# An Experiment on the Effects of Interruptions on Individual Work Trajectories and Performance in Critical Environments

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## Abstract

*Interruptions are a central characteristic of work in critical environments such as hospitals, airlines, and security agencies. Often, interruptions occur as notifications of some event or circumstance that requires attention. Notifications may be delivered actively as disruptions requiring immediate attention, or passively as unobtrusive background messages. This research hypothesizes that the way notifications are delivered can have an impact on how work unfolds over time, which in turn can affect performance. Based on theories of interruption and observations in an actual operating room, a computer-based role-playing game simulating the scheduling of surgeries in an operating room unit was developed. An experiment was conducted using the game to examine the effects of different types of notification delivery on work trajectories and performance. Results indicate that the way notifications are delivered can indeed influence work trajectories and, consequently, performance.*

## 1. Introduction

The structure of many vital organizations that operate in critical environments, like hospitals, airlines, security agencies, and others, is team-based. Safety, efficiency, and performance in these contexts depend not only on the professionalism of each team, but also on the ability of the organizations to support coordination and collaboration across teams, tasks, and resources. Coordination problems across teams are common and are a significant cause of errors, miscommunications, and even loss of life [1, 2]. To develop adequate technologies to support these processes, we need a deeper understanding of how different professionals manage multiple tasks and interruptions. We adopt the concept of trajectory to refer to the sequence of activities and paths through which people and resources move in organizations [3]. In distributed and dynamic environments, the orchestration of trajectories is needed to ensure that people and resources intersect at the right time to achieve an objective [3].

Operating rooms (ORs) are characterized by the interdependence of multiple professionals working on multiple tasks. These professionals, ranging from physicians to nurses, technicians, and clerical staff, are brought together in order to perform services. Of course, the multiple agendas that drive various professionals mean that team goals are ill defined and sometimes conflicted. Moreover, events such as emergencies, cancellations, and unprepared or absent patients create continually dynamic conditions that can upset plans at any moment. Thus, successful surgery depends on a team of highly specialized care providers showing up and working effectively together. Personal and financial stakes are high for the hospital, the care providers, the patients and their families. The needed expertise and resources have to be carefully coordinated to ensure safety and operations efficiency.

In this paper, we adopt the notion of trajectory to refer to the sequence of activities through which a person or entity moves over time. We consider the effects of interruptions on the trajectories of three people role playing medical professionals in a web-based simulation of a master schedule in an operating room. In particular, we explore two types of interruptions players receive on the simulation interface: (1) messages that actively pop-up on the screen or (2) messages that are passively sent to an electronic messaging board. Our goal is to understand how these two types of interruptions affect individual trajectories and performance in critical work environments. Trajectories are examined by observing how often players switch from the master schedule to a secondary task of responding to a reading comprehension task. Performance is based on how well players coordinate surgeries in the master schedule and how many correct responses they are able to complete in the reading task.

We first discuss the concept of trajectories in the context of hospital work. Next, we present the theoretical background behind our study and our research hypotheses. Finally, we present the development and findings from a laboratory study of 39 players divided into 13 teams and discuss implications from these findings.

## 2. Managing trajectories in hospital work

The distributed, dynamic environment of a hospital is characterized by high workload, time pressure, and limited resources. In this environment, patients, staff and resources must interweave or intersect at specific times for specific purposes [4]. For example, the paths of a surgeon, a patient, and the OR meet at the time of the patient's surgery, but not before or after this time. Coordinating multiple trajectories of events and activities requires the orchestration of these trajectories so that they are intersecting or separated at the right time [5].

Team configuration decisions cannot be predicted very well because they depend not only on known parameters, such as the number of OR rooms or patients in the queue, but also on the decisions of other OR medical teams, on the availability of team members who may be attached to multiple teams, and on external and complex unpredictable events such as a spate of accidents. In critical environments like these, coordination problems across teams and specialties are important factors leading to inefficiency and a range of adverse events [6] including dangerous interruptions due to phone calls, pagers, and the need to continually negotiate resources [e.g. 7], and last minute decisions based on availability and time pressure rather than triage guidelines [8].

