OPTIMIZED EXAM ROOM DESIGN TO FACILITATE PHYSICIAN INTERACTION WITH PATIENTS AND ELETRONIC HEALTHCARE RECORD: A CASE STUDY IN OUTPATIENT PRIMARY CARE EXAM ROOM

A Thesis

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by

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ABSTRACT

"Patient-centered care" and "information technology" are both fast growing trends in outpatient care delivery. Yet, studies on how to optimize the physical environments considering these fast growing trends are scares. This study focuses on the design of the physical exam room environment to support patient-physician interactions and physician-computer interactions. We conducted a secondary analysis on the role of exam room design on physicians' musculoskeletal burden and patient engagement. We analyzed video data from 22 patient visits in 5 exam rooms with 3 primary care physicians.

Our analysis showed that physicians' repetitive upper body motions, and patient eye contact duration changed by based on the placement of the EHR and patient exam table. From the three room configurations resulting in narrow angle, moderate angle, and wide angle between the EHR and patient exam table, the physician who delivered care in the room with moderate angle had longest patient eye contact and lowest number of upper body repetitive motions. The finding however did not reach statistical significance potentially due to the small sample size or other limitations. We recommend future research with larger sample size and randomization of physician, room assignment. Design recommendations on the placement of EHR in an exam room, the use of proper furniture, and system engineering functional requirements for consideration in design and renovation are provided.

BIOGRAPHICAL SKETCH

Sung Tsan Yeh holds a BA in Anthropology from National Taiwan University. Prior to matriculating at Cornell University, Sung-tsan served as a user experience researcher at iNSIGHT Center in Taiwan, where he extensively collaborated with designers and engineers to develop user-centered services. Through his professional experiences, he had identified the urgent need for improvement in healthcare systems. Sung-tsan's goals in transitioning to Cornell University were to strengthen his skills in quantitative and qualitative research, and to deepen his knowledge of evidence-based design and healthcare trends.

Sung-tsan received Master of Science in May, 2019 and acquired Evidence-Based Design Credential (EDAC) and Associated System Engineering Profession (ASEP) during his time at Cornell. He will continue his work in improving user experience in the healthcare industry.

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CHAPTER 1

INTRODUCTION

Background

Due to societal changes such as an aging population, people seeking healthier lifestyles, and the advancement of medical technologies, the medical care paradigm has expanded from inpatient hospitals to include outpatient clinics, retail clinics, and furthermore, home-based care (Mehrotra et al., 2009). The market size of all clinic types has increased from 118.6 physicians per 100,000 populations in 2005 to 149.7 physicians per 100,000 populations in 2017, and the number is still to grow (United Health Foundation, 2017; Vogenberg & Santilli, 2018). This trend is paired with a generational change in medical preferences and the vertical integration and cross-industry collaboration in the healthcare industry (e.g., CVS Pharmacy and Walmart.) (Boodman, 2018; Commins, 2018). As such, a study that examines the optimal outpatient clinic design is critical.

Exam room is the essential space in patients' journey in an outpatient clinic. Freihoefer et al. (2013) pointed out that most of the medical activities happen in exam rooms, including encounters between patients and providers. The industry has long been aware of the importance of exam room design.

In general, the design of exam room fits two goals: 1) to cater to a variety of medical tasks and the different needs of patients, and 2) to fill all needed amenities and services in a compact configuration efficiently (Vickery, Nyberg, & Whiteaker, 2015). As depicted in Figure 1-1, there are two main zones in a universal exam room:

a care provider zone and a patient/partners-in-care zone (Vickery et al., 2015). The care provider zone is physicians' working area. The zone generally includes a health record system (e.g., computer) and a sanitizing system, (i.e., sink or hand sanitizer dispensers). The design of the care provider zone is intended to increase efficiency and reduce working injuries. The patient/partners-in-care zone is the area provided to physicians or medical assistants to take care of the patient. The zone usually includes a curtain, an exam table, and furniture. It emphasizes infection control, patient privacy, as well as clinical efficiency. (Vickery et al., 2015).

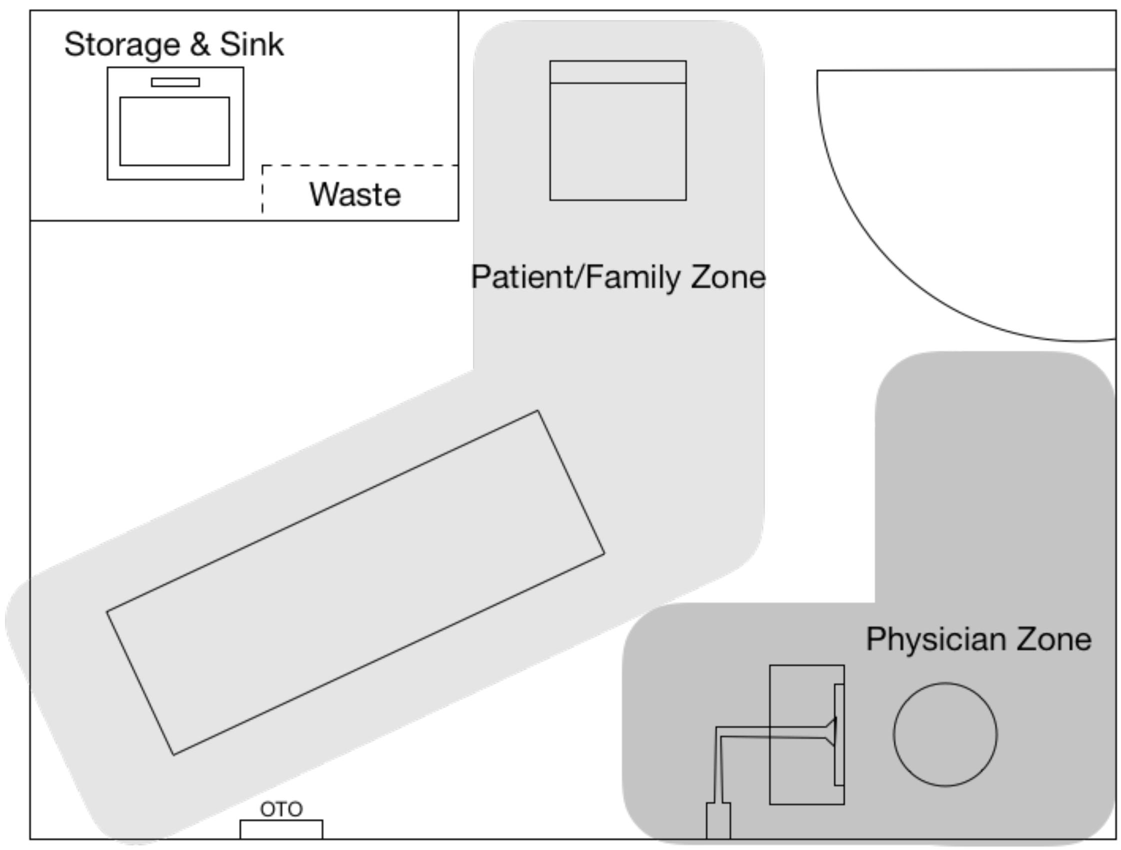


Figure 1-1 Two Zones in a Universal Exam Room

To fulfill various different patient needs, the design of the exam room has become diversified. There are four categories of contemporary exam room design: universal exam rooms, one-stop exam rooms, consultation rooms, and telehealth rooms (Vickery et al., 2015). Universal exam room is the most common among the four, as it is standardized and flexible to cater to a variety of medical tasks and patient needs. One-stop exam room is the type of exam rooms that allows most of the treatments, e.g., registration, tests and diagnostics, minor procedures, and checkout, to be fulfilled in a single space, (Vickery, 2012). The design of one-stop exam rooms supports privacy but raises the construction cost per square area of space. Consult rooms are rooms that caregivers use to educate patients and their families, or to discuss their treatment options with them. The design of this space focused on the quality of communication and the cultivation of a soothing experience. Telehealth room is a relatively new type of exam room which enables remote communication by taking electronic approaches, i.e., telephone or Skype, to communicate with patients (Vickery et al., 2015). Considering that universal exam room is the most common type, this study focused on enhancing efficiency in the universal exam room design and on creating a supportive space for the physicians to provide care.

Literature Review

1.1 The Transformation of Exam Room Design Paradigm

In contrast to the concept of “illness-centered care,” “patient-centered care” is the more widely accepted health system quality paradigm in the current healthcare industry (Kazmi, 2013). Balint proposed patient-centered care in the 1960s (Crampton, Reis, & Shachak, 2016). The study proposed considering disease treatment from patients’ perspectives (Balint, 1969). Later on, discussions and studies surrounding this topic have broadened. Particularly, in the design of primary care, the expectation of physicians has shifted from “fixing the illness” to dictating acceptable orders by understanding patients’ context and causes of their syndromes.

Evidence suggests that successful patient-centered care may lead to high patient satisfaction rates, trust from patients and patients’ families, understanding of the state of an illness and orders, better use of healthcare resources, and adherence to prescribed therapies (Alex J. Mitchell, Stephen Kaar, 2002; Crampton et al., 2016; Fawole et al., 2013; Mead & Bower, 2002; Street, Makoul, Arora, & Epstein, 2009). The results can indirectly affect patient outcomes (e.g., physical and emotional health status, the severity of symptoms, and state of illness) (Crampton et al., 2016).

1.2 The Goals of Outpatient Primary Care Practice

Davis, Schoenbaum, & Audet (2005) enlist seven attributes of patient-centered primary care practices, which include 1) accessibility to medical care, 2) patient engagement, 3) healthcare information technology that supports, practice-based learning, and care quality improvement, 4) coordination between medical teams, 5) integrated care and smooth information transfer across providers, 6) routine patient feedback to a practice, and 7) publicly available information on practices. Within the seven attributes, the second (patient engagement during visit) and the third (healthcare information technology that supports, practice-based learning, and care quality improvement) are directly related to exam room design and thus are within the scope of this study. "Patient engagement" means that patients are encouraged to engage in the decision-making process, that patients have the autonomy to access their medical records, to add or to clarify information in the record, and to counsel on their children's health and well-being issues (Almquist et al., 2009; Davis et al., 2005). "Healthcare information technology that supports, practice-based learning, and care quality improvement" are the use of clinical information systems to reduce time-wastes on testing results, assisting physicians and patients in making decisions, and tracking factors/use of services/outcomes (Davis et al., 2005).

1.3 Outpatient Primary Care Practices' Influence on Exam Room Design

The transformation of care approach to patient-centered care has also been reflected in the physical design of exam rooms. Patel et al. (2017) comprehensively list and rank twelve medical providers' patient-centered behavioral and communication practices: (1) using EHRs to facilitate conversation; (2) adjusting furniture, fixtures, and equipment (FF&E) style and layout; (3) sustaining eye contact with patients while typing; (4) isolating the computer use and interactions with patients; (5) having conversation with patients while looking at the screen; (6) using physical postures to increase the duration of facing patients; (7) inviting patients to view the screen before they ask; (8) informing patients about the functions and role of the electronic health record system; (9) greeting patients and their families at the beginning; (10) informing patients that logging in/out the system is securing their privacy; (11) reviewing the patient visit after finishing with the computer; (12) using aids for typing purposes (e.g., assistant, transcriptionist).

However, from the physicians' perspective, the paradigm shift and the emergence of EHR have greatly changed the working pattern in each patient visit (Crampton et al., 2016; Kazmi, 2013). The two simultaneous changes cause physicians to have to interact with patients and a virtual information system at the same time. Retrieving information, documenting, and charting on EHR while focusing on patient engagement adds challenges to physicians.

The following sections review the role of exam room design on 1) physicians' interactions directly with patients, and 2) physicians' interactions with EHRs during outpatient visits and design recommendations. In this context, this review covers the first seven practices mentioned above (Patel et al., 2017).

1.4 Physicians' Interactions with Patients

1.4.1 Influence on Users' Experience

Studies show that the configurations of exam rooms and the setting of FF&E affect physicians' and patient's experience in privacy, distraction, and information perception (Freihoefer, Nyberg, & Vickery, 2013; Saleem et al, 2018; Unruh, Skeels, Civan-Hartzler, & Pratt 2010; Almquist et al, 2009). For instance, the location of doors and privacy curtains may increase distractions or decrease security in the visit.

