 'Collaboration' thus refers to the broader set joint coordinative actions that emerge from the affordance. Collaborative affordances can be considered a sociocultural extension of social affordances within a defined work practice.

The definition of Collaborative Affordances applies to all artifacts whether computerized or not, and various physical properties of an artifact may afford different collaborative actions depending on their use and framing within workflow. Given the focus on joint action in the concept of Collaborative Affordances, collaborative affordances are particularly useful for collocated interaction and collaboration while less strong in remote and asynchronous collaborative scenarios. In such remote scenarios, communicative practice plays a much more central role, in which case the concept of Social Affordances (as defined by Bradner et al. (1999)) are more apparent. Nevertheless,

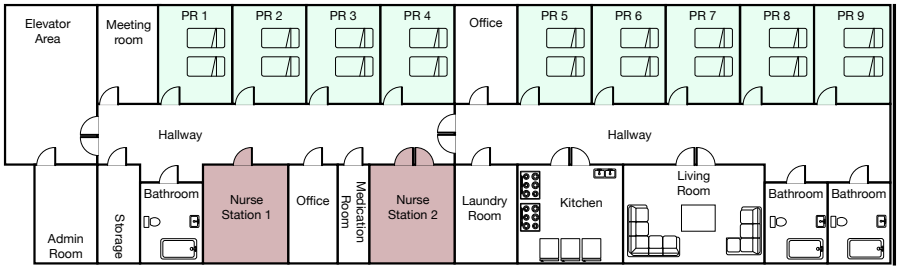

Figure 1. The physical layout of one of the wards from our field study. A typical ward consists of an administration desk and office, a number of patient rooms (PR), stations for the nurses, offices for secretaries, storage and medication rooms for medical equipment, and bathrooms and a living room for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

even in remote asynchronous scenarios, Collaborative Affordances still play an important role. As exemplified by Woo et al. (2011), in a remote Wiki scenario *"collaborative affordances had similar characteristics to social affordances in terms of affording social interactions, but the focus was more on whether the created interactions resulted in collaboration within a team."* The central distinction between social and collaborative affordances is that the latter allows for social perceptions that lead to joint group action within a socio-cultural setting.

The next section introduces our field study of the use of paper-based and electronic medical records in a hospital setting. Based on this study, we have identified four collaborative affordances that such medical records possess. These four collaborative affordances are summarized in Table 1 and discussed in section 4, and highlight how the physical properties of paper-based and electronic medical records in hospitals affords different coordinative and collaborative actions. Although these four collaborative affordances enable analysis and design for a hybrid patient record, they are not an exhaustive list, but *examples* of collaborative affordances. The four examples highlight how the concept can be leveraged to analyze cooperation around artifacts within work practices, and how that analysis can lead to new design features of future technology.

3. Empirical Background: Paper-based and Electronic Medical Records

This section presents the empirical background by introducing a workplace study on the collaborative use of paper-based and electronic medical records within and across departments in a large university hospital.

3.1. SETTING

The workplace study took place in the University Hospital of Copenhagen (UHC) with about 3,000 employees providing care for a municipality of about 400,000 people in greater Copenhagen, Denmark. The study involved five medical departments within the same surgical speciality, 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. The work procedures and use of medical records were aligned and standardized across the entire hospital. Each of the bed wards admit 20 to 30 patients and employ about 25 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. An outline of the patient ward is shown in Figure 1.

3.2. STUDY METHODS

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 paper-based medical record, charts, schemas, and requisition forms; the different medical information systems used including the EHR; other computing devices, such as digital whiteboards, mobile PDA devices, and regular desktop computers; specialized medical equipment and monitors; and other physical artifacts like whiteboards 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 in collaboration with 6 clinicians.

3.3. THE MEDICAL RECORD

At the hospital, the medical record consists of a unique paper-based medical record. 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 medical record varies between different departments, the record itself is standardized within the entire hospital. Figure 2 shows a picture of this record. It consists of a plastic binder that is marked with color-coded sections for different types of documentation. Documentation includes basic patient data, the narrative treatment record (called the 'continuation'), nursing documentation, various schemas and forms, observations, test results (e.g., radiology examinations), and documentation 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 record is 2–3 cm. thick, but the size of a record can be larger if the patient is treated repeatedly. There are typically 25 medical records in active use at a patient ward.

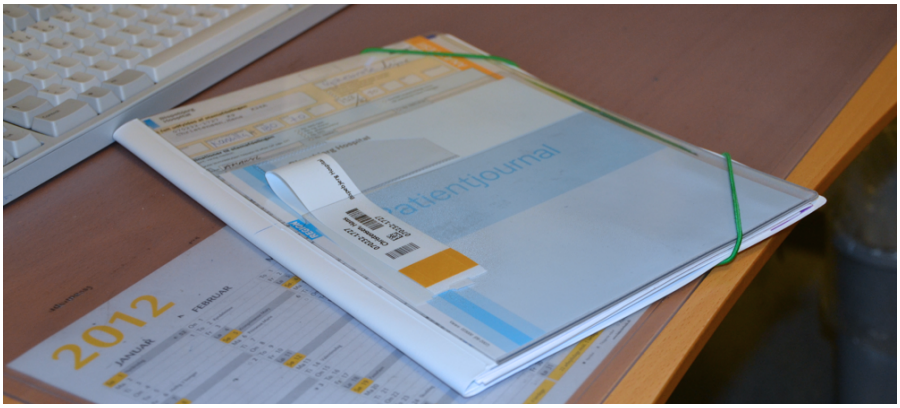

Figure 2. The paper-based medical record consists of a plastic binder, labeled with the name and ID of the patient. The binder holds all patient documentation and provides separate color-coded sections, e.g., for nurse notes, treatment history or other forms and observations.

In parallel to the paper-based medical record, a number of Health Information System (HIS) are used in patient treatment and information retrieval and storage. These system include the Patient Administration System (PAS), the Radiology Information System (RIS), the Electronic Medication System (EMS), the Laboratory Information System (LIS), and the Blood Bank System (BBS). Clinicians access these systems via a system portal, which collates all systems into one access point. This portal is referred to as the EHR, but is in essence a set of non-integrated proprietary systems. Both the paper-based and electronic medical records are almost always used simultaneously and are of equal importance in patient care and treatment. But in

Figure 3. Hundreds of physical paper-based patient records are stored at the ward either inside the administration office or in the storage room (see Figure 1).

order to have electronically stored information 'ready-at-hand' during, e.g., the ward round, information like lab results and radiology examinations are printed from the RIS and LIS systems and added to the physical plastic binder by a secretary – a strategy which has also been documented in many other CSCW studies (e.g., (Berg, 1999; Schmidt et al., 2007)).

