AnatOnMe: Facilitating Doctor-Patient Communication Using a Projection-Based Handheld Device

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ABSTRACT

In this paper, we explore the use of a projection-based handheld device to facilitate in-clinic doctor-patient communication. We present the user-centered design process used to understand the workflow of medical professionals and to identify challenges they currently face in communicating information to patients. Based on the lessons learned, we developed AnatOnMe, a prototype projection-based handheld system for enhancing information exchange in the current practice of one medical sub-specialty, physical therapy. We then present the results of a controlled experiment to understand the desirability and learning tradeoffs of using AnatOnMe to teach medical concepts on three potential projection surfaces – wall, model, and patient body. Finally, we present results of two expert reviews of the system.

Author Keywords

Pico-projector, handheld device, doctor-patient communication, healthcare, physical therapy

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors, Design, Experimentation.

INTRODUCTION

Patient compliance with medical treatments, such as self-administration of drugs and exercises, is essential to achieving successful health outcomes. Despite this, compliance remains an elusive goal. For example, studies have placed the rate of non-compliance with courses of treatment for chronic conditions at between 30% and 50% [13, 19]. Effective *doctor-patient communication* has been identified as one of the most influential factors to increasing compliance [15, 24]. Thus it is no surprise that doctor-patient communication has been the subject of a great deal of attention in medical literature as well as public policy over the last decade (e.g., [10, 11, 15, 21]).

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CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
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While doctor-patient communication is a nuanced and multifaceted pursuit [10, 15], a critical aspect is *information exchange* [15]. In clinics, information exchange typically consists of three components: *information seeking*, where doctors collect information to establish a diagnosis, *documentation*, where doctors record symptoms, diagnosis and treatment decisions, and *patient education*, where doctors impart medical information to the patient [10, 15]. Successful communication and ultimate compliance hinges on patient attentiveness and a sense of shared ownership achieved through effective information exchange, particularly effective patient education [8, 15]. Despite this, the field of Healthcare Information Technology has focused primarily on tools such as electronic medical and personal health records for documenting and retrieving information. Relatively little work has focused on the development of technologies which may facilitate in-clinic information seeking, documentation, and patient education.

In this paper, we present the design, development, and evaluation of AnatOnMe, a projection-based handheld device designed to facilitate medical information exchange (Figure 1). Adopting a user-centered design approach, we interviewed medical professionals to understand their practices, attitudes, and difficulties in exchanging information with patients, as well as to identify their workflow, tasks, and design requirements for a technology intervention. Through a continuous collaboration with domain experts, we iteratively developed an integrated solution for seeking medical information, photo and video capture of disease status and treatment plans for documentation, and a shared, interactive display to support patient education. AnatOnMe provides these features through the combination of com-

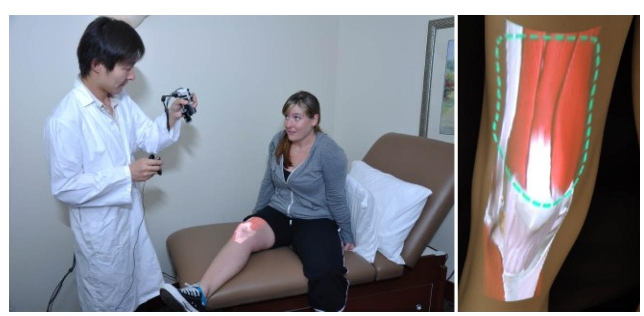

Figure 1: AnatOnMe in use in a simulated physical therapy consultation. The physical therapist explains a knee injury to his patient using on-body projection of medical imagery.

modity hardware, including a pico-projector, webcam, near-IR camera, and modified wireless presenter control.

Our goal was to produce a working prototype with the promise of facilitating in-clinic doctor-patient communication, with a particular focus on information exchange. Our main contribution is in laying the groundwork for inspiring and understanding the opportunities for the use of lightweight, handheld technologies in supporting such exchanges in clinical settings. Through the development and evaluation of a novel prototype, we demonstrate the affordances of projection as well as photo and video capture in flexibly supporting the key communication tasks in physical therapy visits. Finally, by conducting a user study and expert reviews, we establish that both doctors and patients perceive benefits of such technology, and demonstrate the potential of AnatOnMe for positively impacting information exchange. While improving doctor-patient communication is a broad goal that includes several interrelated factors, AnatOnMe contributes to the overall agenda by supporting the critical component of effective information exchange in clinical settings.

RELATED WORK

Three areas of related work are relevant to understanding and positioning the contributions of the present work. First, we will explore the area of computer mediated doctor-patient communication. Second, the area of augmented reality, with a particular focus on projector-based tools will be presented. Finally, a more general overview of the use of projection-based mobile devices will be presented.

Computer Mediated Doctor-Patient Communication

Doctor-patient communication has been a focus of research in the medical field. Ong et al. [15] presented a literature survey of doctor-patient communication, summarizing the key topics of information exchange, interpersonal relationship building, and shared medical decision making. It is from this work that we draw the three elements of successful information exchange, and we refer the reader to this work for a broader survey of the area. Here, we focus on computer-mediated in-clinic information exchange.

Wilcox et al. [23] noted that patients are frequently underinformed and unclear about their own hospital courses. They proposed a design for patient-centric information displays to deliver useful information to a patient during an emergency room visit, and found responses from patients, family members, and hospital staff to be highly positive.