Improper placement of sinks and hand sanitizing dispensers may pose usability issues (Freihoefer, Nyberg, & Vickery, 2013). Unruh, Skeels, Civan-Hartzler, & Pratt (2010) point out that improper physical positions and the lack of support for collaborative document viewing have hampered the communication between patients and physicians. If patients cannot sit properly when having a conversation, it may result in distraction. If patients cannot read the information shared by physicians, it may result in misunderstanding (Unruh, Skeels, Civan-Hartzler, & Pratt 2010).

Almquist et al. (2009) discuss the influence of furniture arrangement and table orientation on communication. The result shows that the shape of the table and the orientation of chairs may directly affect the communication between physician and patient. For instance, when explaining test results or orders, a square table with patients and physicians facing each other is more difficult than a half-moon table for physicians to explain treatments and assist patients in making decisions.

With regard to improving privacy and reducing distractions, studies have suggested installing curtain or adjusting the orientation of the door to prevent other people from interrupting the visit (Almquist et al., 2009; Fonville, Choe, Oldham, & Kientz, 2010; Freihoefer et al., 2013).

To avoid information perception issues, Almquist et al. (2009) suggest using a semicircular table to put the physician, patient and their family on the same side. This orientation allows the patient to have access to the computer screen, which enhances patients' experience of information sharing using electronic medical records and the Internet.

1.4.2 Influence on Medical Providers' Musculoskeletal Burden

While medical practitioners place the most emphasis on taking care of patients and accomplishing medical tasks, their workplace safety is also important (Midmark, 2011; Midmark, 2011). A body of studies focuses on addressing working injuries of medical practitioners of different specialties. For instance, Musculoskeletal Disorder (MSD) is a common occupational injury in healthcare professionals. MSD is the injury or pain related to the human musculoskeletal system which includes muscles, bones, joints, ligaments, nerves, and structures that support limbs, neck, and back (National Institute for Occupational Safety and Health, n.d.). The illness happens to various specialties, such as registered nurses (Dressner & Kissinger, 2018), dentists and dental hygienists (Sakzewski & Naser-Ud-Din, 2014), physicians (Oude Hengel, Visser, & Sluiter, 2011), surgeons and interventionists (Epstein et al., 2018), and radiologists (Hedge, 2013).

In the context of exam room, physicians' repetitive motions from computer use (e.g., typing prescription or dictating orders) may increase their risk of upper body musculoskeletal disorder. For instance, carpal tunnel syndrome is associated with typing and neck/cervical spine, shoulder, upper arm, and lower back musculoskeletal pain is commonly caused by inappropriate screen angle, overly high/low keyboard and mouse position, and improper chair height (Hedge, 2013; Hedge, James, & Pavlovic-Veselinovic, 2011).

Studies suggest that in outpatient care, the design of the workstations, computers and keyboards should be adjustable to cater to different physicians' bodies to minimize work-related musculoskeletal disorder, repetitive stress injuries, and fatigue

(Hedge et al., 2011). Two solutions were introduced: in-room computer wall stations (Figure 1-2) and computers-on-wheels (COWs) (Figure 1-3).

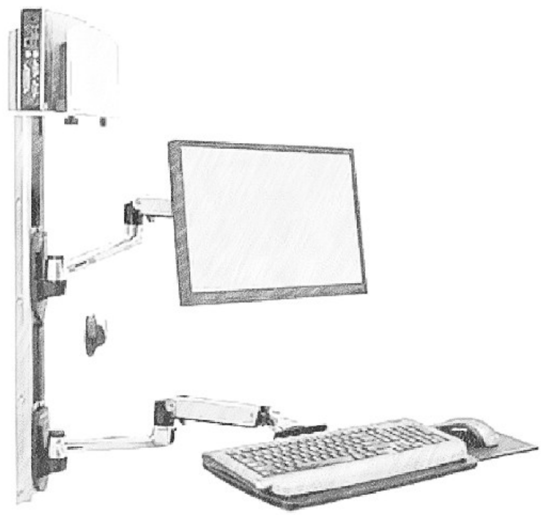


Figure 1-2 In-room Computer Wall Station

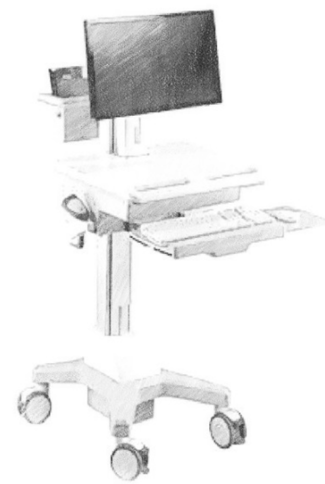


Figure 1-3 Computers-on-Wheels

The in-room computer wall station has the following benefits: First, physicians have high flexibility in adjusting the monitor position to sustain eye contact with patients. The design has also been shown to reduce musculoskeletal disorder and increase support during use (Boothroyd & Hedge, 2007). It is also pointed out that while the ideal vertical position of a monitor may vary with the user and the design of the device, the range of suitable screen height for standing use is 48”-60” and 40”-53” for sitting use (Boothroyd & Hedge, 2007). Second, the wall station provides efficient storage by folding keyboard/mouse platform flat and integrating power management and cables; it rounds sharp edges that could cause injuries (Boothroyd & Hedge, 2007). Third, it reduces hospital-acquired infection (HAI) by reducing touchable surface (Boothroyd & Hedge, 2007).

On the other hand, COWs has the advantage of high mobility, installation-free, high adjustability, and space saving (Whittemore & Moll, 2008). In some cases, COWs can incorporate a battery to provide independent use for up to 8 hours (Whittemore & Moll, 2008). However, COWs also have some drawbacks that should be considered. For example, the metal shell results in cold surfaces and sharp edges, which may lead to discomfort and danger; the all-in-one design makes the system heavy and hard to move around. Moreover, the limited storage space and surface on the cart restrict healthcare providers' work, and the gradually waning battery capacity results in shorter independent working duration. Finally, the size of the cart sometimes makes COWs too large to pass though doors (Whittemore & Moll, 2008).

1.5 Physicians' Interactions with EHRs

A body of studies has shown that the integration of EHR correlates with patient satisfaction with eye contact, information sharing, decision-making process, and patient education (Almquist et al., 2009; Asan & Montague, 2014; Chen, Ngo, Harrison, & Duong, 2011; Crampton et al., 2016; Davis et al., 2005; Fonville et al., 2010; Freihoefer et al., 2013; Kazmi, 2013; Unruh et al., 2010; Yang & Asan, 2016).

Asan & Montaque (2014) study the length of time physicians look at patients when they use an EHR and when they use a paper chart. The study shows that physicians spend a significantly smaller portion of time looking at patients when using an EHR compared with when using a paper chart. Less eye contact may result in patients not feeling engaged in the process (Asan & Montague, 2014). On the same topic, Kazmi (2013) argues that EHR use has both positive and negative impacts on patient-clinician interaction. On the one hand, EHR in an exam room may provide clear explanations, and encourage patient-led questioning and doctor-led information provision. On the other, EHR may negatively affect physician-led patient-centered communication (e.g., typing and screen gaze) by reducing visual contact, trust, and emotional support (Kazmi, 2013).

Chen, Ngo, Harrison, & Duong (2011) propose three screen viewing approaches: exclusive viewing, collaborative viewing, and neutral viewing. Exclusive viewing involves intentionally turning the screen away from the patient. The strategy is commonly used before physicians dictate orders or take notes. The purpose is to avoid patients' reading undictated orders and misinterpreting the information which may cause patients to panic. Collaborative viewing is to share information with patients purposefully. It is often used when physicians explain situations or future treatments to patients. Lastly, neutral viewing is to place screen and adjust orientation without any intention. Under this approach, patients can see physicians' behavior naturally (Chen, Ngo, Harrison, & Duong 2011).

Yang & Asan (2016) identify five design solutions that can provide multi-viewing approaches in an exam room: (1) a separate patient display, (2) a projector, (3) a portable tablet, (4) a touch-based screen, and (5) a shared computer display. Yang & Asan (2016) also point out the pros and cons of each approach: First, a separate patient display empowers physicians to control the contents shared with patients. However, technology availability, reliability, and cost are concerns that impact the design. Additional training and extra workload may reduce physicians' adaptation of the technology. Second, a projector has similar pros and cons to a separate patient display design. It allows physicians to control information transparency, but physicians have to bear additional training and workload. Third, comparing to a COW or a wall station, a portable tablet provides physicians with higher mobility during patient visits. Patients can have more control to the information when using the tablet. The drawback of the design, however, is that physicians and patients may not be having the same understanding to the content during communication. Fourth, a touch-based screen provides a sizeable touchable screen in an exam room. Patients and physicians can interact with the information on the screen. The large font and the visualization make the data accessible for all abilities. Fifth, a shared computer display is a screen shared by both physicians and patients. The strength of the design is that patients can have more engagement during the consultation and that physicians may maintain information transparency.

In summary, a successful exam room design should enable physicians to interact with patients and EHRs effectively by allowing medical providers to adjust the location or the orientation of FF&E and information sharing devices. As such, physicians would have flexibility to determine the information transparency while increasing patients' satisfaction and engagement.

Aims

As outpatient clinics become pivotal in the American healthcare industry, and as much of outpatient medical care activities happen in exam rooms, the design of exam rooms is critical. However, studies that discuss the design of the physical and virtual exam room to support the physicians' health and performance during care delivery are scarce. To address this gap, this study sought to examine a case study to understand the physical and virtual components in exam rooms that affect physician-patient interactions and the physicians' musculoskeletal burden during patient visits. Ultimately, this study tried to answer the following question: What are the characteristics of an optimally designed physical and virtual exam room environment that support patient-physician interactions and physician-computer interactions?

Specifically, building on past evidence, we test the hypotheses stated below:

a. The strategic placement of the computer is linked to the frequency of physicians' upper body motions when attempting to balance maintaining eye contact with a patient and working with a computer screen.

b. The strategic placement of the physician work station with respect to a patient to reduce the angle between the patient and the EHR may be linked to a longer duration of the physician's eye contact with a patient.

CHAPTER 2

METHODS

2.1 Research Design

This study used space syntax (Hillier & Hanson, 1984) method to investigate the influence of exam room design on physicians' interactions with patients and EHR during care delivery. The framework of Hillier and Hanson's (1984) theory of space syntax was used to determine the effect of spatial arrangement on physicians' behavior. We conducted secondary data analysis on spatial and behavioral data collected by a healthcare institution in the Maryland-DC-Virginia area. The dataset included the floorplans of exam rooms and 22 eye tracking video footages that totaled 5 hours 57 minutes and 41 seconds. We coded the total duration of physicians' eye contact with a patient and the duration of each patient eye contact. The results were expected to determine whether the environment had an effect on physicians' musculoskeletal burden and patient engagement.

This study was approved by the Cornell University Institutional Review Board (#1604006302).

2.2 Description of the Dataset Analyzed in this Study

2.2.1 Setting

The floorplans provided were conducted on three clinics, one clinic located in a dense urban area and two in suburban areas. The size of the three clinics ranged between 2400 - 5300 sqft. Each clinic had 4-8 primary care physicians. The same healthcare institution managed all three clinic centers. The size of the exam rooms ranged between 50 - 120 sqft. Exam rooms were equipped with furniture and equipment, but each clinic offered a slightly different layout in terms of location of EHR with respect to the clinician and patient position in the room. The data set provided recorded data in five different exam rooms. We categorized the exam rooms into three types based on the location of physician concerning the EHR's location and the patient's location (type 1: $\leq$40°; type 2: 41°-80°; type 3$\geq$81°). A summary of the specifications of clinics are displayed in Table 2-1.

	Clinic A	Clinic B	Clinic C
Location	Urban area	Suburban area	Suburban area
Size of the clinic	2925 Sqft	5252 Sqft	2465 Sqft
# of primary care physicians	8	4	5
Total number of exam rooms	13	11	19
Exam rooms code	Exam room A-1 Exam room A-2	Exam room B-1	Exam room C-1 Exam room C-2
Typical size of an exam rooms	56 Sqft	111 Sqft	90 Sqft
Service	• Annual Physicals • Male/ female health • General consultations • Sick visits • Testing and screening • Preventive care	• Annual Physicals • Sports Physicals • Injury evaluation • Sick visits • Geriatrics care • Male and female health • General consultations • Sleep disorder care • Vaccines	• Acute care • General physicals • Geriatric care • Well children care • Women's Health Care • Chronic Disease Management • Colposcopy procedures • Laceration repair procedures

	• Sexually transmitted disease care • Urinary tract infection care • Weight loss assistance	• Mole biopsy procedures • Skin procedures

Table 2-1 Characteristics of the Clinics

The five exam room layouts from three clinics are showed as follows (Figure 2-1 to 2-5).