In the hospital, the general workflow surrounding the paper-based medical records is primarily managed by the ward secretaries and the nurses. When a patient is admitted to the hospital, the ward secretary locates the patient's plastic binder. Most patients are readmitted to the same department and this 'home' department hence physically stores the record in the storage room (see Figure 3). However, if a patient was previously treated at another department, locating the record can be a rather cumbersome process. Once located, the referral letter (e.g., from the GP) is added to the binder. If a new patient with no prior record is admitted to the ward, a new record in a plastic binder is created. The record is placed inside the nurse station the day before 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. Once the daily treatment and care of the patient has ended, 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. Once the patient is discharged from the department, the paper-based record is finalized and stored at the ward. This implies that hundreds of records are archived at the department, as shown in Figure 3.

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 notes collected in the plastic binder, as well as the information located in the EHR. As a consequence of having medical records both on paper as well as electronically, 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 4, both the paper and digital information are of equal importance and are thus often used simultaneous.

Figure 4. Clinicians are using both the paper-based records and the EHR to lookup and update patient 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 plastic binder. 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.

4. Collaborative Affordances of Medical Records

In a hospital setting, several studies have highlighted how the medical record is not just a record but plays two roles in work practice; they accumulate information while also coordinating collaborative activities and as such "affords the handling of more complex work tasks" (Berg, 1999)[p. 373]. Medical records, thus, hold different collaborative affordances as introduced above. This section will describe how medical records as used in hospitals posses physical properties that affords and enables smooth collaboration in work, i.e. collaborative affordances as defined above. This analysis builds on the

Table 1. Four basic collaborative affordances.

	Affords the ability to...	*Examples*
Portability	...physically carry, share, position, and use paper-based artifacts in different places.	Bringing printouts to a meeting; Carrying the medical records around during the ward round.
Collocated Access	...simultaneous and collocated reading, annotating, and updating.	Reading and annotating case documents during a review meeting; Shared reading of a patient record during a medical conference.
Shared Overview	...collectively create an overview of the content of paper-based artifacts.	Breaking open the case binder and putting it on the walls of a meeting room; Spreading out patient charts on the patient bed during the ward round.
Mutual Awareness	...signal and monitor information between users.	Positioning of air traffic control strips to signal flight status updates. Monitoring of a tray for patients to visit during the ward round.

field study of the use of paper-based and electronic medical records at UHC, while also drawing in many of the CSCW studies of medical work in hospitals (as e.g. summarized by Fitzpatrick and Ellingsen (2013)). Specifically, we have identified four types of Collaborative Affordances, which play a central role in the coordination and collaboration around medical records. These four collaborative affordances are summarized in Table 1. Let us consider these in turn.

4.1. PORTABILITY

Portability, the ability to carry, maneuver and navigate, is an important affordance of paper (Sellen and Harper, 2003). But just like portability is an important affordance for individual use of paper, portability may also affords collaborative actions. As also pointed out by Sellen and Harper (2003) the portability of paper allows people to bring it to, e.g., a meeting for sharing and collaboration. Moreover, the portability and lightweight nature of paper allows people to use it in more ad-hoc non-office settings for social and collaborative activities. Examples include the real estate broker bringing paper-based sales portfolios when meeting with potential buyers at the property; students bringing scientific papers and notes for group discussion at a coffee shop; and the engineer bringing large blueprints of a building to the construction site for discussion with the construction workers.

Medical work in hospitals is inherently nomadic (Bardram and Bossen, 2005a), which implies that clinicians and the tools they use move around

inside patient wards, between departments, and throughout the entire hospital. Mobility in hospitals is intrinsically tied to collaboration as clinicians move from one collaborative setting to another. For example, the ward round is typically done by a team of 1-2 physicians and 1-2 nurses; medical conferences for radiology, laboratory, and pathology are done at the different departments situated around the hospital; and physicians need to move between bed wards, emergency departments, and their offices. Therefore, in a hospital setting the portability of paper-based medical records is a central reason for its success in mediating cooperative medical work. As argued by Østerlund (2008), the paper-based medical record 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.

The paper-based medical record used at the UHC departments has evolved to fit this nomadic nature of medical work and it travels across the entire hospital. As such, the paper-based medical record affords portability since it is designed and packaged in a way that makes it easy for clinicians to carry it around during their nomadic work, such as bringing it on wards rounds, and to medical conferences and team meetings. The plastic binder affords this mobility since the binder wraps and hold the different paper documents inside the binder, it makes the record robust and durable in handling, and makes it resistent to wear, dirt, and fluids when it is taken to many different locations. Figure 5 shows a picture from a team meeting at one of the patient wards. Here we see the doctor engaging with the paper-based medical record for the patient being discussed, while information on the patient in the EHR is accessed from the desktop computer. Hence, the portability of the records allows — or affords — the doctor to bring, hold and use the physical records in its binder as a coordination token during a team meeting. In general, the portability of paper-based medical records is an important collaborative affordance, since this is essential to support the highly nomadic and collaborative work of clinicians, as they move around inside a hospital.

Investigating the use of the EHR at the hospital, it is evident that it supports mobile and concurrent medical work; it is accessible from desktop computers all over the hospital and it allows several users to simultaneously access patient data. As such, the EHR is addressing the core challenges of a paper-based record; the need for manually finding, moving, and updating the record, as well as the fact that a paper-based medical record cannot be accessed or used in different places by different clinicians concurrently. In terms of mobility and portability, the use of the EHR, however, also introduces a set of challenges since the systems were only available from desktop computers, as shown in Figure 5 and 6. As such, the EHR could only be used in places where a desktop computer was available, which primarily was in the nursing

Figure 5. A team meeting between a doctor and nurses in the nursing station. Both paper-based and electronic medical records are used during the meeting as each patient is discussed.

stations at the patient ward (see Figure 1). No computers were available in the patient rooms, for example, and since the EHR was not designed to run on mobile devices, it could therefore not be accessed during the ward round.

4.2. Collocated Access

One of the most prominent affordance of paper is that it supports quick and flexible navigation and simultaneous access to update multiple documents (Sellen and Harper, 2003). Paper and paper-based artifacts afford collaborative and simultaneous reading, reviewing, editing, and annotation in shared collocated situations such as meetings or conferences. For example, early work done by Sellen and Harper (1997) showed that printed paper-based versions of documents were preferred in 82% of all collaborative review processes, which shows how paper affords such collocated review meetings.