Previous work has also demonstrated that technology can positively impact communication during clinic visits. For example, Hsu et al. [9] conducted a longitudinal study to evaluate the impact of in-room access to electronic health records (EHRs) on doctor-patient interactions during outpatient visits. They found that the presence of the tools appeared to have overall positive effects on interactions between the two parties, including greater patient satisfaction with communication of medical issues and comprehension of decisions made during the visit. While, importantly, Hsu's study found no evidence that the technology intervention worsened interpersonal satisfaction measures, a similar study by Frankel et al. [7] warned that in-room EHRs can undermine the communication between patients and doctors with already-weak interpersonal skills. Towards addressing such effects, Choe et al. [6] studied current strategies that doctors use to express empathy during a consultation, and presented design ideas that may foster relationship-building. For example, they suggested the use of handwritten notes for sharing and discussing information, a shared place to sketch a drawing, and orienting doctors' workspaces toward patients. Our design of AnatOnMe incorporates several of these recommendations, as well as those drawn from the clinic-base fieldwork of Unruh et al. [22] that suggested the need for shared information spaces and support for meeting capture and reuse.

While the widespread availability of computers and internet offers patients easy access to educational materials beyond the clinic, relatively little attention has been paid to designing technologies that help doctors communicate educational concepts to patients during a consultation. A notable exception is the research of Bickmore et al. [3] which replaces a human doctor with a conversational agent for imparting educational resources to low-literacy patients. With AnatOnMe, we explore how technology might be used to enhance the patient education process in real-time during face-to-face doctor-patient communications.

Medical uses of Augmented Reality

One use of the AnatOnMe system is the projection of medical content directly on the body (Figure 1), providing an augmented-reality view for both patients and doctors. See-through displays have been explored to enable augmented reality (AR) visualizations for medical procedure training and education [2, 14, 18]. These systems were designed to provide an enhanced experience to a single user, necessitated by the use of a head-worn display. Yet for doctor-patient communication, face-to-face dialog and a shared information space are essential elements [6, 10, 15]. In the present work, we seek to leverage advantages of AR, but use a projection-based approach to facilitate communication between the two parties via a shared frame of reference.

Projection-Based Handheld Devices

With the recent trend of miniaturizing projection technology, a number of research systems have explored the use of a mobile handheld projector to create flexible shared interactive spaces [4, 20], and for spatially augmented reality [17]. Compared with traditional fixed installations, handheld projectors are particularly suitable for applications where portability, mobility, and flexibility of projecting and interacting with virtual information are preferable. Meanwhile, they preserve an important benefit of projection, which provides a shared visual surface for supporting face-to-face dialog among multiple users (e.g., [4]).

Before we began the process of selecting technologies, we first sought to understand the barriers to effective information exchange between doctors and their patients.

MEDICAL PROFESSIONAL INTERVIEWS

In order to arrive at design requirements for an assistive tool, we interviewed a variety of medical doctors to gain an understanding of their work practices, attitudes, approaches, and difficulties in communicating information with patients and supporting patient uptake of medical regimens.

Interviews: Medical Doctors

The doctors we interviewed spanned several medical subspecialties. These included a primary care physician from a large local managed health organization, a hospitalist from a local hospital, an internist from a large local private medical service business, a physiatrist in private practice, and an emergency room physician from another hospital. Clear inhibiters to improving doctor-patient communication emerged: time, incentives, and negative prior experience.

Time: The Hidden Costs of Communication

As has been discovered by previous researchers, medical doctors of all stripes are notoriously short on time [12]. In fact, all but one of the MDs we interviewed cited the high cost of spending time with a patient on communication. Each stated their preferred approach is to prescribe a course of treatment as quickly as possible, while spending minimal time educating patients. The only exception to this was the internist employed in the private medical business, which commercially distinguishes itself by providing long consultations with each patient (at a significantly higher cost).

Incentives: Disconnected from Health Outcomes

While the cost for communication is high, it can be offset if there is sufficient return on that investment to the medical professional. Since research has shown the value of effective doctor-patient communication on health outcomes [13, 15, 19], we believed that if we could provide a tool to increase the benefit of the time spent on communication and information exchange, medical professionals would see the value. We were surprised to learn, however, that each of the MDs we interviewed was disconnected from health outcomes. While each appreciated the moral value, it was also clear that their incentives were tied to the quantity of patients they treated and procedures administered, rather than to the effectiveness of that treatment.

Negative Prior Experience: Technology, Patient Compliance

Another inhibiter was the MDs' prior experience with new technologies and with patient compliance. On the technology side, each had experience with new technologies which slowed their process, were unreliable, or were introduced and later unsupported. This led to an extreme reluctance to participate in the development of new technologies. In the case of patient compliance, each doctor had experiences which echoed the findings cited earlier: that a very large number of their patients simply failed to follow the course of treatment they prescribed. This prior experience led generally to pessimism with motivating patient compliance, rather than to an eagerness to solve the problem.

While each of these findings points to goals for the prototype, it was clear that MDs were not the ideal partners for a user-centered design process. Although our goal was to facilitate information exchange and improve doctor-patient communication in general, we sought a sub-specialty with an ingrained emphasis on patient communication in order to ease our process and later extend our findings to the broader field. We identified two factors for selecting a subfield for study: first, a focus on education as a part of current practice; and second, a measurable benefit to practitioners for an improved patient condition, such as patient satisfaction or justification for services rendered for billing purposes. We found several such disciplines, but focused on one: physical therapy, which had the greatest emphasis on the role of communication [5, 8]. Note that we did not focus on patients in the design process of the early prototype because we learned that patients always want to be better informed [15, 23], but that doctors are the ones critically constrained by time, cost, and acceptable technologies. And since fitting into doctors' workflows is crucial to any tool's adoption, we targeted doctors as the primary "user" of our system.