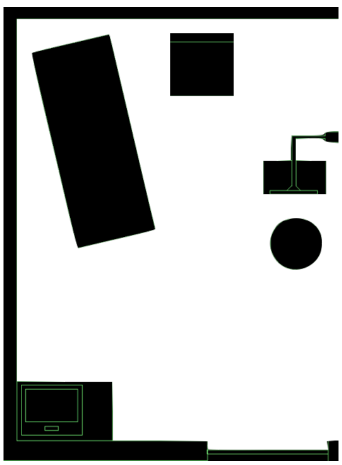


Figure 2-1 Exam Room A-1

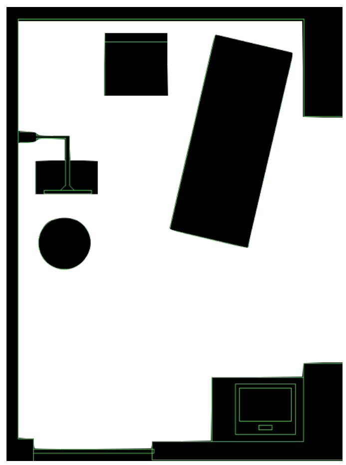


Figure 2-2 Exam Room A-2

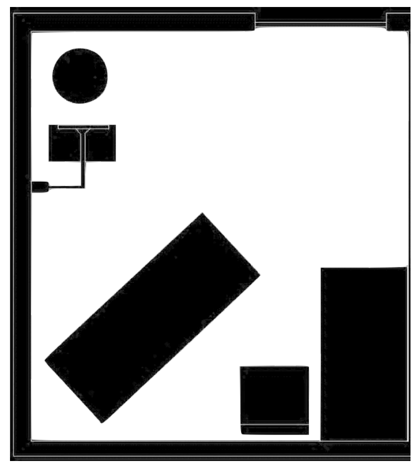


Figure 2-3 Exam Room B-1

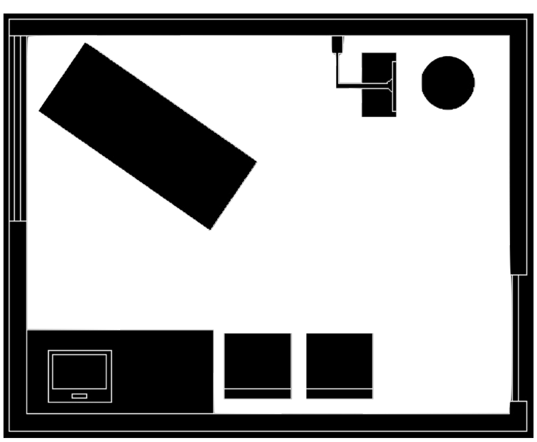


Figure 2-4 Exam Room C-1

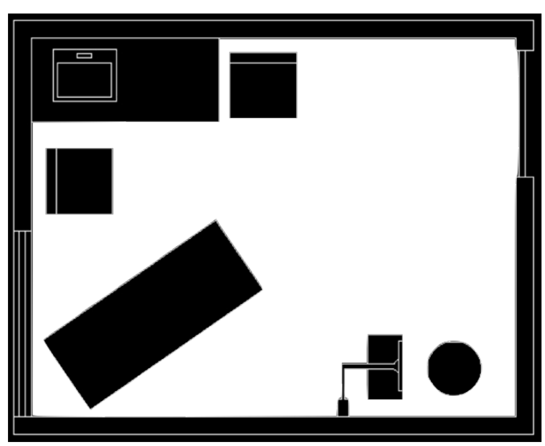


Figure 2-5 Exam Room C-2

Identical equipment used in each exam room in all three clinics included: EHR: the same electronic health record system provided by the same provider (Figure 2-6); Exam table: the same adjustable table that could change the height and the sitting/lying position for appropriate examination or patient communication (Figure 2-7); Curtain: a curtain was installed in the room to increase privacy (Figure 2-6); Storage system: the storage system provided space for basic medical supplies, such as Band-Aids, pills, cotton, and healthcare education brochures (Figure 2-8); Sink: each exam room was equipped with a sink for medical providers to wash hands before and after treatments (Figure 2-8). However, the age of the facilities varied. The size and the configuration of exam rooms also varied with clinics.

Figure 2-6 EHR System & Curtain

Figure 2-7 Exam Table

Figure 2-8 Sink and Storage Space

In this dataset, researchers from the partner institute collected video footages by using the wearable eye-tracking device (ASL mobile Eye X) in order to understand the physicians' viewing point during the patient visit (Figure 2-9). The videos recorded the physicians' focus, interactions with computer, and interactions with patients in each patient visit. Each video started when the exam room door was opened and ended when the physician finished the session and closed the door.

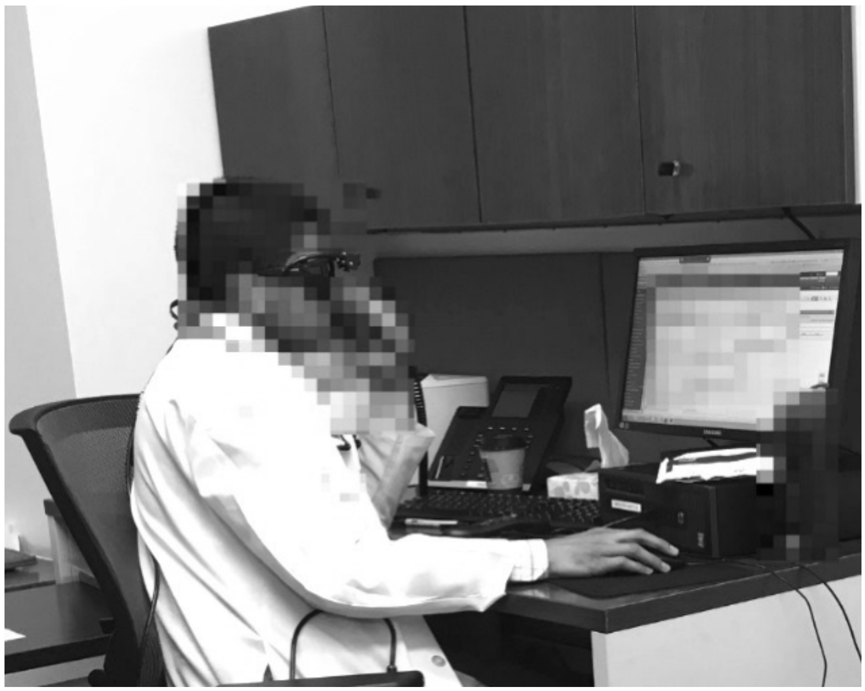


Figure 2-9 Wearable eye-tracking device (ASL mobile Eye X)

2.3 Data Analysis

2.3.1 Independent Variable

The independent variable representing the physical component of the exam room in this study was the angle from the physician's location to the EHR monitor and to the patient's location (it is abbreviated as "the angle" in the following paragraphs). We used Mackintosh Keynote (Dec 2018, version 8.3) to measure the angle from the physician to the computer screen and to the patient location within the floorplans. Based on the angle measured, this study used Depthmap X (May 2015, version 0.50) to quantify the physicians' sightlines (Isovist) in the exam room. Depthmap X is an open source software platform. The software can perform spatial network analyses to understand social processes within the built environment (Space Syntax Network, n.d.). Isovist is a set of all points visible from a given vantage point in space (Benedikt, 1979). Understanding the Isovist area helps this study to understand how the location of a physician affects the relationship between the physician and their patient in an exam room.

The attribute in the Depthmap we used was "Partial Isovist." Compare to full Isovist, partial Isovist defines an orientation of a visual area. In this study, the visual area would focus on the screen and the partial exam room. The colored area represented the area that can be seen from the point. As such, the result was close to the actual situation in an exam room. The data included visual analysis and value. The visual point started at the physician's seat, generally in front of the computer screen. The results show as follows (Figure 2-10 to 12).

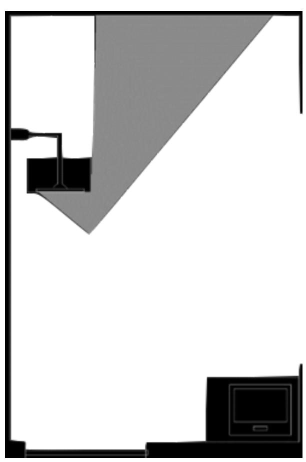


Figure 2-10 Type-1 Isovist area

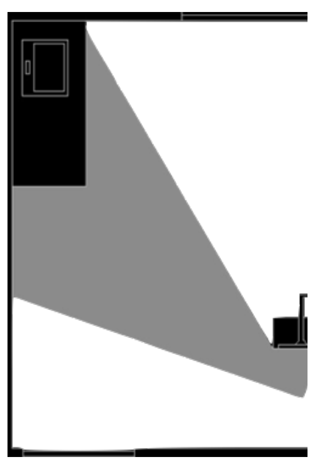


Figure 2-11 Type-2 Isovist area

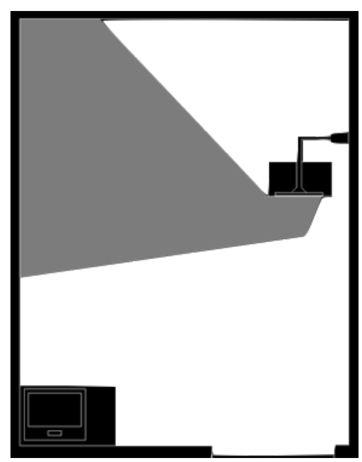


Figure 2-12 Type-3 Isovist area

2.3.2 Dependent Variables

The coding software, Studiocode (2016, version 10.3.34) provided by the healthcare facility was used to analyze the video footages. Coding categories included: 1) the frequency of physician's upper body repetitive motions between computer screen and patient; 2) the duration of maintaining eye contact with a patient; 3) the duration of looking at a screen; 4) the duration of maintaining eye contact with patients' families; 5) the duration of conducting physical examinations; 6) the duration of talking to staff. Each video started from the moment the physician opened the exam room door and ended when the physician sent the patient out.

Given the limitation of the dataset analyzed, we did not have a direct measurement to the physician's upper body repetitive motions. Therefore, we coded the times of an eye tracking device moved when physicians were adjusting positions in the footage.

2.4 Statistical analysis

This study used IBM Statistic Package for Social Science version 25 (SPSS 25). Frequencies, means and standard deviations for each variable was calculated descriptively. The hypotheses were tested using one sample t-test. To test H_1 (*The strategic placement of the computer is linked to the frequency of physicians' upper body motions when attempting to balance maintaining eye contact with a patient and working with a computer screen*.), one sample t-test and univariate analysis were applied to compare the effect of Isovist value on (DV1) the physician's upper body repetitive motions (Figure 2-13).

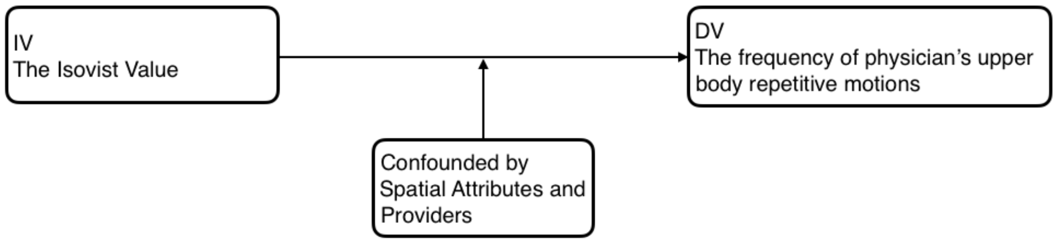


Figure 2-13 Hypothesis 1

To test H_2 (*The strategic placement of the physician work station with respect to a patient to reduce the angle between the patient and the EHR may be linked to a longer duration of the physician's eye contact with a patient.*), one sample t-test and univariate analysis were conducted to compare the effect of Isovist value on (DV1) the duration of physicians looking at patients, and on (DV2) the average duration of each time physicians looked at patients (Figure 2-15).