In collocated medical settings, such as a team conference, the medical record is often shared amongst the participating clinicians by taking out paper forms from the record binder and sharing this on a table. This allows all clinicians to concurrently read, annotate, and update information in the record. As such, paper and paper-based artifacts afford collocated collaborative actions where papers, records, articles, etc. can be shared amongst a set of people and be subject for concurrent reading and editing as part of a shared, collaborative

activity, such as performing a review, assessing a (patient) case; deciding on actions to take, or shared editing of a working document.

The studies of the use of the medical record in the UHC departments emphasize the collaborative nature of simultaneous access to records. Records were often used in a collocated setting in which typically a pair of a nurse and a doctor would access it simultaneously, and 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 (Figure 5) and the use of the record at the patient's bedside during a ward round. In these collocated situations, the micro-mobility of a paper-based medical record plays a central role. Micro-mobility is defined as *the way in which an artifact can by mobilized and manipulated for various purposes around a relatively circumscribed, or 'at hand', domain* (Luff and Heath, 1998). For example, during the ward round a physician and nurse jointly worked on a medical record by standing next to each other reading the record, handing over parts of the record to each other, and pointing out specific results. Moreover, the paper-based medical record also affords 'in-situ' annotation and documentation directly on the paper. For example, filling out health checklists, medicine admission schemas, and making nursing notes. Intermediate and working records and notes are made in the course of the working shift. Clinicians keep these documents to continuously gather information on the move that will later be transferred back to the official record (Østerlund, 2008; Fitzpatrick and Ellingsen, 2013). As such, these micro-mobility and annotation properties of a paper-based record affords clinicians to read, manipulate, arrange, annotate, and update the record during collocated collaborative sessions.

The EHR is designed as a multi-user, distributed information system and hence supports concurrent access in terms of both reading and writing of patient information. Moreover, since the EHR is not one system, but an aggregation of several systems each serving different purposes, it is possible for clinicians to work concurrently on a patient's information in the EHR sub-systems. Therefore, as shown in Figure 4, shared collocated access to the EHR is possible and is often done during meetings at the hospital. But since the EHR is only accessible from personal computers fixed to office desks, the affordance for collocated access is quite limited since it is designed only for personal use; the hardware (display, keyboard, mouse) of a personal computer is designed for one person only; the login to the operating system and the EHR is personal; and hence only one person can access the record on the computer at a time. Moreover, there is no way to align what patient is being looked at in the two systems; for each patient the right paper-based records needs to be found and the relevant patient and his or her data needs to be looked up in each of the relevant EHR sub-systems, like the HIS, RIS, and LIS systems. As such, the EHR to a very limited degree supports — or affords — simultaneous shared access to medical records. Therefore, our

study, in line with many others, found that clinicians often used '*working records*' (Fitzpatrick, 2004) and *transitional artifact*s (Chen, 2010) as a co-ordinative reflective tool to bridge the gap between day to day work in the hospital and managing the EHR.

4.3. Shared Overview

Overview of a case often require aggregation, re-organization, and alignment of a wide range of more detailed information. Such overview can be achieved by creating dedicated overview charts and documents, which re-represent and arrange information for better overview. Since paper affords reading across multiple documents at once, it is particular useful for creating an overview of, e.g., a business case by taking documents out of the binder and spread it out on a table (Sellen and Harper, 1997; Sellen and Harper, 2003). This also extends to a collaborative setting, in which documents in a case file or a medical record can be taken out of the binder, spread out on a table, and can be re-organized and realigned for all participants to get a shared overview. This overview is shared in the sense that it is collectively created and collectively used, and thereby collectively constructed and understood by the people involved in its creation and use.

The collaborative affordance of shared overview refers to the physical properties of an artifact that allow for collectively building and sharing an overview. For example, when collocated cooperating clinicians want to get an overview of a patient case, it is a common approach to 'break open' the paper-based record by taking out essential paper charts, curves, schemas, forms, etc. from the plastic binder and spread them out on, e.g., a desk or even in the patient's bed (Bossen and Jensen, 2014). As such, binders holding paper-based records hence supports — or affords — clinicians in achieving a shared overview of the medical situation at hand.

Figure 6 shows a situation from one of the UHC patient wards in which a doctor and nurse have 'broken open' the record. In this specific case, a doctor and nurse engaged in an ad hoc meeting to discuss a patient case for which they need to access the paper documents in the patient record. The doctor and nurse jointly break open the record and divide the relevant documents between them. The nurse is presenting and discussing the Early Warning Score (EWS) assessments that were done during the earlier shifts, while the doctor is inspecting the blood test. Together, this information is core to get an overview of the status of the patient, which is achieved by putting the EWS chart next to the list of blood test results. By having this overview, the doctor realizes that the last lab results are missing, and as shown in Figure 6, he phones the lab directly to inquire about the status. The studies of the paper-based medical record showed that this creation of an overview is primarily a collaborative effort, and that the binder with its ability to take

Figure 6. A doctor and nurse breaking open the patient record and distributing the relevant documents among them.

out the individual documents affords the creation of a shared overview by aligning different documents. On the other hand, this alignment and creation of an overview is an entirely manual process and needs to be redone at every meeting, conference, or ward round.

Hence, 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 paper-based record, as well as the information located in the EHR and its different sub-systems. The EHR supports a more automatic aggregation of information to provide an overview of a patient's status. For example, blood test results were summarized and visualized in different tables and graphs in the LIS system, and the latest prescriptions for a patient were highlighted and put on the top of the medication list in the EMS system. The EHR and its sub-systems did not, however, support ways for clinicians to create their own overviews.

Since patient information was residing in both the paper-based and the electronic record, both the paper and electronic records are of equal importance and are thus often accessed simultaneously in order to create a shared overview. This is shown in Figure 4 in which the paper-based record is spread across the table and used by one nurse and the doctor, while two nurses in the background are looking up information in the EHR on the computer. As such, each time a patient case was discussed, significant effort was put into collation and alignment of medical information from several sources to get

a comprehensive overview of a patient's medical state. The main challenge of the EHR was, however, that it was comprised of several separate medical systems and there was no way to get an overview of patient information across the different sub-systems on one computer. Hence, there was no way to create an overview of a patient case in the manner that was done by 'breaking open' the paper-based record, unless several computers with separate displays were used access the different sub-systems.