Interviews: Physical Therapists

AnatOnMe was ultimately created in a user-centered design process in collaboration with two physical therapists (PTs). To begin, we conducted structured interviews with each in order to understand their workflow, extract tasks in exchanging information with patients, document challenges they face with patient compliance and their strategies for improving compliance, and identify design requirements for a technological intervention. The two PTs we recruited were the director of physical therapy at a large local fitness facility, and the founder of a small specialty practice, both of whom manage a staff and also continue to practice physical therapy. We believed that focusing on managing practitioners would provide useful perspective, and that this perspective would be somewhat different in an established large-scale practice and in a smaller, more specialized one. The two PTs were compensated financially for their time.

Through our initial interviews, we learned that a typical workflow of a physical therapy consultation consists of phases roughly equivalent to the three components of typical information exchange described in [10, 15]. These are *information seeking* in the form of injury assessment, two forms of *education*—medical context and treatment—and *documentation* of the injury status and progress.

Information Seeking: Injury Assessment. A PT starts with establishing an understanding of a patient's level of injury by asking her to perform several Range of Motion (ROM) tests. For example, Carpal Tunnel Syndrome (CTS) is a common occupational wrist injury for which patients often seek the help of physical therapy, either in lieu of surgery or for post-surgery recovery. Patients suffering from CTS typically present limited ROM in their wrist, and upon consulting a PT, they will be asked to perform a series of wrist flexion, extension, and rotation procedures in order for the PT to obtain quantitative measures on the severity and nature of the condition.

Education: Medical Context. A PT then educates the patient with information about their condition. The PT commonly teaches the relevant anatomy and bio-mechanics of the affected area, the signs and symptoms of the injury, rationale of treatment, and physical therapy goals. Although this education does take time and effort, it is an integral part of physical therapy consultation. It is believed that improving patient knowledge of their bodies and the underlying mechanism of an injury helps patients better comply with a treatment plan, leading to satisfactory outcomes.

Education: Treatment. A PT prescribes a treatment to the patient, nearly always in the form of exercises to perform, and instructs the patient on the exercises' forms and functions. Education about exercises often includes both demonstration by example and adjustments to correct the patient's form, as correct form is important to achieve the desired outcome. An initial physical therapy consultation typically concludes with the PT providing the patient with instructions on the exercises to perform at home. These instructions can take many forms, including verbal descriptions, handwritten notes, or generic exercise sheets that contain sketches annotated with patient-specific details.

Documentation. Three types of documentation are produced by a PT. The first is a medical record which is maintained to track the injury's recovery over time (e.g., ROM measurements). The second is the take-home exercise sheet for the patient, as explained above. The last is documentation created for the purpose of billing the patient's insurance company. While each of these includes similar information, the intended audience and mandated forms lead to the generation of similar, though distinctly different text.

Tasks and Limitations in Current Practice

While it was clear that both PTs had refined their protocols over time, each identified limitations and potential opportunities for technology to improve their workflow.

Buy-In. Buy-in emerged as a key theme. This is the term PTs use to describe the degree of patient adherence to a course of treatment. PTs associate buy-in with two factors: the degree of engagement of the patient with their instruction, and the level of understanding of how the treatment will lead to a desired outcome. Both participants explained independently that achieving buy-in is among the primary goals of a PT, and that, while this was already a focus, any tool which might improve buy-in would be highly beneficial. This echoes previous findings [5, 8].

Personalization of Documentation. Each PT expressed interest in better ways to document ROM and other visibly apparent symptoms. While professional tools enable measurement and electronic recording, patients have difficulty associating ROM metrics with their own conditions. Both PTs suggested that documenting ROM using photographs would provide patients personalized documentation to better visualize their status, goals, and progress, and in turn, could bolster buy-in. The PTs also agreed that the photographs would be valuable for their own record keeping and for justification of billing. They also each noted that digital cameras were available to them already, but that the overhead in producing imagery and associating it with the three different types of documentation required was inhibitive.

Medical Education. PTs found it essential to teach medical concepts in reference to the patient's own body, typically by manipulating a patient's body during verbal explanations. They also use supplementary visual materials such as imagery from anatomy books to enhance verbal explanations. Nevertheless, PTs noted that switching away from the body to reference materials made it difficult for patients to associate the concepts to their own bodies. Current practice can also be insufficiently engaging to maintain patient attention, thus negatively impacting patients' buy-in and ownership over their progress.

Treatment Education. There is no question a patient's compliance with a prescribed exercise regimen has an enormous impact on the rate and level of recovery, yet there are significant challenges in compliance. The exercises are often repetitive, boring, uncomfortable, or even painful. When working at home, patients often forget the correct form of an exercise or omit it entirely. Similar to the solution noted around documentation, our PTs noted the need for personalized education materials, ideally augmented with imagery of the patient themselves doing the exercises correctly.

Multiple Locales. Each of the PTs described multiple locations in which they perform the various stages of their sessions. These included multiple exercise rooms, exam rooms, and offices. Both solutions of toting education aids among these locations and purchasing multiple versions of each of the aids were viewed as overly burdensome.

Design Requirements

These findings led us to four design requirements.