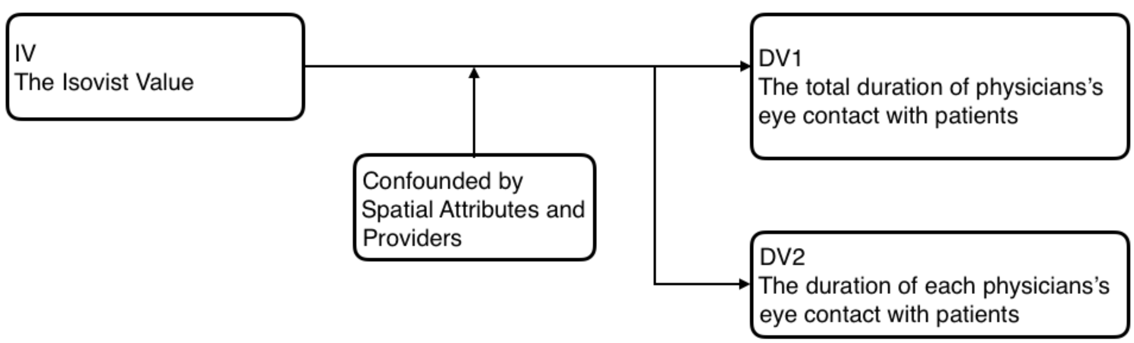


Figure 2-14 Hypothesis 2

The assumption of multivariate normality was that the residuals of all continuous variables were normally distributed and homoscedastic. For all analyses, the level of statistical significance was set at $P < 0.05$.

CHAPTER 3

Results

3.1 Demographics

In this study, the data from a total of 22 primary care patient visits provided by the healthcare organization were analyzed. Twenty-one of the 22 studied visits were adult patients and one was a pediatric visit. The primary diagnoses varied widely and included acute conditions (e.g., infections, pain symptoms, ear infection, disease management and follow-up (e.g., diabetes and depression), and well-child visits.) The participant demographics is summarized in Table 3-1. Standard Error is abbreviated as SE.

Patients		Physician 1 *n* = 10	Physician 2 *n* = 7	Physician 3 *n* = 5
Male/Female		8 / 2	2 / 5	3 / 2
Total time of visit (mm:ss)	Mean SE	15:29 1:34.25	22:2.29 3:50.09	16:26.2 2:15.19
Count of physicians' repetitive upper body motions (#)	Mean SE	39 4.624	132.11 21.18	40.8 12.87
Total duration of patient eye contact (mm:ss)	Mean (%) SE	5:51.83(37.9 %) 1:3.2	5:25.12(24.6 %) 1:17.49	5:50.82(35.6 %) 1:21.63
Total time of looking at screen (mm:ss)	Mean (%) SE	4:39.60(30%) 0:48.31	11:13.41(50.1 %) 2:19.74	2:39.14(16.1 %) 1:12.49
Duration of each patient eye contact (mm:ss)	Mean SE	9:53 1:90	2:28 0:29	22:38 16:24
Duration of looking at screen (mm:ss)	Mean SE	0:09.91 0:01.36	0:04.84 0:00.55	0:04.40 0:01.55

Table 3-1 Descriptive Statistics by Physicians

3.2 Measurement of the Independent Variable (the Angle)

In each patient visit, patient might decide to sit on the chair provided in the room or the exam table. The angle between the EHR and the patient varied. Based on the scatter plots generated from SPSS 25 (Appendix G), we categorized the exam rooms into three types. Type-1 exam rooms had an angle smaller or equal to 40 degrees; type-2 had an angle ranging from 41 to 80 degrees; type-3 had an angle larger or equal to 81 degrees. The number of patients in each type of exam room also varied (type-1 *n*=9; type-2 *n*=4; type-3 *n*=9). The average angle was 30 degrees in type-1 exam room; 66.25 degrees in type-2; 90 degrees in type-3. The average Isovist value in type-1 exam room is 88950;114247 in type-2; 85020 in type 3.

Given the data limitation, we were not able to randomly assign physicians to exam rooms. Some exam rooms were larger than others, which resulted in the larger Isovist value in type-2 exam rooms.

3.3 Measurement of the Dependent Variables (Physicians' Repetitive Upper Body Motions and the Duration of Eye Contact with Patients)

Physicians have an average of 111.67 times repetitive upper body motions in type-1 exam rooms and 43.5 times and 38.22 times in type-2 and type-3 respectively. Physicians in type-1 exam rooms had an average of 4 minute 39.39 seconds of eye contact with a patient; the figures for type-2 and type-3 were 9 minute 28 seconds and 3 minute 53.51 seconds. Physicians had an average of 3.11 seconds in each eye contact with patients in type-1 exam rooms; 27.1 seconds in type-2 exam rooms; 9.64 seconds in type-3 exam rooms (See Table 3-2).

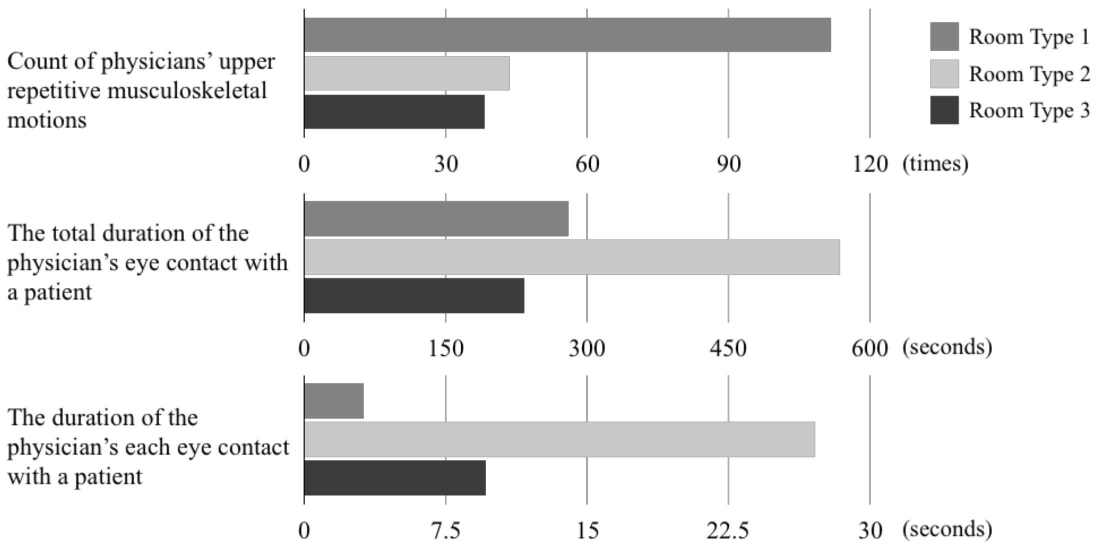


Figure 3-1 Measurement of the Dependent Variables

Patients		Type 1 *n* = 9	Type 2 *n* = 4	Type 3 *n* = 9
Angle between screen and patient		≤40°	41°-80°	≥81°
Isovist value		88950	114247	85020
Total time of visit (min:sec)	Mean SE	20:30.78 9:41.71	18:08 3:49.69	14:54.22 4:53.81
Count of physicians' repetitive upper body motions (#)	Mean SE	111.67 21.12	43.50 16.47	38.22 5.10
Total duration of patient eye contact (min:sec)	Mean(%) SE	4:39.39 (22.76%) 1:37.27	9:28 (52.2%) 3:00.67	3:53.51 (26.11%) 2:44.69
Total duration of looking at screen (min:sec)	Mean(%) SE	6:58.04 (43.71%) 2:19.73	3:18.93 (18.28%) 1:18.23	4:56.39 (33.15%) 00:50.64
Duration of each patient eye contact (min:sec)	Mean SE	00:03.11 00:00.73	00:27.10 00:20.06	00:09.64 00:02.13
Duration of each time looking at screen (min:sec)	Mean SE	00:04.09 00:00.69	00:05.50 00:01.41	00:10.69 00:01.25

Table 3-2 Descriptive Statistics by Room Types

3.4 Statistical Analysis

H_1: *The strategic placement of the computer is linked to the frequency of physicians' upper body motions when attempting to balance maintaining eye contact with a patient and working with a computer screen*.

In H_1, we tested a correlation between the independent variable (the angle formed by the computer screen and the patient's location) and the dependent variable (physicians' repetitive upper body motions).

The correlations between the independent variable (the angle) and dependent variable (physicians' musculoskeletal repetitive motion) are summarized in Table3-3. Given the data limitation, we were not able to separate the effect of individual physicians from the room layouts. The results reflected this limitation. The result showed that the effect of the angle on repetitive upper body motions was not significant ($F (2, 22) =0.04$, $p=0.961>0.05$). However, the spatial attribute (confounded by physician assignment) had a significant effect on physicians' musculoskeletal repetitive motion ($F (2, 22) =4.711$, $p=0.024<0.05$). Given the distribution of physician assignment to rooms, it was uncertain if this significant effect was due to the environment attributes, the physicians' behavior, or a combination of the two.

Source	The Frequency of Physicians' repetitive upper body motions				
	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	40997.542[a]	4	10249.385	7.272	.001
Intercept	89909.516	1	89909.516	63.794	.000
The angle formed by the monitor location and the patient position	112.244	2	56.122	.040	.961
Spatial Attributes (confounded by physician assignment)	13279.143	2	6639.571	4.711	.024
Error	23959.413	17	1409.377		
Total	169837.000	22			
Corrected Total	64956.955	21			

a. R Squared = .631 (Adjusted R Squared = .544)

Table 3-3 Hypothesis 1 Univariate Analysis Result

H_2: *The strategic placement of the physician work station with respect to a patient to reduce the angle between the patient and the EHR may be linked to a longer duration of the physician's eye contact with a patient*.

In H_2, we tested the correlation between the independent variable (the angle) with the dependent variables (the total duration of patient eye contact and the duration of each patient eye contact). The correlations between the independent variable and the dependent variables are summarized in Table3-4. Due to the data limitation, we were not able to separate the effect of individual physicians from the room layouts. The limitation was reflected in the result. The result showed that the effects of the angle on the total duration of patient eye contact ($F (2, 22) = 0.862$, $p=0.44>0.05$) and on the duration of each patient eye contact ($F (2, 22) = 0.734$, $p=0.494>0.05$) were both insignificant. The spatial attributes (confounded by physician assignment) also had insignificant effects on both dependent variables ($F (2, 22) = 0.562$, $p=0.581>0.05$; $F (2, 22) = 0.057$, $p=0.945>0.05$).

Source	The total duration of patient eye contact					The duration of each patient eye contact				
	Type III Sum of Squares	df	Mean Square	F	Sig.	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	71855.477[a]	4	17963.869	.452	.770	1631.177[a]	4	407.794	1.344	.294
Intercept	2318304.617	1	2318304.617	58.340	.000	3019.460	1	3019.460	9.951	.006
The angle formed by the monitor location and the patient position	68532.034	2	34266.017	.862	.440	445.705	2	222.852	.734	.494
Spatial Attributes (confounded by physician assignment)	44635.398	2	22317.699	.562	.581	34.492	2	17.246	.057	.945
Error	675544.264	17	39737.898			5158.551	17	303.444		
Total	3337207.747	22				9052.367	22			
Corrected Total	747399.741	21				1631.177[a]	4	407.794	1.344	.294

a. R Squared = .096 (Adjusted R Squared = -.117)

a. R Squared = .240 (Adjusted R Squared = .360)

Table 3-4 Hypothesis 2 Univariate Analysis Result

CHAPTER 4

DISCUSSION

This study examined the effect of the strategic placement of EHR on patient engagement and the physicians' musculoskeletal burden. The findings confirmed that the physician-computer interaction was a critical component of outpatient clinic visit. In this study, EHRs were used for major documentation tasks, including reviewing information and writing and dictating notes and orders, which was consistent with past literature (Yang & Asan, 2016; Asan, Smith, & Montague, 2014). We found that the physicians' time looking at screens was up to one-third of the total duration of patient visit. In their study of electronic medical record use and physician-patient communication, Margalit et al. reported the physicians spent nearly one-quarter of visit gazing at a screen (Margalit et al., 2006).

4.1 The physician-patient-EHR Triangle

The result of this study showed that the angle formed by an EHR and a patient might influence physicians' repetitive upper body motions. In our descriptive analysis, physicians in type-1 exam rooms with the smallest angle had the highest repetitive upper body motions (111.67 times). Under a small angle (smaller than or equal to 40˚), physicians tended to shift gaze frequently between the computer and the patient in order to maintain eye contact with patients. However, it turned out that each instance of patient eye contact was brief and the total duration of patient eye contact was also short. The plausible reason was that it was easy for physicians to shift gaze with minimal movement when the distance between the screen and the patient was short.