4.4. Mutual Awareness

Several studies in CSCW have pointed out that paper and paper-based artifacts play a central role in coordinating actions amongst collaborating actors. As summarized by Sellen and Harper (2003) (p. 144), an important affordance of paper is its ability to 'render action visible to others'. By placing, annotating, or positioning paper-based artifacts in certain ways, one actor can displays his or her actions, which then becomes visible to others in the same location. For example, workplace studies of air traffic control rooms show that the use of paper flight progress strips makes the activities of individuals visible to others, as these strips can be positioned in various ways to signal important changes to information or status (Mackay et al., 1998). Similarly, in a hospital domain, medical records are often placed in different places to reveal status information inside a patient ward; if the medical record is placed on a particular shelve, it is ready for archiving and if it is positioned in the tray on the left hand side of the secretary's desk, then the record is ready for use during the ward round. As such, paper-based medical records are extensively used in achieving workplace awareness in a hospital setting (Bardram and Hansen, 2010; Schmidt et al., 2007). Hence, physical placement, orientation, and manipulation of an artifact is key in both providing an awareness of the status of work as well as in signaling status changes or work to be done.

Looking specifically at paper, it is not only easy to annotate and manipulate, but paper also provides an intrinsic historical account on these actions or changes (Sellen and Harper, 2003). Since such historical accounts and traces reflects changes to the object of work, they may afford collaborative actions. For example, when a nurse sees that a prescription of medication for a patient has been added to the medical record by the doctor, the nurse knows that s/he can now take over and administer the drug to the patient. As such, physical and digital properties of an artifact may afford collaborative teams to maintain a mutual awareness of the progress of work.

Our study of the use of the paper-based medical record verifies prior findings that records are central in non-verbal coordination of work in a hospital ward. The physical placement and positioning of records often reveal status information and is used to signal and draw attention to important matters. For example, the record shown in figure 7 has deliberately been placed open

on the desk by a nurse to signal to the doctor that the paper forms on top should be inspected and validated. Similarly, a paper-based record is often placed in the patient's bed in way that it is visible from the hallway. This is a signal to the porter that this patient is ready for being transported, e.g., to surgery. This phenomenon of signaling through document placement has also been observed in many other studies of medical work (e.g. (Harper et al., 1997; Bardram and Hansen, 2010; Bång and Timpka, 2003; Schmidt et al., 2007)), and Schmidt et al. (2007) argue that *"coordinative action by means of spatial arrangements of items, on surfaces or in real space, is prevalent"* in medical work and thus constitutes a 'higher-order' practices.

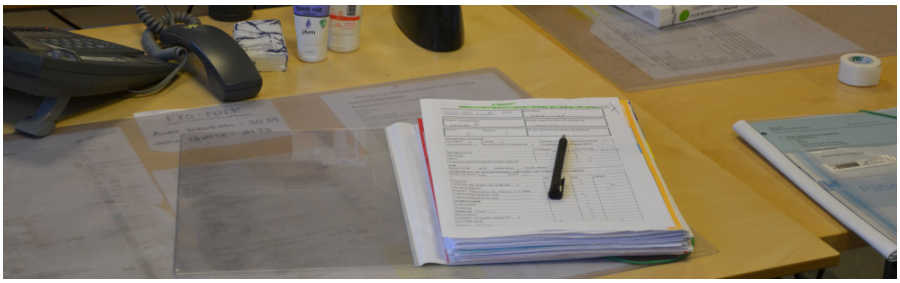

Figure 7. The placement of a paper-based record (e.g., placement on a specific desk, spatial orientation, or opening the record) is used to signal information or status changes to other clinicians.

The EHR, on the other side, is not to any significant degree designed to support – or afford – mutual awareness in clinical work. There is limited support for making up parts of a medical records for other to pay attention to, and there is very limited support for, e.g., being notified when a patient's data or status is changed. Other studies have similarly revealed the loss of coordinative properties of paper-based medical order after the adoption of electronic systems and how different workarounds are created to address such problem (Zhou et al., 2011). Such workarounds include assigning a clerk to monitor new orders in the Computerized Prescribed Order Entry (CPOE) system. In our study, we found similar 'monitoring' tasks in which secretaries and nurses on a regular basis would go and check for updated information on e.g. radiology or lab tests in the EHR. However, in our study we also observed that one way of addressing this 'invisibility' of important events in the EHR was a clever us of the the printer in the LIS system. This system was configured to print out the test results of a blood test on the printer in the ward in which the patient is admitted. In this way, the printing of a test result on the printer was a signal from the LIS system that a blood test result was available, and the printer then became a mechanism for coordination.

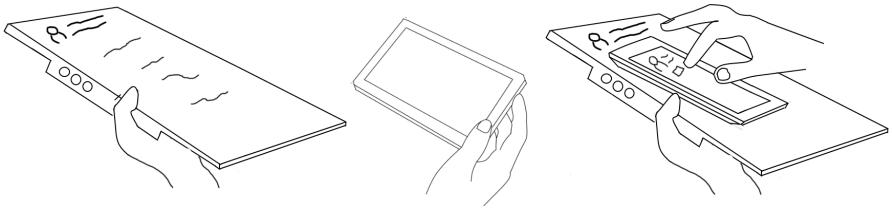

Figure 8. The HyPR medical record concept consisting of the HyPR binder (left) and a tablet computer (middle), which can be combined into a hybrid record (right) that uniquely combines the paper-based with the electronic medical record for a specific patient.

5. Designing for Collaborative Affordances

The UHC study shows how paper-based and electronic medical records to different degrees support and afford collaboration. When designing technologies for use in a collaborative setting, collaborative affordances becomes part of such technologies. To illustrate this, this section presents the design case of the HyPR record. The goal is to present an illustration of how the concept of Collaborative Affordances translate from mundane paper-based artifacts to advanced digital technology and seeks to understand how the four collaborative affordances as observed in the field study translate into the HyPR approach.

5.1. Design Study of the Hybrid Patient Record

In order to provide a technical design to mitigate the challenges of aligning and configuring paper-based and electronic records, the notion of an augmented hybrid patient record (HyPR) have been proposed (Houben et al., 2014a; Houben et al., 2015). Figure 8 and 9 shows the HyPR medical record. It consists of the HyPR binder, which is designed to replace (or 'augment') the existing plastic binder used for collecting and 'binding' all paper-based material in a medical record. The HyPR binder embeds electronics that supports location tracking, unique identification using Near-field Communication (NFC), and notification through colored light and sound.