Mobility and Integration: Because a PT's workflow is dynamic and spans multiple rooms, a system intended to support the practice should be a small, lightweight device that is easy to carry around. Meanwhile, it should be a single, integrated unit that supports several different tasks.

Documentation and Review: The system should support photo and video capture for documenting information throughout a patient visit, as well as retrieving and reviewing documented information together with patients. Allowing PTs and patients to review and discuss documented materials provides an opportunity to enhance patients' understanding of their conditions and treatment plans.

Augmented Medical Education: The system should augment the current medical education practice by using visual materials with the patient's body serving as the referent, given PTs insistence on the use of the body as context.

Personalized Material Generation: Finally, the system should allow doctors to generate personalized, rather than generic take-home materials for patients.

ANATONME: HARDWARE & SOFTWARE

Given these requirements, we developed AnatOnMe, a device that supports the full process of a physical therapy consultation. AnatOnMe combines projection, photo and video capture, and a pointing device for input. The projection and capture device is held in the non-dominant hand (Figure 2a). The projection is intended to be made opportunistically on walls and other surfaces in a mobile setting, as well as directly on the patient's body. Input is made using a modified presenter device in the dominant hand (Figure 2b).

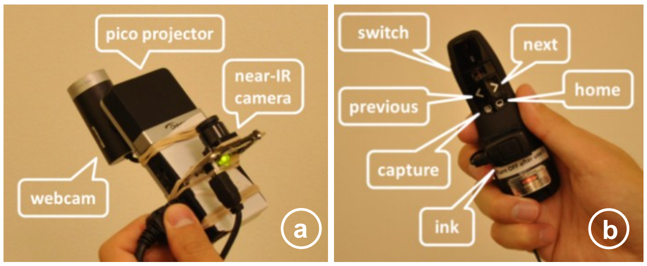

Figure 2: (a) AnatOnMe projection and capture device; (b) AnatOnMe input device: a modified presenter.

The projection and capture device consists of three components: an Optoma PK102 pico projector, a Microsoft LifeCam™ for capture, and a FireFly® MV USB near-IR camera for tracking the light emitted from a Logitech R400 presenter, modified by replacing its red-laser diode with an IR laser diode. A third state is afforded with the addition of an *Ink* button (Figure 2b) using an Arduino controller: when held, movements of the laser are applied as annotation to the projected image; when released, the movements are applied only to a system-generated cursor. The button can be tapped to make selections. The presenter's four built-in buttons were repurposed for AnatOnMe-specific functions.

Calibration of the IR camera and projection area was achieved mechanically. All input and output processing were provided by a laptop to which the two components of AnatOnMe were tethered. We envision that in a future version these functions would be offloaded to a small handheld computer with built-in projector and camera.

User Interface and Functionality

AnatOnMe use starts at the home screen, consisting of four main menus, as shown in Figure 3. A green cursor represents the movement of the IR laser. Moving the cursor over a menu icon and clicking the *Ink* button selects the menu. The user can return to the home screen at any time by hitting a dedicated *Home* button on the presenter (Figure 2b).

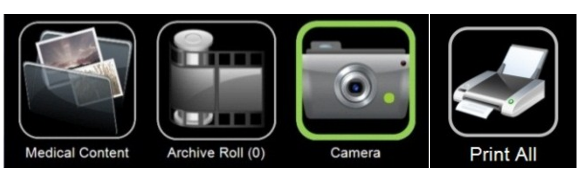

Figure 3: Home screen icons (cursor above *Camera*).

With *mobility and integration* addressed by the physical form factor, the remaining three requirements (*documentation and review*, *augmented medical education,* and *personalized material generation*) were addressed through specific software-enabled functionalities. *Documentation and Review*: Documentation was primarily designed for the *injury assessment* and *treatment education* phases of a physical therapy consultation, and is supported via photo and video capture. The PT enters the camera mode by selecting the "*Camera*" icon on the home screen. In this mode, a red boundary and center crosshair are projected to show the PT what is visible to the camera; the PT presses the presenter's *Capture* button (Figure 2b) to take a photo. The PT can toggle between photo and video mode by pressing the *Next* or *Previous* buttons; in video mode, the *Capture* button both starts and stops video recording. PTs and patients can review the photos together by selecting "*Archive Roll*" on the home screen, projecting photos on a shared surface such as a wall (Figure 4), and navigating photos with the *Next* and *Previous* buttons. To support explanations and discussion (e.g., ROM status and goals), the PT can annotate the projected images using the *Ink* button (Figure 4b). The annotations can be saved or erased by selecting the respective icons on the interface.

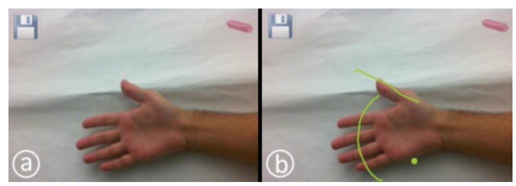

Figure 4: Photos taken during the injury assessment can be retrieved later for discussion and annotation.

Augmented Medical Education: To support the *medical education* phase of a physical therapy office visit, AnatOnMe allows the PT to access and project *injury-specific* teaching materials from the home screen's "*Medical Content*" menu. The medical content differs from the type of generic anatomy diagrams in a typical reference book in two important ways. First, each set of AnatOnMe content is comprised of several images related to a specific medical injury. The linear ordering of the images is significant, as it tells a "story" that corresponds to a dialog spoken by the PT. Second, portions of the images have been pre-annotated to draw the patient's attention to the anatomical structure referred to in the teaching dialog. We developed six content packages in collaboration with the PTs. Example images from two packages are shown in Figure 5.