Whether these increased motions are beneficial to physicians' health or effective patient engagement should be further studied.

We also found that the angle might influence patient-physician eye contact. The result showed that, compared to both type-1 and type-3 exam rooms, the physicians in type-2 exam rooms had the longest total duration of patient eye contact as well as the longest duration of eye contact in each instance. One explanation could be that the slightly larger angle in type-2, compared to type-1, enabled physicians to have better focus on patients and thus maintained a longer eye contact. The duration dramatically reduced in type-3 exam room. This might be due to the fact that physicians needed to make extreme adjustments to face the patient and to face the screen. Whether the middle scenario of type-2 exam rooms indeed represents a more ideal arrangement for successful patient interaction is to be studied in the future.

The correlations between the angle from the physician's location to the computer and to the patient's location and (1) physicians' repetitive upper body motions ($F(2, 22) = 0.04$, $p = 0.961 > 0.05$), and (2) the duration of patient eye contact ($F(2, 22) = 0.862$, $p = 0.44 > 0.05$) were not significant. The following data limitations might be the reasons why significance was not achieved. Future research is needed to test the notions stated in this study.

A larger sample size is needed for such studies to control for confounding variables. For one, patients' health conditions need to be controlled: Primary care has to address a wide range of unknown syndromes and different stage of medical treatments, and this variety of patient conditions may influence physicians' communication strategies. For instance, a participating physician of this study usually spent only around 3-5 minutes on patient engagement, but in one particular well-being consultation, the physician spent 10 minutes out of 16 minutes 40 seconds looking at the patient and only 16 seconds using the computer. Similarly, physicians' individual approach to treat patients also needs to be controlled - different physicians will have different approaches even to the same case. Also, as clinics could be located in different areas (e.g., urban or suburban), population setting should also be regarded as a confounding variable. Lastly, while we focused only on patient-physician interactions in this study, it was likely that the presence of patient families also had influence over physicians' movements and postures. The role of families in the context of exam room design remains to be studied.

In addition to health conditions, patients' personalities, emotions, and cultural backgrounds might influence patient-physician interactions. For instance, physicians might need to spend more time listening to patients if they were talkative; physicians might also need to ease patients' anxiety if they were too worried about their illness, resulting in more extended visits; it was equally likely that physicians had to spend additional time explaining their orders if patients did not understand the physician, or had questions requiring clarification.

Another limitation of this study was that we were not able to assign physicians randomly to rooms. The three physicians in the dataset each used one of the three different types of exam rooms. Thus, we were not able to parse out the effects related to the physician's individual approach from those related to the room layout.

The placement of an EHR in an exam room might influence the level of patient engagement not just by the angle it formed but also by its distance from the patient

(Figure 4-2). We observed that when the computer was placed far away from the patient zone, patients often seemed distracted and both physicians and patients had to use a louder volume to communicate. Placing the computer too close to the patient zone might lead to usability issues for staff when they provided other treatments. For instance, we observed that the physicians had to maneuver the equipment to yield space for treatments. Thus, an optimum distance and angle should be identified to balance these competing needs.

Based on our observation, the inclusion of ergonomic furniture may help to reduce physicians' musculoskeletal burdens. In this study, the clinics used the wall-mounted computer system, which allowed physicians to adjust the height and orientation of the monitor and keyboard based on their needs. This seemed to be a positive feature of the three types of exam room designs, for that it might have reduced the physicians' risk of musculoskeletal disorders (Boothroyd & Hedge, 2007). Likewise, stool-on-wheels provided physicians the flexibility to adjust the height according to their needs, as well as to move to the optimal position to have conversations with patients (Figure 4-3). In addition, the adjustable exam table allowed patients to sit up straight when having a conversation with physicians. It might have mitigated the patients' risks of distraction and miscommunication (Figure 4-4) (Unruh, Skeels, Civan-Hartzler, & Pratt 2010).

4.2 Implications

In summary, corresponding to the nature of primary care, a good exam room design provides flexibility to support physicians' works. From our literature review and a case study, we can infer the following preliminary recommendations for exam room design. The System Engineering originating requirements tool (Table 4-2) was provided to create a description of the list of tasks that must be supported for an exam room design to be considered good. These inferences need to be tested before they are considered implementation strategies.

4.2.1 The Angle Between EHR and Patient Location

In our study, a room arrangement with an angle of 41˚-80˚ (Figure 4-1) indicated longest physician eye contact with patient compared with smaller and larger angles. A moderate frequency of repetitive upper body motions was noted for this typology. The findings suggest there may be an optimum angle to balance the competing needs of working with the monitor and focusing on patient. Future research is needed to identify that angle.

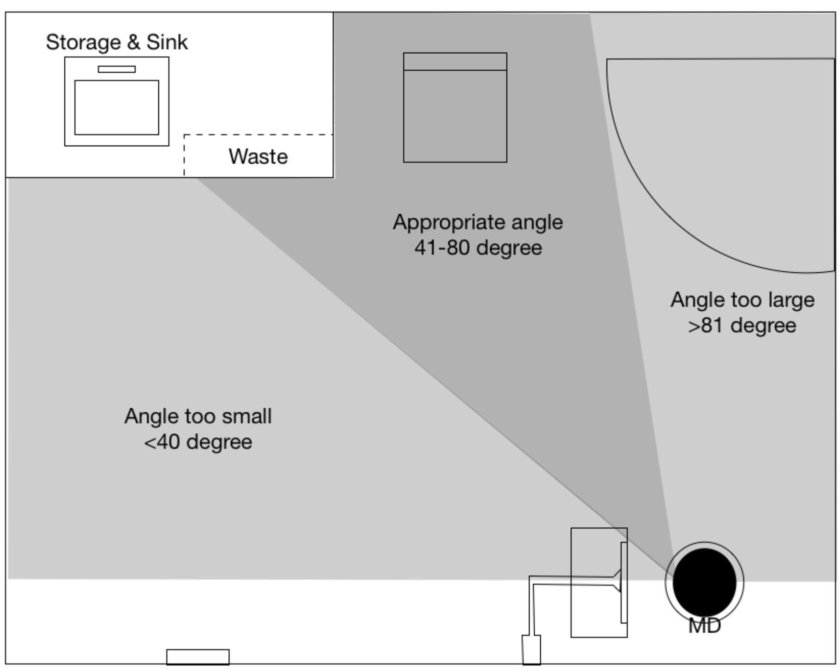


Figure 4-1 Preliminary Recommendation for Patient Location in an Exam Room

Also, in our observations we found that the distance between computer and patient may influence the patient-physician conversation quality. Therefore, we suggest that in an exam room, the EHR should be placed at the midpoint of the care provider zone and the patient/partners-in-care zone. This will allow physicians to share information on the EHR with patients while maintaining the usability of the space (Figure 4-2).

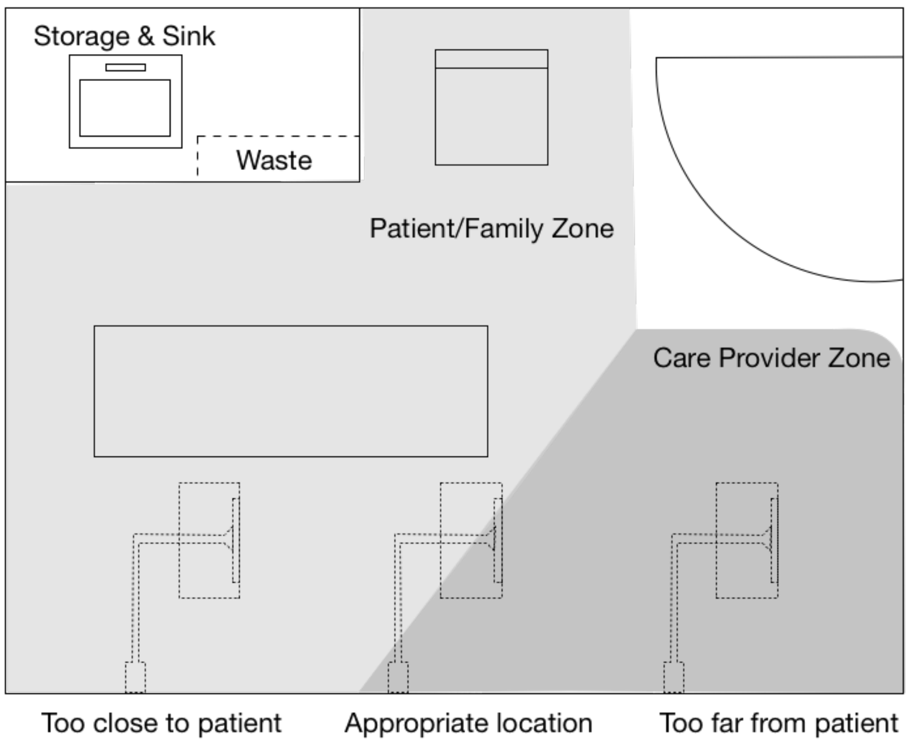


Figure 4-2 Preliminary Recommendation for the EHR Placement

4.2.2 The Use of Ergonomic Furniture

4.2.2.1 Wall-mounted EHR System

Studies have shown that the wall-mounted EHR system may reduce the user's risks of musculoskeletal disorders by allowing users to adjust computer screens' angle and height based on the situation (Boothroyd & Hedge, 2007). The exam rooms in this study had this feature which our observation indicated to be useful to physicians' work processes.

4.2.2.2 Stool-on-wheels

In our anecdotal observation, we found that providing a stool-on-wheels in an exam room might increase physicians' mobility while sitting. In this study, we noticed the stools-on-wheels (Figure 4-3) in exam rooms were widely used as they allowed physicians to move or turn their body to patients easily. It added flexibility for the physician to adjust the furniture based on their needs. Studies also show that a height-adjustable stool can reduce musculoskeletal burden when using computers (Hedge, 2013).

Figure 4-3 An Example of Stool-on-wheels

4.2.2.3 Adjustable exam table

Studies show that poor physical positions hamper communications between patients and physicians (Unruh, Skeels, Civan-Hartzler, & Pratt, 2010). In our study, we found that in some compact exam rooms, patients intended to sit on the exam table while having conversations with physicians. Therefore, we recommend that the exam room design integrate the adjustable exam table that enables patients to maintain proper positioning when having conversations with physicians (Figure 4-4).

Figure 4-4 An Example of Adjustable Exam Table

4.3 Use Cases

System Name	Physicians' interaction with a patient and using EHR in an Exam Room		
User	Physician		
Use case group	No.	Use cases	Priority
Interact with patient	1.	User greets a patient.	M
	2.	User asks a patient their history and reason for a visit.	H
	3.	User asks a patient questions.	H
	4.	User informs a patient their body status quo.	H
Use EHR	5.	User retrieves the history medical record to double check the information.	H
	6.	User retrieves the test results on EHR.	H
	7.	User shows a patient the test results.	H
	8.	User updates notes on EHR.	H
	9.	User arranges next visit on EHR for a patient.	H
	10.	User reserves next exam on EHR for a patient.	H
	11.	User cannot find the correct page to type down notes.	L
	12.	User realizes the computer operation system crashed	L
	13.	User cannot find the correct tab to retrieve the test result	L
	14.	User misreads the test result.	L
	15.	User does not have sufficient evidence to diagnose a patient's syndrome.	L

Table 4-1 System Engineering Use Cases

4.4 System Engineering Originating Requirements:

Index	Originating Requirements	Abstract Function Name
OR.1	The system shall be able to adjust the height of computer-keyboard-mouse to physician's PREFERENCE-HEIGHT1.	EHR height
OR.2	The system shall be able to adjust the screen orientation to face the exam table or to opposite the exam table.	EHR screen orientation
OR.3	The system shall be able to locate the EHR system in the mid-point of the patient/partners-in-care zone and care provider zone.	EHR location
OR.4	The system shall be able to allow a user to sit at the location that in respective to EHR and patient in 40-80 degree.	User Location
OR.5	The system shall be able to allow a user to maneuver the screen to avoid the screen block the sightline between physician and patient.	EHR screen location
OR.6	The system shall be able to provide a stool that allows a user to adjust the height to maintain a comfortable position when having a conversation with patients.	Stool height
OR.7	The system shall be able to provide a stool that allows a user to move around in the space efficiently.	Stool mobility
OR.8	The system shall be able to maintain the physician's workflow clear when they are changing position.	Workflow in the Space
OR.9	The system shall be able to put the exam table in flat.	Exam table position I
OR.10	The system shall be able to put the exam table in straight.	Exam table position II
OR.11	The system shall be able to adjust the height of the exam table.	Exam table height
OR.12	The system shall be able to notify the people outside the exam room when the room is in use.	Patient privacy

Table 4-2 System Engineering Originating Requirements

CHAPTER 5

CONCLUSION

5.1 Overall Conclusions

Exam room design is being influenced by the fast-growing focus of patient-centered care combined with the integration of information technology. Under the two trends, physicians have to keep patients feeling engaged whilst focusing on meeting the standards and following protocols presented through an EHR. Literature suggests that the physical environment of the exam room may affect health providers' ability to effectively provide care and minimize risk of injury.