Figure 9 illustrates how the HyPR binder contains all paper-based material in a patient record (just like the plastic binder). The HyPR binder embeds a unique id, which can be associated with a specific patient in the EHR. When placing a mobile device, such as a tablet computer or a smart phone, on top of the binder, the mobile device detects the binder's unique id (using NFC). The HyPR systems software on the mobile device reads this unique id and displays the patient information in the EHR system on the mobile device. In this way, the mobile device shows patient information in a context-aware manner (Bardram, 2004). Once a mobile device is paired with a HyPR binder,

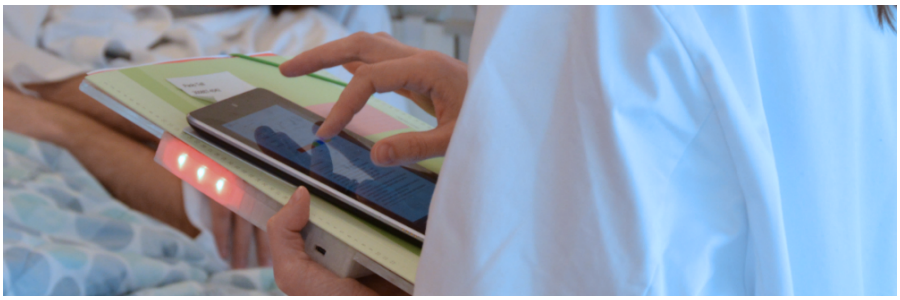

Figure 9. The HyPR binder augments the paper-based record with support for location tracking, NFC technology that uniquely identify the medical record, and notifications via color and sound. Clinicians can pair a tablet computer with the HyPR binder, and the tablet will then display the digital information associated with the patient.

they remain paired until the mobile device is paired (i.e., put on top of) with another HyPR binder. Hence, once paired, the mobile device can be removed from the binder and used next to the binder and even handed over to another clinician.

Notifications are supported by light in terms of the array of LED lights on the side of the binder and via a small buzzer for sound notifications. Sound and light notifications 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. It can also be used to locate a specific record in a huge pile of records as shown in Figure 3 by 'pinging' a record and asking it to buzz or blink. The HyPR system software provides an interface on the mobile device to set the light of the HyPR binder and to sound the buzzer. Finally, the HyPR binder also embeds a location tracking tag that enables room-based location tracking of the physical paper record. This allows clinicians to find the paper-based record when missing. The sound and/or light notification can be used to locate a specific record amongst many inside a room.

The HyPR approach supports flexible and dynamic configuration of paper and digital information, which allow for a gradual transition back and forth between paper and digital records. For example, paper-based forms can be digitized and stored in the EHR or digital material can be printed and stored in the Paper Medical Record (PMR), all of which can be handled by the HyPR approach. As such, the overall design goal of the HyPR approach is to create a transitional artifact (Chen, 2010) 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 (Houben et al., 2014b) required to use and setup this dual record.

5.2. EVALUATION

The HyPR system was evaluated in a clinical simulation. A clinical simulation is a method frequently applied to train and educate clinicians in critical clinical scenarios, such as surgery, medicine prescription, and emergency cases. It has proved very efficient and reliable for the initial phase of training and assessment of clinical staff (Ahmed et al., 2011) and has lately been used also as a method for testing clinical systems with representative users doing representative tasks, in an ecologically valid setting (Kushniruk et al., 2013).

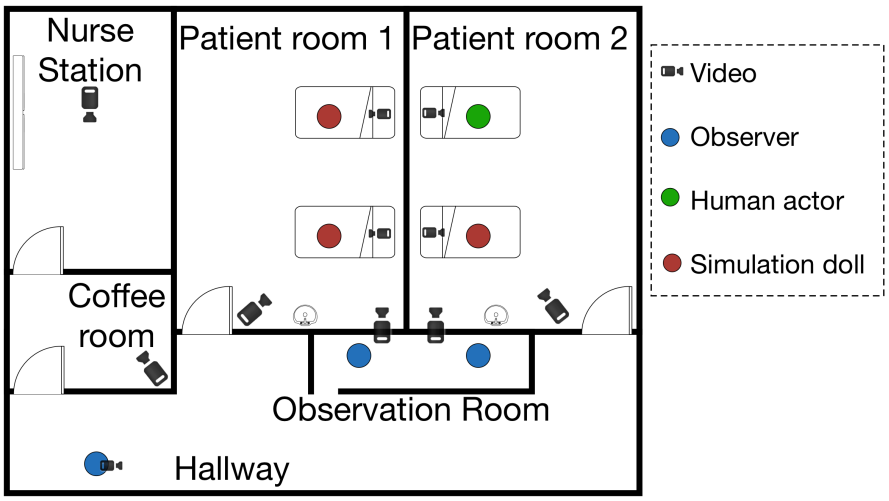

Figure 10. The simulation setup was comprised of a medical ward with five zones including two patient rooms, a nurse station, a coffee room and a hallway. The simulation facility is equipped with hidden cameras and an observation room behind a one-way mirror. The simulation included three simulation dolls (patients) and one human acting as a real patient.

The study[4] was conducted in a 1:1 clinical simulation and training facility located in a large university hospital. This simulation facility supports the simulation of different hospital departments ranging from patient wards to surgical and emergency departments. For our study, we set up the facility to be identical to a fully equipped patient ward with two patient bed rooms. Figure 10 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 10, 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. The study applied a scenario-based evaluation of the HyPR approach. The following three scenarios were drawn directly from the field study and revolved around interacting with the patients and/or assessing patient case:

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 EWS to describe their current status.

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

Lost Record — Clinicians were asked to find a number of medical records, which, after a shift change, were not at their usual place.

Participants were then asked to perform all three scenarios. 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 evaluation was 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 field studies of medical work emphasize its highly collaborative nature – involving both doctors and nurses – the scenarios were done in pairs of two clinicians from the same department.

A list of patient cases with realistic names, backgrounds, social security number and medical background was compiled for the study. The medical record 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 equipped the simulation facility with the Sonitor[5] ultrasound location tracking system in all rooms. Since there was no open access to the medical information systems used in the hospital, we implemented a simple EHR application to be used in the simulation. This application was running on the tablet computer and contained all patient cases with a set of medical entries such as blood test results, continuation records and nursing notes.