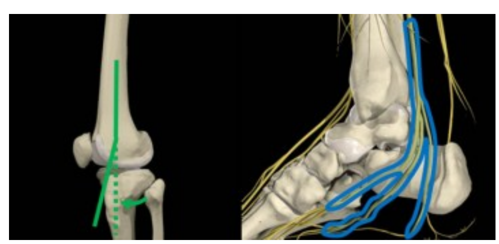

Figure 5: Example imagery with pre-rendered annotations.

To educate a patient about her injury, the PT navigates to relevant medical content, and projects the imagery on the appropriate location on the patient's body. The PT uses the *Next* and *Previous* buttons to navigate the medical images while verbally explaining the condition. As in the *documentation and review* phase, the PT can use the *Ink* button to make annotations over the projected image and use the *Capture* button to take a photo of the (annotated) image superimposed on the patient's body. Captured images are automatically stored and can be annotated and printed.

Personalized Material Generation: Finally, AnatOnMe allows PTs to generate personalized handouts for each patient at the end of a consultation. By selecting "*Print All*" on the home screen, an HTML file is generated that includes all photos and videos taken during the consultation. The PT can edit the file in a word processor to add patient-specific notes for each artifact. The generated document includes a section for assessment results (for the medical file) and another for exercise instructions (for the patient).

STUDY: PATIENT RESPONSE & SURFACE CHOICE

Although we were confident in the grounding of AnatOnMe's feature set with respect to the design requirements of *mobility and integration*, *documentation and review*, *augmented medical education*, and *personalized material generation,* our design led to an obvious question: *is on-body projection appropriate for medical education?* We did not doubt that on-body projection provided a novel education experience, but as part of our design process, we felt it was important to obtain feedback on AnatOnMe's patient-facing experience, and to more formally understand the potential desirability and learning tradeoffs of teaching medical concepts on different presentation surfaces.

Goals and Hypotheses

We designed a controlled experiment with two main goals. The first was to understand patient responses to the use of a projector in facilitating patient education in general, and to collect feedback on patients' experiences. The second goal was to establish the trade-offs among potential presentation surfaces, selecting from among walls (simulating opportunistic projection) and patients' bodies. We also considered a third option—projecting on anthropomorphic models—which could provide the contextual cues [16] of on-body projection, but perhaps overcome some of its limitations.

Patient Response

Little is known about patient response to the use of projection, in particular on-body projection, in facilitating communication with their doctor. A focus of this study therefore was whether this technology and technique can be helpful. We hypothesized that participants might react negatively to a variety of issues. These included non-optimal viewing angles, physical discomfort, emotional discomfort (e.g., a "creepy" feeling), or image misalignment on different body sizes. Furthermore, we were concerned that the novelty of the experience might inspire a degree of narcissism that would distract the patient, and lead to decreased learning.

Presentation Surface Trade-Offs

Given the wide flexibility in choosing a target presentation surface, we wanted to understand any measurable tradeoffs that might guide the design of projection-based systems. For example, are certain surfaces better suited to different styles of medical imagery or visual image characteristics? We also considered that image misalignment, distortion or instability might detract from the handheld projection and reduce patients' learning of medical concepts during a teaching session. We framed the experiment as a formal study of learning to ensure we met these goals, at the same time collecting data to support our patient experience goals.

Participants

18 paid participants (8 females) aged 19 to 59 (μ=35) were recruited from the local community. Participants were pre-screened for 1) no background in medical education; 2) no diagnosed medical conditions pertaining to body parts involved in the study, within five years; and 3) a high-school level of medical literacy, assessed using the short-form rapid estimate of adult literacy in medicine [1].

Experimental Design

The independent variable was *presentation surface* (*body*, *model*, and *wall,* Figure 6). Ordering was controlled with a Latin-square design across participants. Six *medical injuries* (see below) were used, two taught using each *presentation surface*. The order of *medical injuries* was held constant, so that the pairing with *presentation surface* varied across participants, and to ensure consistent learning effects. Dependent variables collected during the study were *retention* (quiz scores) and *satisfaction* (subjective ratings). Our design can be summarized as: 18 participants × 3 *presentation surfaces* × 2 *medical injuries* per surface = 108 total education sessions.

Materials

We selected six medical injuries for which patients often seek physical therapy. For each, we and our PTs developed an educational unit comprised of projection imagery and a script. To ensure consistency, scripts were pre-recorded. Anatomy images were exported from the Primal Pictures™ 3D software[1], and were pre-annotated to emphasize regions referenced in the scripts (e.g., the red outline in Figure 6a).

Imagery and scripts were modeled after a typical physical therapy session, including 1) general anatomy (e.g., bone structure); 2) specific anatomy (e.g., tendons and muscles involved in the injury); 3) causes of the injury; 4) consequences of the injury (e.g., location of pain); and 5) physical therapy goals (e.g., relieve the pressure on a nerve). We selected 3 upper- and 3 lower-body injuries to teach during the study. Three upper-body injuries were *lateral epicondylitis* (LE), *carpal tunnel syndrome* (CTS), and *scapholunate ligament injury* (SL). Three lower-body injuries were *patellofemoral pain syndrome* (PFPS), *medial collateral ligament injury* (MCL), and *tarsal tunnel syndrome* (TTS). We paired one upper-body injury with one lower-body injury

[1] All anatomy imagery courtesy and copyright of Primal Pictures Ltd. www.primalpictures.com.

for each *presentation surface*, with an order of TTS + SL, PFPS + CTS, and MCL + LE for all participants.