This study further suggests that the strategic placement of an EHR may influence physicians' repetitive upper body motions and eye contact with patients. Due to small sample size and study design, we cannot draw definitive conclusions. But this study offered insight into possible directions in future research. We concluded that a range of optimal angle and a distance must be identified for the placement of an EHR and a patient in an exam room with respect to the physician's seating. Additionally, selecting ergonomic furniture and equipment is equally important to maintain patient eye contact and working with EHR without additional burden or musculoskeletal strain. We suggest to include furniture, such as height-adjustable stool-on-wheels, wall-mounted EHR systems, and adjustable exam tables, to improve exam room design.

5.2 Limitations of the Study

Although this study contributed insights to understand the relationships between the physical and virtual components in exam rooms, physician-patient interactions, and the physicians' musculoskeletal burden during patient visits, the actual outpatient clinic environments posed challenges to control confounding variables.

First, this dataset might be influenced by the Hawthorne effect during the data collection. The Hawthorne effect is also called observer effect. It refers to the situation in which individuals change part of their behaviors as a result of their awareness of being observed. In our study, the participating physicians wore the eye tracking device during patient visits, which was easily observable. In some cases, two observers from the healthcare institution participated in patient visits. These factors might have influenced the results.

Second, the coding of the study videos was completed by only one researcher, the principal investigator of this study. This raises the issue of possible bias. More than one coder should be included in future studies to increase inter-rater reliability.

APPENDICES

Appendix A Exam Room Floorplans with Furniture

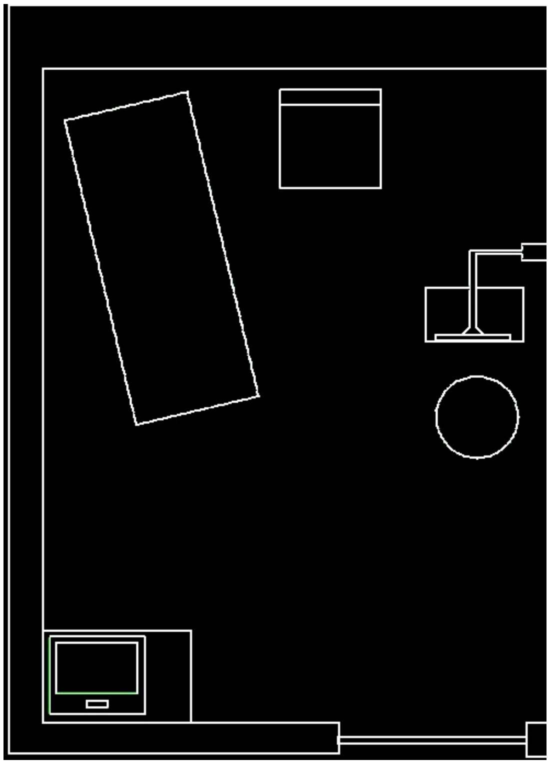


Figure B-1 Floorplan of Exam Room A-1

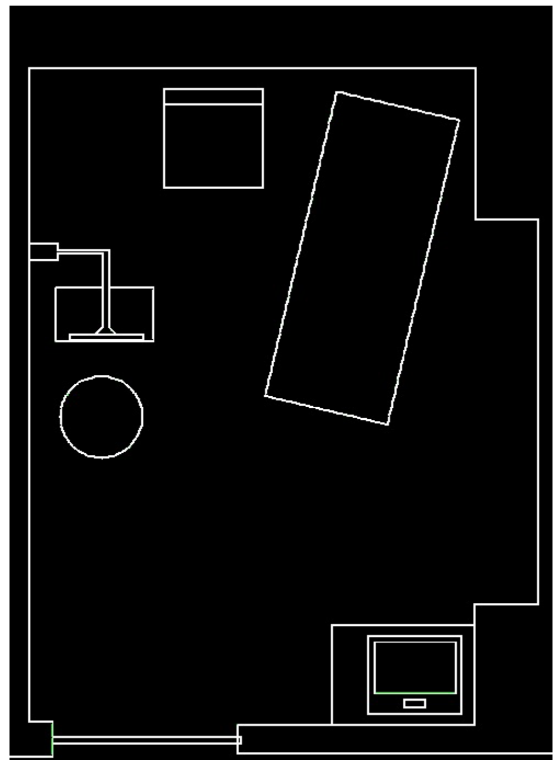


Figure B-2 Floorplan of Exam Room A-2

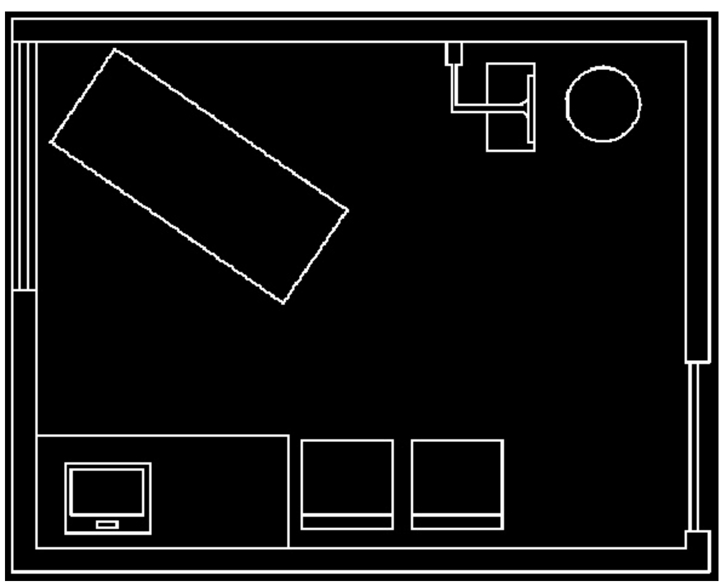


Figure B-3 Floorplan of Exam Room B-1

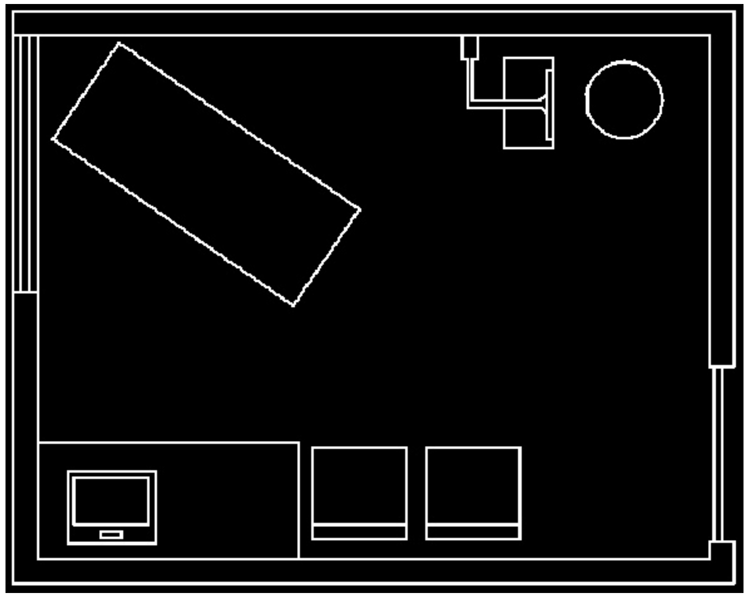


Figure B-4 Floorplan of Exam Room C-1

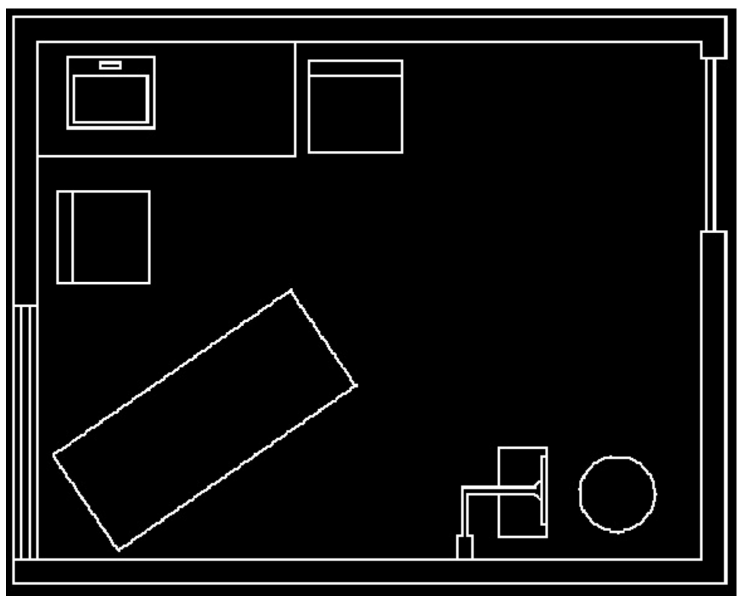


Figure A-5 Floorplan of Exam Room B-2

Appendix B The Measurement of the Angle (Selected)