5.3. Collaborative Affordances in Hybrid Medical Records

The concept of Collaborative Affordances was not developed or materialized at the time the HyPR technology was designed; as outlined above, the core design of the technology is to help align paper-based and digital medical information on a patient and make this easy accessible during everyday care and treatment at the hospital. But by reflecting on the design of the HyPR record through the lenses of the Collaborative Affordances concept, we can see how this technology has different collaborative affordance which helps support collaborative work, which again helps mitigate some of the limitation of the paper-based and electronic medical records. This section provides an analysis of the HyPR record according to the collaborative affordances of portability, collocated access, shared overview, and mutual awareness. Table 2 summarizes the collaborative affordance of all three types of medical records: paper-based, electronic, and hybrid medical records.

5.3.1. *Portability*

The HyPR record was designed to maintain the portability affordance of the binder used for the paper-based record in combination with a portable EHR running on a tablet computer. During the medical simulation study, it became evident that the HyPR record was carried around in the simulation facility just like the paper records were. This can be seen in the video fragments in Figure 11 where two clinicians during a ward round are visiting two patients while carrying two HyPR records; one for each patient.

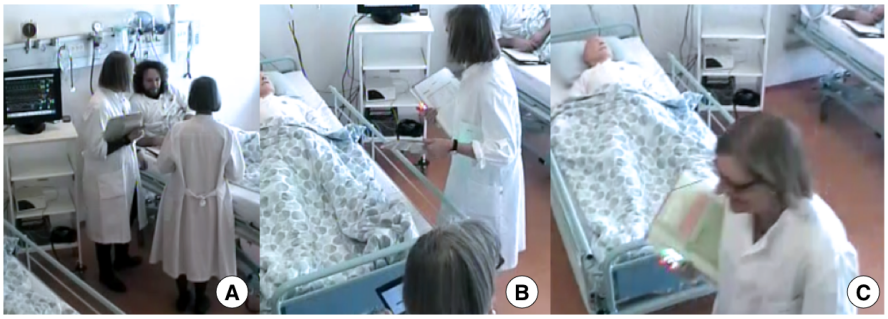

Figure 11. Clinicians using the HyPR record during the ward round. Visiting the first patient using his record (A); visiting the next patient directly using his record (B); and leaving the bed room (C).

The study showed that although the HyPR in its current state is relatively heavy and bulky due to the sensor platform, the technology still affords portability which helps reduce the amount of mobility work (Bardram and Bossen, 2005a) required to configure the work setup. The portability affordance of the HyPR is much closer to that of a paper-based medical record, specially if compared to other approaches that attempt to include mobility use for the

EHR (e.g., Computers on Wheels (COW) (Tang and Carpendale, 2008)). As such, portability as a collaborative affordance was found in both of the studies; the paper-based record as well as the HyPR record were carried around and used during collaborative care activities (e.g., ward rounds) and this portability of the record helped clinicians to jointly accomplish their work while moving around (Luff and Heath, 1998).

5.3.2. *Collocated Access*

The HyPR device was originally designed to address the significant work associated with aligning and collating paper-based medical records with information in the EHR, as evident in Figure 4. The evaluation of the HyPR device showed that record alignment and collation no longer took place at the desk in the nursing station, but was be done by clinicians while working closely together collocated inside the bed ward. Figure 12 shows how the HyPR record was taken to the patient's bedside and used in a collocated collaborative setup. The clinicians first pair the paper and digital record to get an overview on the patient case (A). Then they jointly inspect both the paper and digital information and explicitly check if any new observations were added either to the paper-based record or to the digital record (B). 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 (C).

Figure 12. 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).

As such, both the paper-based and hybrid record — but not the EHR — affords collocated access and use; paper-based schemas, forms, notes, etc. in a paper-based record allows clinicians to simultaneously access, read, manipulate, and update them during, e.g., a ward round or in a team meeting. The HyPR record extends this simultaneous access to also include the EHR by allowing clinicians to align and inspect both records in parallel.

5.3.3. *Shared Overview*

During the study of the HyPR record, we observed that clinicians would often spatially organize information that was needed to better get an overview of the case. For example, the video fragment in Figure 13 shows two clinicians doing a ward round while using the patient bed to organize and collate both the paper forms stored in the paper-based part of the recored as well as information accessible on the tablet computer. Figure 13 shows how the clinicians 'break open' the paper-based record and collaboratively build an overview of the case by spreading out the paper-based material in a patient bed. In parallel, one of the clinicians uses the tablet computer — which is also 'broken loose' from the HyPR binder —- to find relevant information in the EHR which makes up a part of the overview. 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.

Figure 13. Two clinicians are 'breaking open' the medical record by spreading out paper-based material on the patient bed while simultaneously accessing the EHR on the paired tablet computer (A-B). Then the tablet computer is used to add content to the digital record (C).

5.3.4. *Mutual Awareness*

When studying the use of the HyPR device in the clinical evaluation, it was observed that it supports – and affords – using it for building and maintaining mutual awareness in work. Placement of the HyPR combined with the color light is used for deliberately signaling status information. For example, the signaling strategy of placing the medical record in the patient's bed, as observed during the field study, is adopted and enhanced when using the HyPR record. The clinical simulation showed that clinicians carefully consider location and orientation when placing the HyPR. In the patient rooms, for example, clinicians often positioned the records in such a way that the lights were visible from the hallway. This approach was adopted so that clinicians could easily glance inside the room and check if the colored light has changed, or if there is a new message regarding the patient. Clinicians consid-

ered 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.

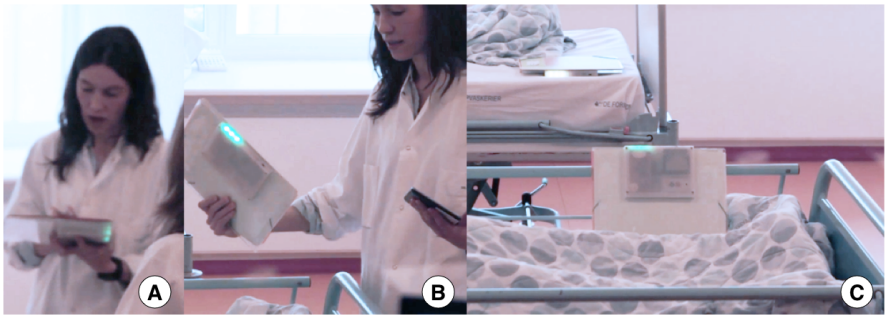

Figure 14. The clinician uses the record (A), checks if the colored light matches her assessment (B) and places both records in such a way that they are visible from the hallway (C).