Apparatus

Audio scripts were played from speakers attached to a desktop computer while the experimenter used AnatOnMe to project, navigate, and point to medical content during each teaching session. In the *body* condition, presentation was done directly on the patient's body (Figure 6a). In the *model* condition, projection was done on an arm and lower body of a mannequin (Figure 6b). To provide context for the *wall* condition (without changing imagery), the contours of a hand and forearm (front and back) and a leg (top and side) were drawn on paper and hung on the wall as the presentation surface (Figure 6c).

Figure 6: Three presentation surfaces: (a) body, (b) model, and (c) wall.

Procedure

We began by reading to the participants an example teaching script and sample quiz questions to familiarize them with the nature of the medical content and questions. We then began a teaching session with the first pair of injuries, using one of the three *presentation surfaces*. Each session consisted of an education phase and an assessment phase.

During the education phase we taught two medical injuries using the materials described above. During the assessment phase, we first asked participants to rate on a 7-point Likert-scale (7=strongly agree) if the *presentation surface* was *engaging*, *disturbing*, *enjoyable*, or *fun*. We then orally quizzed participants on the medical concepts taught in the education phase. Quizzes for the two injuries were administered in the same order they were taught. For accuracy, two experimenters independently coded the responses.

After completing the three studies, participants completed a final questionnaire asking them to rank the three presentation surfaces from most preferred to least preferred for each of which 1) best helped them *understand* the medical concepts; 2) provided the most *engaging* learning experience; 3) was most *effective* in conveying medical concepts; 4) best helped them understand the *precise locations* of medical concepts in reference to their own bodies; and 5) was preferred overall. Lastly, participants were asked open-ended questions about their learning experience. The study required approximately 2 hours.

Results

Likert-scale ratings were analyzed using Friedman tests, with *presentation surface* being a within-subjects variable. Follow-up pairwise comparisons were conducted using Wilcoxon tests with LSD corrections. Figure 7 shows the results. Those values enclosed in the rectangles were *not* significantly different from one another (p>.05).

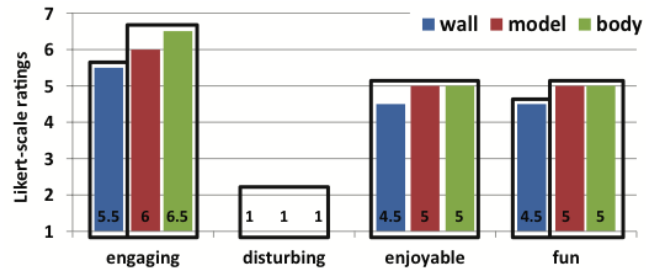

Figure 7: Likert-scale ratings for each presentation surface, with median values shown for each. Rectangles bound regions without significant difference.

For ranking questions we used one-sample Chi-Square tests to evaluate whether there were differences in the overall proportion of participants selecting any of the three *presentation surfaces* as 1 (most preferred), 2, or 3 (least preferred). Follow-up pairwise comparisons used Bonferroni corrections. Figure 8 shows the number of participants who ranked a *presentation surface* as 1 (best) for the five questions. Those values enclosed in the rectangles were *not* significantly different from one another (p>.05).

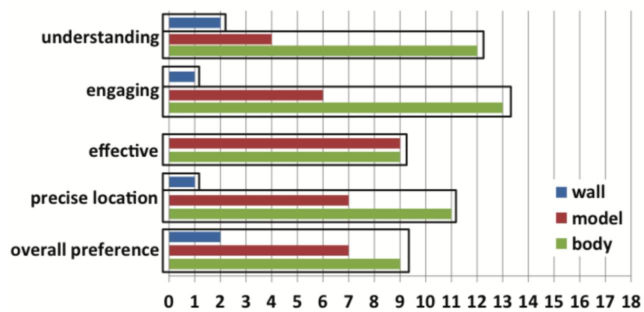

Figure 8: Freq. of #1 ranking for each presentation surface (some participants rated more than one conditions as 1).

Quizzes assessed different conditions. We therefore performed three one-way between-subjects ANOVAs for quiz scores for each pair of *injuries*, with an independent variable of *presentation surface*, and found no significant differences per Figure 9.

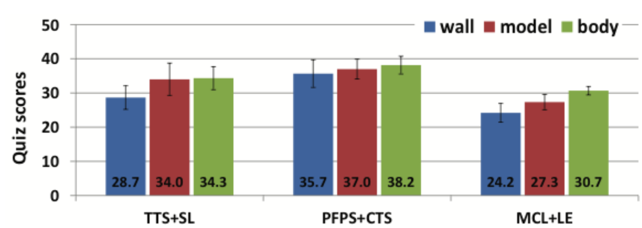

Figure 9: Mean results for quiz scores by medical injuries, mean values shown for each.

Discussion

The two goals of the experiment were to collect patient responses to the various types of projector-mediated education and to establish any trade-offs of the different surfaces.

Patient Response

Participants in general enjoyed the medical education throughout the study, but projection on *body* and *model* were clearly more engaging and provided more fun, as reflected in the questionnaire scores.