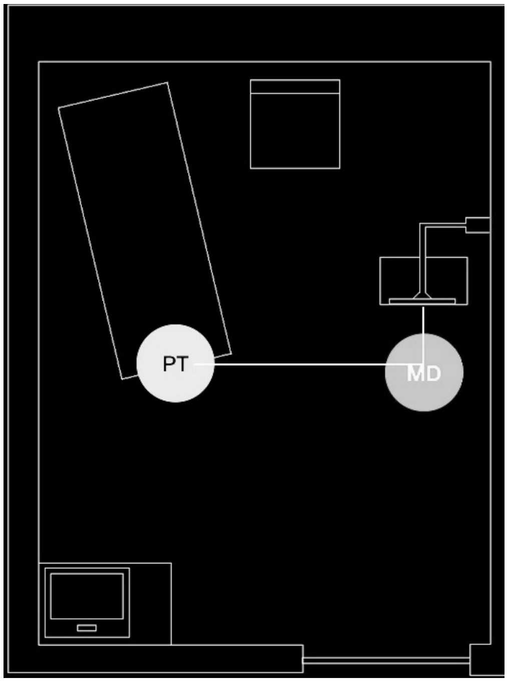


Figure C-1 The Patient-physician-EHR Angle in Exam Room A-1

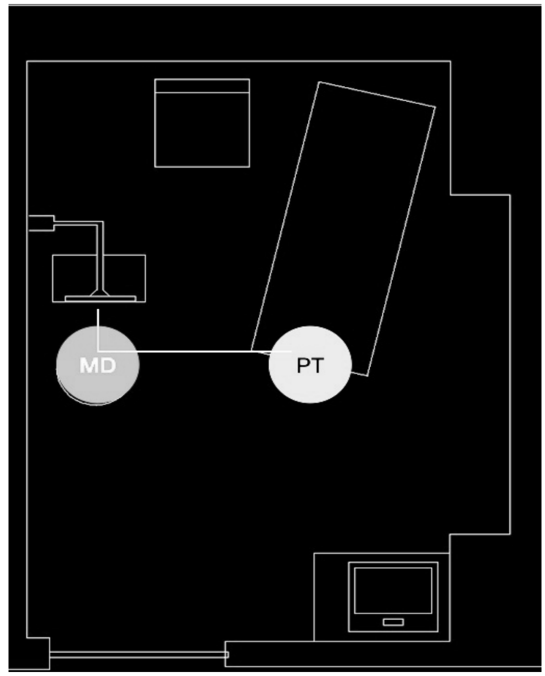


Figure C-2 The Patient-physician-EHR Angle in Exam Room A-2

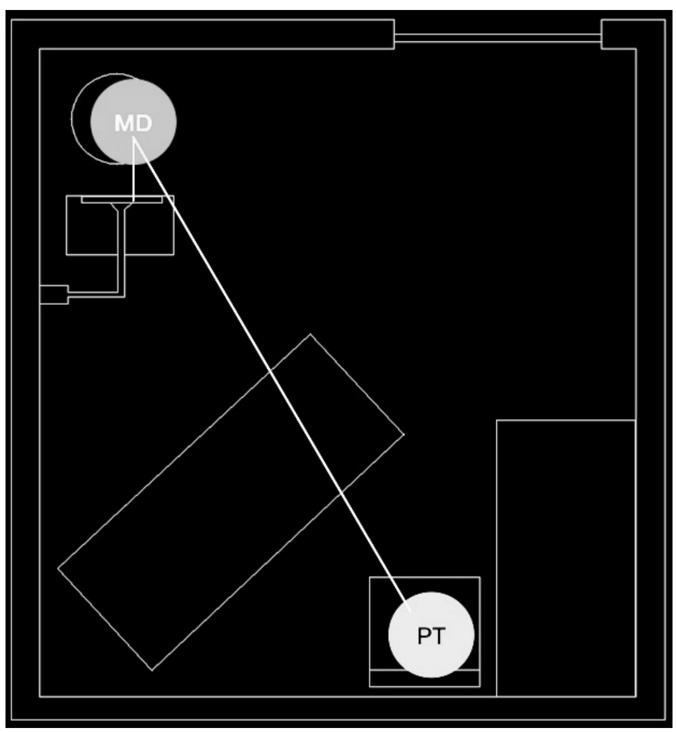
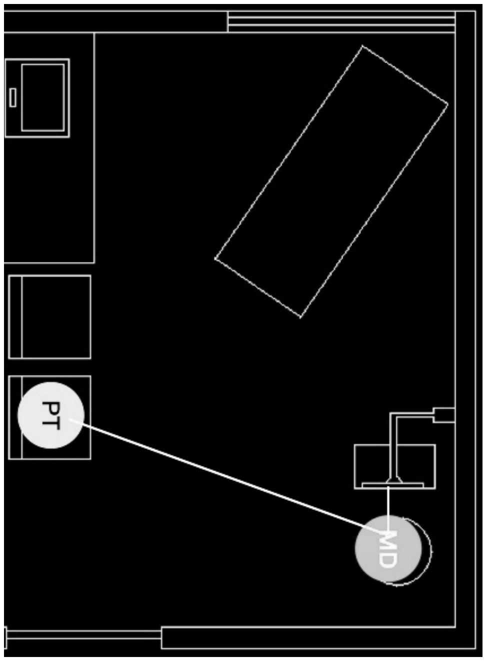


Figure C-3 The Patient-physician-EHR Angle in Exam Room B-1



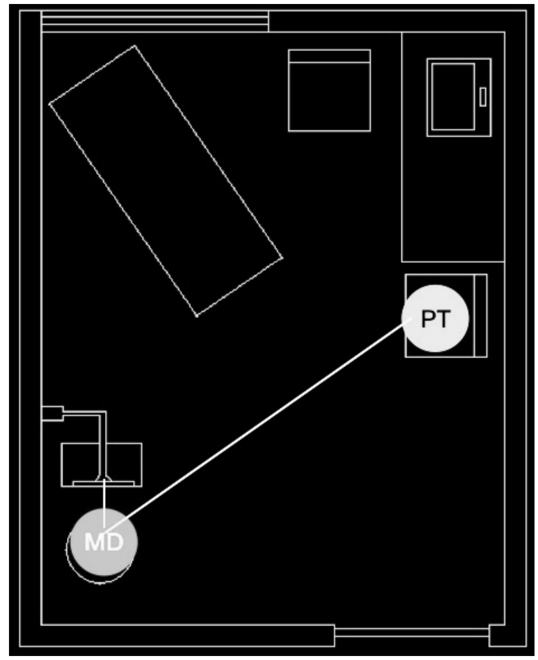


Figure C-4 The Patient-physician-EHR Angle in Exam Room C-1

Figure C-5 The Patient-physician-EHR Angle in Exam Room C-2

Appendix C Exam Room Floorplans with Only Wall Feature

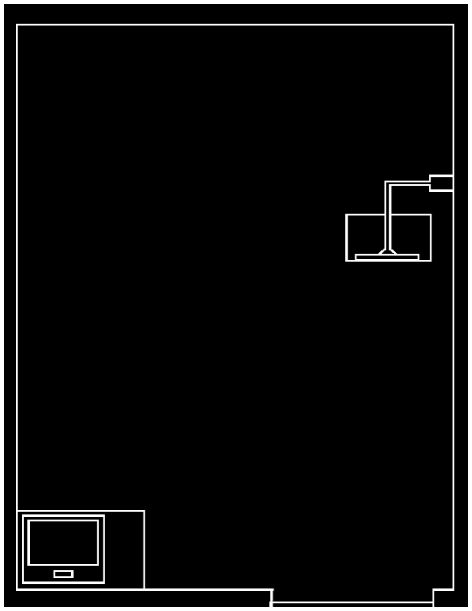


Figure D-1 The Exam Room A-1 Floorplan with Only Wall Feature

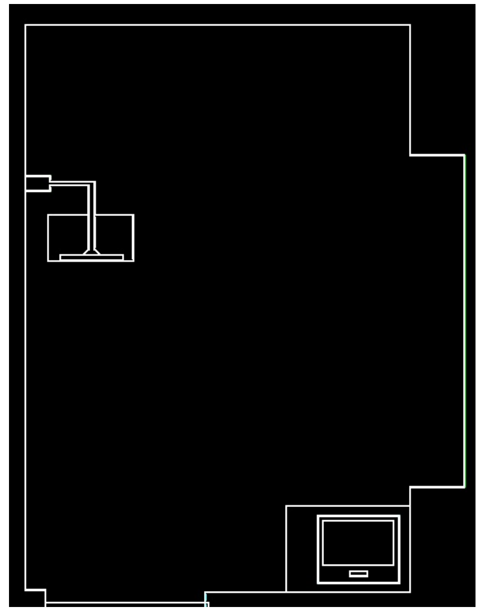


Figure D-2 The Exam Room A-2 Floorplan with Only Wall Feature

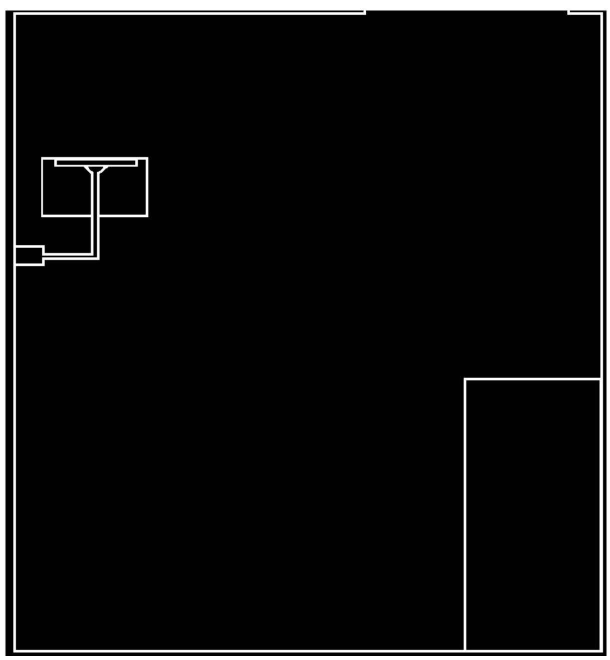


Figure D-3 The Exam Room B-1 Floorplan with Only Wall Feature

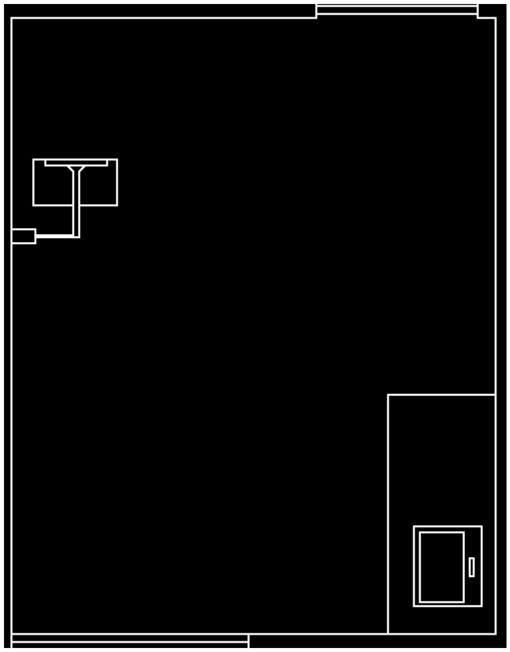


Figure D-4 The Exam Room C-1 Floorplan with Only Wall Feature

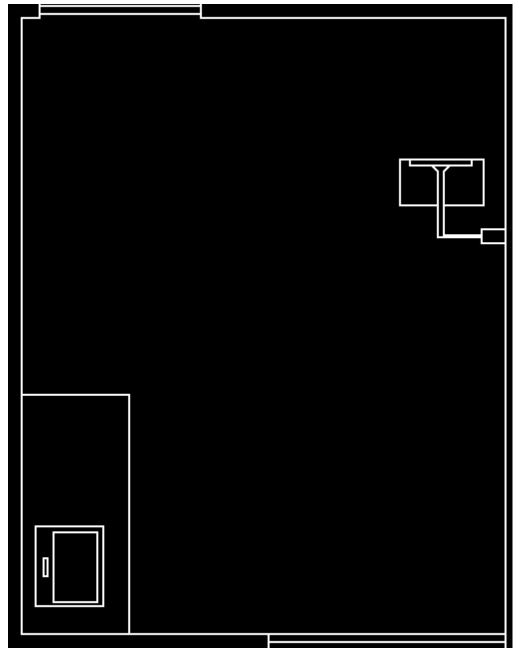


Figure D-5 The Exam Room C-2 Floorplan with Only Wall Feature

Appendix D Space Syntax Data

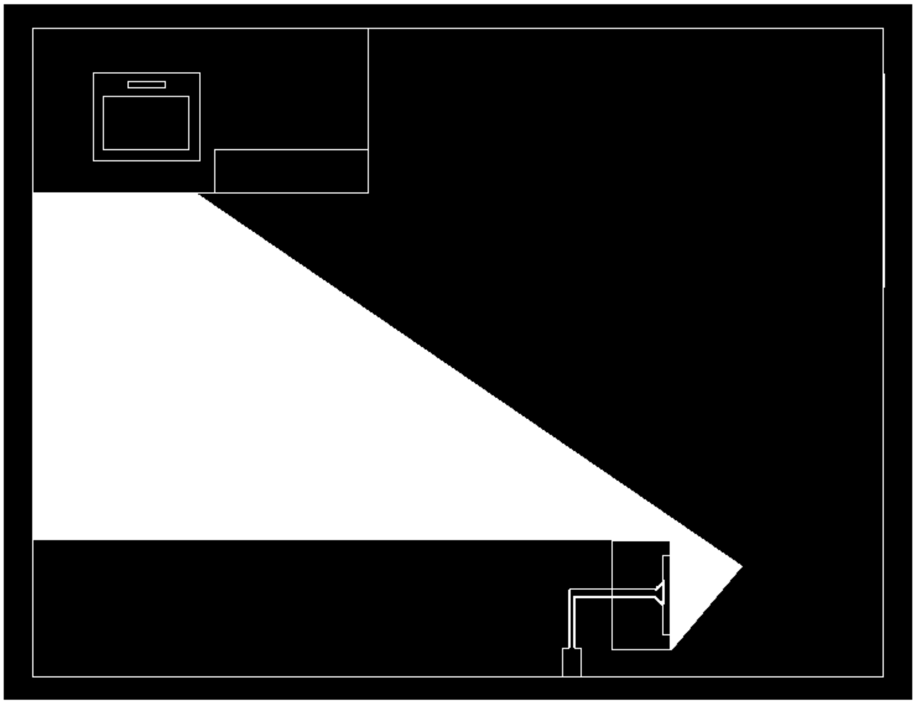


Figure E-1 Type-1 Exam Room (≤40°)