Figure 14 shows a video fragment of a nurse using the HyPR for signaling purposes. After finishing assessing the patient case (A), the nurse double-checks the color to see if it matches her assessment color (B) and then positions the record to allow for visibility from the hallway (C). Interestingly, this positioning of the two records is done differently depending on the location of the bed in the patient room. As seen in Figure 14(C), when glancing inside the room from the hallway, the record on the second bed in the background is positioned differently than the one on the bed in the foreground. This is done because the bed in the foreground is closer to the door, 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.

In summary, the properties of medical records can to a high degree support – and afford – mutual awareness that helps coordination in a clinical work setting. The physical properties of the paper-based medical record allow for placement in different locations and positions — something that the EHR does not affords. The HyPR continues to possess the original collaborative affordances of the paper binder, while adding new physical properties for creating mutual awareness. The colored lights, for example, are physical properties that allow clinicians to externalize work practices into signals that help them to optimize internal coordination at a hospital ward.

Table 2. Collaborative affordances of the paper-based, electronic, and the hybrid medical records.

	Paper-based record	*EHR record*	*HyPR record*
Portability	The record in its binder is easy to pick up and carry along while clinicians move between different places in the hospital to meet and attend the patient. The size, weight, and the collection of paper artifacts inside the plastic binder affords clinicians to bring it with them to collaborative engagements.	In the hospital of this study, the EHR could only be accessed from desktop computers, which does not affords portability of the record. Instead, collaborative session involving the EHR was often done in an office in front of the computer, as shown in Figure 4.	The HyPR device, including the HyPR binder holding the paper-based part of the record as well as the HyPR tablet computer running the EHR, afford portability. Clinicians carry around and use the HyPR record in a similar manner as the paper-based record during mobile work configurations.
Collocated Access	The record can be shared between collocated cooperating clinicians and the paper documents and forms allow for 'in-situ' and simultaneous sharing, reading, annotating, and form filling.	As a client-server system, the EHR supports simultaneous access to a patient's medical record from different Personal Computers (PCs). However, since a Personal Computer (PC) can only be operated by one user at a time, the EHR provides very limited support for collocated access to a patient's record.	The HyPR device affords collocated access by supporting easy pairing of the paper record with multiple tablet computers, each of which can be used to simultaneously access a patient's EHR.
Shared Overview	The paper-based medical record allows clinicians to 'break open' the record and spread out paper documents, charts, forms, graphs, etc. on a table or a patient bed. This affords clinicians to collaboratively create a shared overview of the patient's state.	The EHR allows clinicians to access the patient's data from several PCs simultaneously. However, since the EHR was made up of non-integrated individual systems, there was little support for creating a shared overview in the EHR.	The HyPR allows clinicians to 'break open' both the paper-based record, as well as the EHR. Several mobile computers can easily be paired with the HyPR binder, thereby allowing clinicians to create a shared overview of patient data from many sources.
Mutual Awareness	The paper-based record can be located, positioned, and annotated in a way to signal important changes to the status of the patient or workflow. This affords getting and creating a mutual awareness amongst collaborating clinicians.	The EHR provided little support for rendering actions visible to others, except for printing out lab test result on the printer at the ward.	The HyPR record possesses the collaborative affordances of the paper binder, while adding new physical properties for mutual awareness, including the colored lights and the buzzer.

6. Discussion

In this paper, we defined Collaborative Affordances as '*a relation between a [physical and/or digital] artifact and a set of human actors, that affords the opportunity for these actors to perform a collaborative action within a specific social context.*'. The studies of paper-based, electronic, and hybrid medical records have shown how these artifacts, in various ways, possess properties that to different degrees support and afford collaboration. In particular, these studies have revealed four such Collaborative Affordances; portability, collocated access, shared overview, and mutual awareness. These four collaborative affordances for the paper-based, electronic, and hybrid medical record are summarized in Table 2. As such, these studies have illustrated the concept of Collaborative Affordances as essentially shared perceptions of physical artifacts in work practices, which can be recognized by clinicians as possibilities for achieving joint work.

When designing technologies for use in a collaborative setting, collaborative affordances can be designed into such technologies. As an example, the HyPR technology embodies many of the collaborative affordances from paper-based records that foster cooperation among clinicians. The combined HyPR binder and the tablet computer affords portability which allow clinicians to take the record with them for collaborative sessions, like a medical conference or the ward round. The easy pairing of the paper-based and electronic records in the HyPR record affords collocated access to medical information, and multiple pairing of devices affords clinicians to build a shared overview during such collaborative sessions. The physical properties, including the size, light, and sound properties, of the HyPR devices affords clinicians to render actions visible for each other in order to maintain a mutual awareness during the flow of work. However, since the HyPR technology is deliberately designed to augment and hence extend the paper-based medical records, this technology in many respects gets several of its collaborative affordance 'for free'; the HyPR technology with its electronic binder to a large degree inherits the affordances of the paper-based medical record. Moreover, the HyPR record does not solve the basic problem of keeping the record up-to-date; there still has to be someone at the ward collecting and inserting paper-based documents in the binder.

Enhancing and utilizing physical properties of existing artifacts to facilitate collaborative affordances is one strategy. But collaborative affordance can also be designed into other kinds of technology. Looking, for example, at the EHR used at the hospital, it could be (re-)designed to afford collaboration to a larger degree. For example, by designing a portable version of the EHR, which is not tied to a personal computer on a desk, would significantly improve its affordance for use in collaborative settings throughout the hospital and its wards. This can be achieved by designing an EHR that can be used

from, e.g., a tablet computers, like in the case of the HyPR device. Such a portable EHR should then provide easy access to relevant clinical data in different usage situations and usage context, thus, minimizing the need for clinicians to manually look up relevant patient informations while moving around. As such, just like the HyPR tablet device shows the relevant patient records when paired with the HyPR binder, such a portable EHR should be context-aware and provide easy access to relevant clinical data in a specific clinical work situation (Bardram, 2004). Similarly, a portable EHR should support collocated access, thereby allowing collocated and collaborating clinicians to align and share patient information. One way of supporting this would be to have a context-aware portable EHR running on portable devices which could both sense and broadcast its current usage context, such as a patient identification. During the ward round, for example, this would allow a clinician using one tablet computer to 'pick up' the patient case shown on another collocated tablet computer. Such a context-aware portable EHR would also allow clinicians to 'break open' the record to a larger degree than the EHR enables them to do today. Multiple portable computers and even large wall-based displays (Bardram et al., 2006) can be used to show and align information from multiple sources and used for collocated decision making between clinicians. Finally, affordances for mutual awareness could be added to the EHR. The use of the printer in signaling the arrival of a lab test result is one simple, but yet prototypical, example of this. Since the use of colored lights and buzzers in the HyPR binder is still based on the assumption that one HyPR binder holds one specific patient case, this might not be directly transferable to an EHR based on tablet computers. However, signaling of changes in patient status is clearly something that an EHR and other clinical systems can be designed to support (Bardram and Hansen, 2010). One way of doing this could be to allow a tablet computer to be 'locked' (at least for a period of time) to a specific patient. In this way, status updates could be routed to this device, which then could blink, buzz, and signal changes. In this way, the physical and tangible properties of the tablet device would afford mutual awareness about the status of a patient. As such, medical records could be designed with the affordance of mutual awareness in mind, thus, providing clinicians with tools to configure awareness (Heath et al., 2002).