We had hypothesized that patients might respond negatively to various aspects of *on-body* projection. To the issue of viewing angle, only 1 participant complained that it was problematic when projecting on her knee (for PFPS), because the viewing angle of the imagery was not ideal. Four participants liked the fact that *on-model* projection allowed them to walk around and view the imagery from various angles, although they did not report viewing angle as an issue for *on-body* projection.

We were also concerned about physical comfort of *on-body* projection. Only 2 participants noted physical discomfort in manipulating their bodies to enable the projection in the *body* condition. We attribute this to individual differences in flexibility and body type. Nonetheless, addressing this issue will be a key challenge for on-body projection. Designs which include mirrors, or switching to model-based projection for certain body areas or medical injuries are possible mitigations, as might be the doctor using his or her own body as a presentation surface.

Regarding emotional discomfort, none of the participants reported feeling disturbed during any of the teaching conditions. Yet most participants had spontaneous reactions to seeing imagery projected on them, eliciting ooh's, wow's, and cool's—all evidence of positive engagement. Yet, some participants' experiences tipped toward the negative when viewing an x-ray of a broken wrist bone on themselves (e.g., P17: "*it is scary to look at*"); on the other hand, others experienced an unpleasant disconnect when the x-ray was projected on the model: "*it was weird to see realistic bones on a model since models don't have bones*" (P3).

Presentation Surface Tradeoffs

Figure 9 indicates that using the body as a presentation surface did not negatively affect participants' learning. Rather, it showed potential of improving medical education over traditional approaches such as presentation on wall, reflected by both the quiz scores and the participants' rankings on subjective questions.

Participants' comments also pointed to the merits of *on-body* projection. For example, "*[projection on] body provided a better 3D visual effect*" (P10), but wall is "*just a 2D surface*" (P2) and provides "*no benefits over reading a textbook or a website*" (P12). Twelve participants felt that using *on-body* projection allowed them to better associate medical concepts to their own bodies. For example, "*I feel like I am directly looking through my skin… and thinking about what is going on inside*" (P5); "*[on-body projection] was easier to visualize body structures*" (P2); and "easier *to relate graphical parts to my own body*" (P16). Four participants felt that projection on a *model* was also helpful: "*[on-model projection] was easy to map [concepts] to my body*" (P3); "*it is easy locating areas of discussion*" (P18).

Furthermore, we were concerned about the image quality decrease due to the distortion when projecting uncorrected imagery on irregular surfaces, as well as hand shaking when holding AnatOnMe. Only two participants noted that image jitter was "*a little distracting*" (P2 and P3). While clearly not a major issue, future versions might address image jitter with a form factor that includes a stand.

While body and model were more desirable than wall across several subjective measures, the insights that participants gave concerning the utility of different imagery styles on body vs. model suggest that the presentation surface can interact with imagery type in nuanced ways, to which system operators and designers will need to be sensitive. For example, certain patients may be anxious when viewing detailed body structures on their own bodies; for these cases, doctors may consider the model or wall as a presentation surface. Doctors can opt to project realistic (rather than pictorial) representations of muscles or nerves on patients, but should be cautious about the potential emotional discomfort this may cause. Furthermore, we noticed that human skin is generally not as reflective as other surfaces. Thus, increasing image contrast and saturation and using distinctive annotations are recommended to emphasize regions of reference. Finally, certain colors like red, yellow and blue seem to be better for projecting on body than other colors such as green.

General Design Recommendations

While on-body projection was shown promising, we recognized that it does not work for body parts that are not easily viewable (e.g., shoulder). For these occasions, one may use a model instead, since our study showed that a model as a presentation surface did possess several merits of the body. On the other hand, a wall is a better surface for interacting with the AnatOnMe UI and for reviewing the photos. Fortunately, the handheld system allows for the flexible and opportunistic choice of presentation surfaces in practice.

Moreover, several participants commented that they would like to see textual annotations alongside the visual imagery, since seeing words would help them remember and recall the medical terms. Others suggested they would like to see animated content along with the imagery in the teaching.

Overall, we were encouraged by the study results, and believe that they provide evidence for a positive effect of projection-mediation on in-clinic patient education. The evaluation also helped us to develop and understand the types of education materials that work best with AnatOnMe. So having examined the patient-facing aspect of AnatOnMe, we turned our attention to soliciting feedback from the ultimate end users of the full AnatOnMe system: physical therapists.

EXPERT REVIEW

We conducted expert reviews with the two PTs who were involved throughout the design process. While each had provided input during development, their levels of involvement differed during the various stages of design, and neither had been exposed to the end-to-end use of the system. Thus this phase allowed us to demonstrate the entirety of the AnatOnMe design in a dedicated two-hour session. We first introduced the AnatOnMe prototype, and explained its functionality in detail. We then performed two end-to-end physical therapy sessions, each of which included the three key elements of patient information exchange.

After demonstrating the use of the device, we conducted a structured interview assessing several elements. The first was whether we met the goals of *mobility and integration, documentation and review, augmented medical education,* and *personalized material generation*, and thus whether the device would integrate well into current practice. The remaining three goals were 1) how we might iterate on the *medical content*; 2) whether the device would affect *buy-in* and lead to better outcome; and 3) whether the functionality of the device meets their needs in each of the tasks it is intended to support.