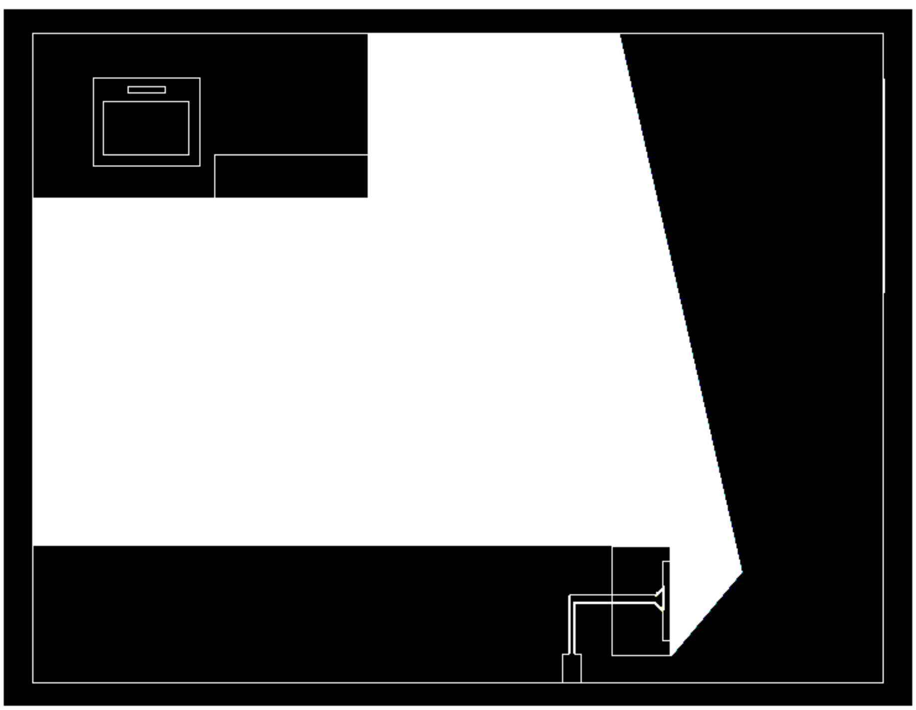


Figure E-2 Type-2 Exam Room (41°-80°)

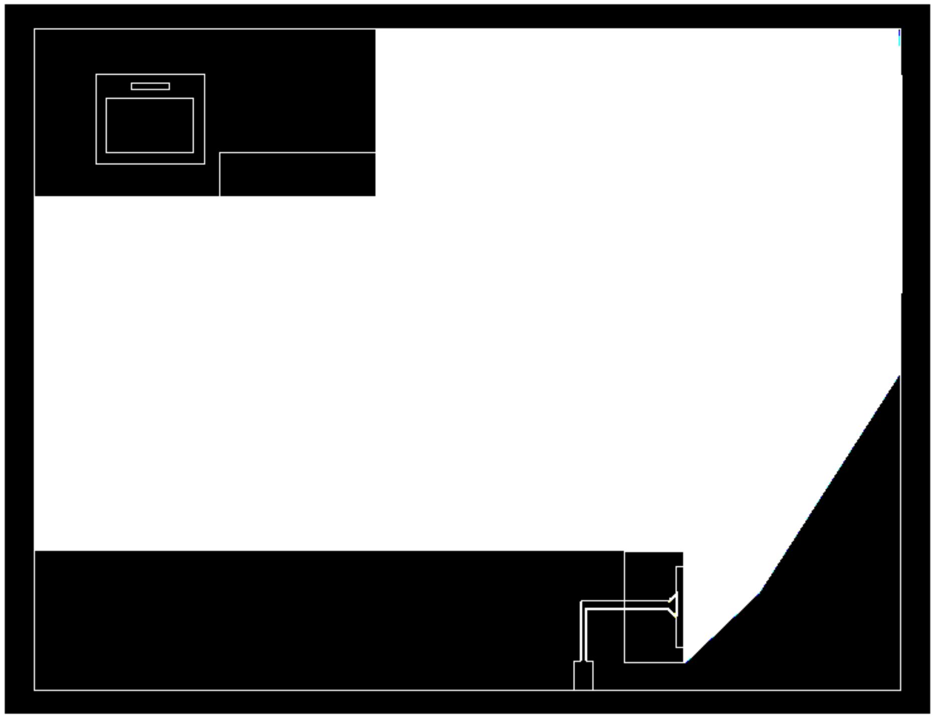


Figure E-3 Type-3 Exam Room (≥81°)

Appendix E Univariate Analysis Result

Dependent Variable: Physician's Repetitive Upper Body Motion

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	40997.542[a]	4	10249.385	7.272	.001
Intercept	89909.516	1	89909.516	63.794	.000
Room Type	112.244	2	56.122	.040	.961
Spatial Attribute	13279.143	2	6639.571	4.711	.024
Error	23959.413	17	1409.377		
Total	169837.000	22			
Corrected Total	64956.955	21			

a. R Squared = .631 (Adjusted R Squared = .544)

Table F-1 Univariate Analysis of Room Type and Spatial Attribute on Physician's Repetitive Upper Body Motion

Dependent Variable: Total Duration of Patient Eye Contact

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	71855.477[a]	4	17963.869	.452	.770
Intercept	2318304.617	1	2318304.617	58.340	.000
Room Type	68532.034	2	34266.017	.862	.440
Spatial Attribute	44635.398	2	22317.699	.562	.581
Error	675544.264	17	39737.898		
Total	3337207.747	22			
Corrected Total	747399.741	21			

a. R Squared = .096 (Adjusted R Squared = -.117)

Table F-2 Univariate Analysis of Room Type and Spatial Attribute on Total duration of patient eye contact

Dependent Variable: of looking at patient

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1631.177[a]	4	407.794	1.344	.294
Intercept	3019.460	1	3019.460	9.951	.006
Room Type	445.705	2	222.852	.734	.494
Spatial Attribute	34.492	2	17.246	.057	.945
Error	5158.551	17	303.444		
Total	9052.367	22			
Corrected Total	6789.728	21			

a. R Squared = .240 (Adjusted R Squared = .061)

Table F-3 Univariate Analysis of Room Type and Spatial Attribute on Duration of Each Patient Eye Contact

Appendix F Scatter Plot

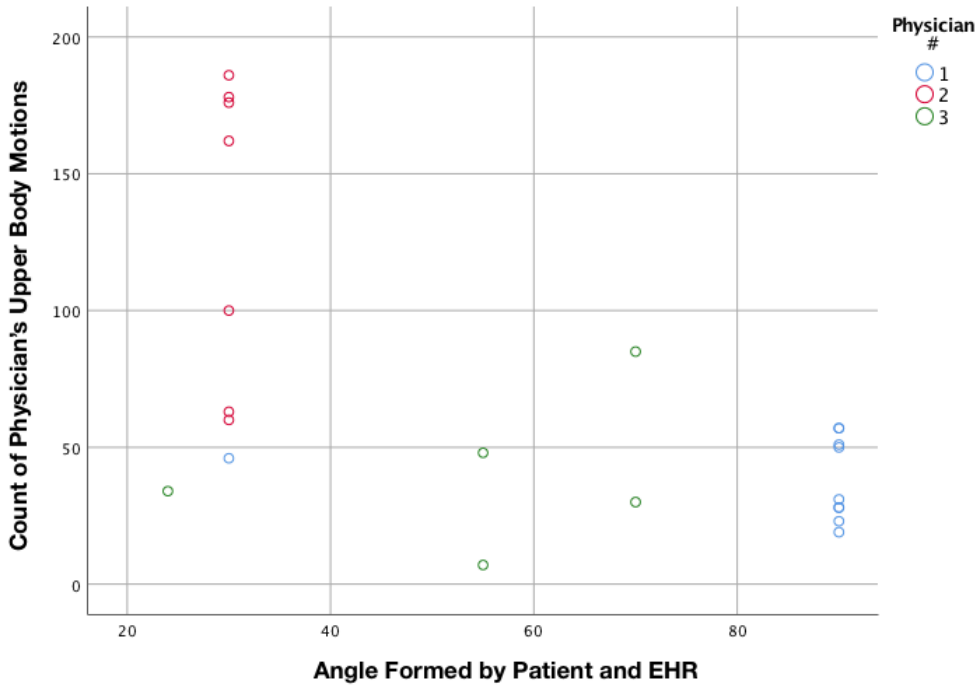


Figure G-1 Scatter Plot of the Relation between Angle and Physician's Upper Body Motions

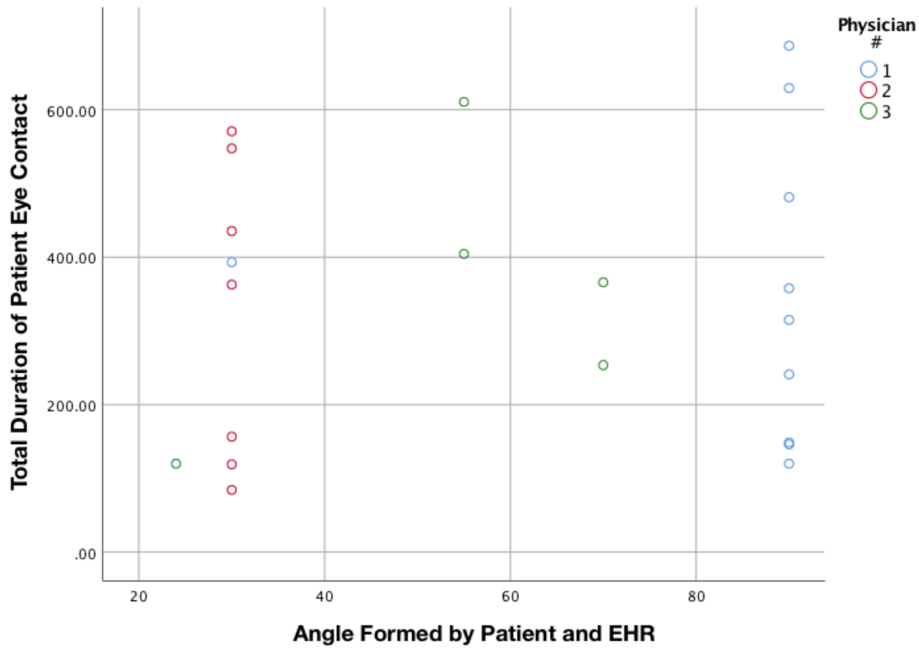


Figure G-2 Scatter Plot of the Relation between Angle and the Total Duration of Patient Eye Contact

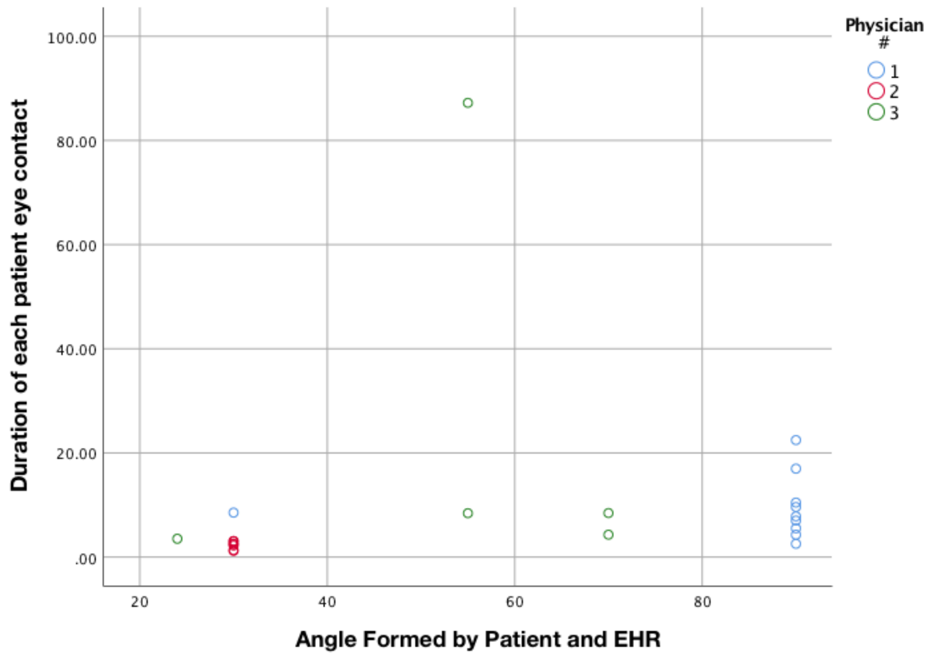


Figure G-3 Scatter Plot of the Relation between Angle and the Duration of Each Patient Eye Contact

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