The list of collaborative affordance discussed in this paper is based on our study of the use of paper-based, electronic, and hybrid medical records in hospitals. This list covers, we would argue, a set of core collaborative affordances for many types of artifacts that play a role in collaborative work. If we, for example, take a look at another central artifact in a hospital, namely the omnipresent whiteboard, many studies have shown that such whiteboards have — what we have defined as — a number of collaborative affordances (Bardram, 2000; Xiao et al., 2001; Hertzum and Simonsen, 2015). Whiteboards provide collocated access to information; they clearly provide a shared overview;

and one of their key features is that they provide cooperating clinicians with mutual awareness of the flow of work. Whiteboards are, however, clearly not portable. But the lack of portability is actually one of the main challenges and drawbacks of conventional whiteboards since the whiteboard and its information is only available in the location, in which it is situated. Often significant effort is put into synchronizing the information on, e.g., a surgical whiteboard with clinicians who are in other locations, like the surgery room (Bardram, 2000). The lack of 'portability' of whiteboards — or rather the information on them — have been addressed through the design of synchronized digital whiteboards for clinical use, such as the AwareMedia system (Bardram et al., 2006). Hence, the Collaborative Affordances listed in Table 1 provides a good starting point. But this list is, however, not exhaustive and other physical and/or digital artifact may posses — or be designed to possess — other Collaborative Affordances. Similarly, the printer, which in our study was used to share the results of patient lab test, supports mutual awareness, collocated access by and shared overview as it is used as a central coordinative artifact in the patient ward. However, the four initial Collaborative Affordances introduced in this paper primarily focused quasi synchronous collocated interaction and collaboration, and do not consider asynchronous and remote collaborative scenarios. In these types of scenarios, other types of Collaborative Affordances could be discovered.

Although our application and example of Collaborative Affordances has been medical work in a clinical setting, we positioned Collaborative Affordances next to the classic Gibsonian Affordances (Gibson, 1977), Perceived Affordances (Norman, 1988) and discussed how they extend Social Affordances (Bradner, 2001) to include both recurring communicative and collaborative practices in work. The central differentiation between Social and Collaborative Affordances is that the latter focuses on how social perceptions can lead to joint work within a group. Artifacts and tools which possess such Collaborative Affordances within a socio-cultural frame, thus form a web of interrelated cooperative artifacts (Bardram and Bossen, 2005b). The concept of Collaborative Affordances focuses on the design of physical and digital properties of technology artifacts for close-knit team work in situations like the ward round and group meetings discussed above. For future work there are, however, opportunities to perform further analysis of how tools, artifacts and boundary objects are shared and used beyond group work. For example, Collaborative Affordances might be extended to explain bundles of affordances in a larger organizational structure (Strong et al., 2014), to understand the generative power or the 'politics' of artifacts within larger sociocultural context (Allen, 2013), and analyzing emerging work practices such as collaborative reification in clinical management of patients (Hardstone et al., 2004). Fundamentally, the concept of Collaborative Affordances is built on an inclusive interpretation of affordances that describes that while artifacts have

fundamental designed or natural perceived affordances, their interconnected use are determined by the sociocultural setting (Hutchby, 2001).

7. Conclusion

In this article, we introduced the concept of Collaborative Affordances to describe the physical and digital properties (i.e., affordances) of an artifact, which affords coordination and collaboration in work. Collaborative Affordances is based on the original definitions of Gibson (1977) and Norman (1988), and extends the work by Sellen and Harper (2003) on the affordances of physical paper. The concept of Collaborative Affordances is specifically targeted to understand how collaborative actions can be afforded by physical and digital artifacts in a specific socio-cultural context. Specifically, this paper identified four core types of Collaborative Affordances; portability, collocated access, shared overview, and mutual awareness. By building on extensive research and studies into the use of paper-based, electronic, and hybrid medical records in a hospital setting, this article made a detailed analysis of the four Collaborative Affordances in this setting. In particular, we demonstrated how the beneficial collaborative affordances of the paper-based medical record to some degree were transferred to the hybrid medical record, while also utilizing the advantages of digital technology. More generally, we argued that the concept of Collaborative Affordances may be used to design collaborative digital and hybrid technologies both in the medical domain but also in others. The detailed analysis of four main types of Collaborative Affordances in this article, is limited to the specific medical domain of hospitals. We would argue, however, that the concept might be broaden by identifying other collaborative affordances, potentially in other domains. Our future work includes further investigation in and development of Collaborative Affordances, and we invite others to join this effort.

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Notes

[1] This article is a revised and extended version of the Houben et al. (2015) paper presented at the 2015 CSCW Conference. The focus and contribution of the CSCW 2015 paper was a study of an evaluation of the HyPR technology. In contrast to the CSCW 2015 paper, this article focusses on the theoretical development and definition of the concept of Collaborative Affordances and presents a more elaborate and in-depth description of the empirical studies of the collaborative affordances of paper-based and hybrid patient records.

[2] Although Norman nowadays prefers the terms 'perceived affordance' (Norman, 1999) or 'signifier' (Norman, 2008) over affordance.

[3] The original concept of affordance as suggested by Gibson and further developed by Neiser was very generic and talks about the perception of an 'organism' which also includes primitive animals. The concept of Collaborative Affordances, however, only makes sense for humans as a collaborative specie. Furthermore, since the primary motivation of this concept, and this article, is to talk about design of digital technology, focus is entirely on collaborating human actors in a socio-cultural context.

[4] More detailed information about the study, the setup, and the methods applied are reported in Houben et al. (2015).

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

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