Workflow

Both PTs indicated that AnatOnMe as it is currently designed would, in general, facilitate and augment their current workflow. One, however, had some reservation about the utility of the device for the injury assessment portion of the *information seeking* phase. He pointed out that PTs use measurement scores from standardized metrics for injury assessment, which are critical in patient documentation. However, both agreed that combining traditional measurement scores with photos, projecting them to a surface, and making annotations for both the in-room discussion and for their medical files did benefit patients in qualitative ways. Among other things, they indicated it was likely to enhance both patient *buy-in* and understanding of goals of treatment.

Both PTs saw great value in projection during the medical context portion of the *patient education* phase: "*I think it's very helpful, by projecting…on the actual person, they can see what is under the skin, and they can see the proportionality as opposed to just surface anatomy*". The other mentioned that he "*would use [the device] 70-90% of time*" for the teaching, since "*it fits in with how we teach today*".

As for the treatment portion, both commented that taking photos and videos of exercise instructions and including them in take-home materials are "*very useful*". One commented that "*there is a definite value of having an individual's picture as an exercise model, as opposed to a pre-print or artist's rendering [as from our current software], since it is more personal, and…easier to recall [what they have done] by [reviewing] their own pictures or video*".

Both PTs noticed that with the current form factor of the device, they cannot touch or manipulate a patient's body part as they explain an injury, which is very common in their work practice. They commented that palpating injured areas during verbal explanation reinforces patients' understanding. Moving the controls from the presenter to the projection device (e.g., via a touchscreen device) could address this issue, making the use of the presenter optional. Both PTs indicated that the device would not negatively change their current workflow in terms of time and schedule with patients. One did express his concern over the restriction of the lighting in the assessment and exercise rooms, since dimming a room for projection may not be desirable. He also understood that advances in projector technology would eventually eliminate this constraint.

Content

As previously explained, a concept we introduced in AnatOnMe is the use of *injury-specific* teaching material, rather than generic anatomy pictures as those offered by current anatomy software, posters, or books.

In response to whether they prefer such injury-specific materials or generic imagery, both PTs expressed their preference for injury-specific content. However, they held different opinions about pre-annotated images. One commented that he would prefer making annotations himself, since different patients learn in different ways and it is beneficial to customize each teaching. The other thought that "*pictures with such arrows and highlights are good, and even though I customize my teaching to different patients, I do not think it is a problem to have annotations because I can explain around them*". He suggested that combining both generic and pre-annotated content would be a reasonable compromise. As did several participants in the earlier study, both PTs noted that the addition of text labels would be useful. In addition, both PTs indicated that the misalignment between the image and body was not problematic, which agrees with the patient feedback in the earlier study.

Buy-In and Patient Outcomes

Both PTs believed that better patient education and understanding of an injury leads to better buy-in, and motivates patients to do their exercises. One commented that "*I always make sure that my patients really understand [the injuries], and I see [this device] as something that would help them understand better*". In addition, both PTs commented that the ability to send patients home with personalized materials would be "*extremely valuable*".

In our user study, we found that projecting on body was more engaging than on other presentation surfaces. In the expert review we asked PTs if the resulting increased level of engagement would result in better buy-in. Both agreed that more engagement would improve patients' understanding and hence, better buy-in.

Usefulness

Finally, we asked if AnatOnMe provides sufficient or excessive functionality to meet PTs' needs. Both PTs commented that as a standalone handheld device, AnatOnMe did offer sufficient functionality for patient education and documentation in a consultation. Both commented that to better integrate AnatOnMe into their work practice, it is important to access medical content for different injuries quickly. For example, it is conceivable to preload a teaching library in AnatOnMe that would allow PTs to browse and select one for a specific diagnosis. As for the size of library, one PT commented that a library of 10 to 15 diagnoses could cover the most common injuries he encounters.

CONCLUSION AND FUTURE WORK

Grounded in the challenges that medical professionals face in motivating patients to comply with treatment regimens, we developed AnatOnMe to explore the opportunities for technology in supporting information exchange, a core aspect of doctor-patient communication. AnatOnMe embodies the requirements for *mobility and integration*, *documentation and review*, *augmented medical education*, and *personalized material generation* in physical therapy consultations, and through a formal study and expert reviews, we have established that handheld projector technology provides benefits to practitioners in improving information seeking, documentation, and patient education practices, and provides a more engaging and informative learning experience to patients over common alternatives.

Our study informed early insights about the design space for medical handheld projection aids. Our findings revealed patient responses to inherent issues of projection-based education, and preferences and tradeoffs of choosing presentation surfaces for appropriate imagery type and quality, thus justifying a handheld form factor that can flexibly project on a variety of surfaces as per the usage context.

We are enthusiastic about both the immediate potential of AnatOnMe as well as directions for further explorations with respect to studies, interaction designs, and usage domains. A clear progression of this work is to study whether the use of AnatOnMe with real patients in real settings can validate our findings. Also, AnatOnMe's two-handed design may not be necessary to meet a practitioner's goals, and since it represents just one point in the design space of interactive handheld projection-based aids, there is much room to explore other industrial design choices. Finally, while AnatOnMe was instantiated within a physical therapy context, we believe the workflow of *information seeking*, *documentation,* and *patient education* can be usefully adapted to general medical settings; however, further contextual design is necessary to understand the nuanced requirements of other sub-specialties and use scenarios.

ACKNOWLEDGEMENTS

We thank Andy Wilson, Hrvoje Benko, and Paul Dietz for helping us with AnatOnMe hardware, Sarah Williams for participating in the video, Lauren Wilcox and Dan Morris for discussions, and PTs Scott Kelley and Erik Moen.

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