Taken together, hospital work requires intensive coordination among trajectories for staff, patients, and resources. Although scheduling algorithms can be used as a starting point for coordination, the dynamic nature of medical work makes preset schedules untenable in many situations [9]. Surgeries can last longer or shorter than anticipated, requiring on-the-fly adjustment of the surgical schedule. Patients can experience setbacks that affect their planned trajectory, and doctors, nurses and other staff can experience interruptions that affect their work trajectories. Even fixed resources, which would seem to be stable, can experience unplanned changes—equipment breakdowns and repairs, rooms that need to be disinfected with special agents, and computer viruses. At the same time as any one trajectory is experiencing change, others are changing too, necessitating adjustments in still other, related trajectories.

### 2.1 Trajectories and interruptions in OR scheduling

In scheduling cases in an OR for a given day, there is extensive prior planning that is designed to maximize efficiency; planning and scheduling are done for the long-term schedule to fit staffing requirements, as well for the short-term surgical schedules for individual cases. Despite these planning and scheduling efforts, much coordination effort is needed on the day of surgery. A charge nurse (CN) is employed to "run" the OR scheduling. The CN has to deal with a number of trajectories, including the status of each patient, the availability of OR nurses, the status of the OR room, the availability of anesthesia care providers, and the availability of the surgical team [10]. Although there is a scheduled start time for any case, the CN and others must monitor these trajectories and their inevitable changes through a range of communication mechanisms, such as face-to-face encounters, phone calls, and paging messages. In many situations, the coordination of trajectories is vastly more complex due to the number of trajectories to be considered and due to the fact that these trajectories are interwoven in complicated ways, as many workers are multi-tasking and collaborating with different people over time:

A senior surgeon is scheduled to perform an operation in the OR soon while at the same time she is leading the discussion of discharge plans for intensive care unit (ICU) patients. She is deciding on when to pause the discussion with the ICU staff and to go to OR.

An anesthesiologist in a trauma center is taking care of a patient in the OR with an assistant while providing coverage for the needs of unpredictable incoming trauma patients. He is deciding on how best to triage his time between the two tasks.

Because of the interwoven nature of trajectories among multiple people and tasks, interruptions are expected as people move from one activity to another [11]. Though there has been a growing body of field and ethnographic research investigating the dynamics of an operating room [e.g. 5, 10, 12], there have been few empirical studies to understand how people actually perform when faced with multiple trajectories and interruptions.

Based on observations conducted in an actual operatinr room unit, we developed a web-based role-playing game to simulate a master schedule in an OR. In this game, we ask three players to manage a simulated OR master schedule, with the goal of attending to OR scheduling dynamics as they manage their individual trajectories and objectives in the face of interruptions. Our goal is to answer the following research questions:

- How do different interruption delivery methods affect players' trajectories?
- How do players' trajectories affect their performance on competing game tasks?

## 3. Theory and hypotheses

Interruptions have been defined as incidents or events that disrupt the continuity of work [13, 14], or the process of coordinating abrupt changes in people's activities [15]. Researchers have observed that interruptions can have both positive and negative consequences. Because interruptions affect allocation of finite cognitive resources across tasks, they may result in decreased accuracy, increased error rates, and reduced efficiency [16-20]. They can also have psychological consequences such as increased stress [21, 22] and feelings of “time famine” [23] and role overload [24]. However, interruptions can also provide valuable cues for the proper execution of critical tasks, as well as opportunities for informal feedback and information sharing [14]. These advantages may be particularly important in environments such as hospitals, where timely access to information is crucial to patient safety.

Research has also indicated that the source of an interruption and the way it is managed by the recipient is likely to influence the performance outcomes. People can interrupt their own work as well be interrupted by others [25]. Self-generated, or internal, interruptions originate from the thought processes of the individual, while external interruptions result from events in the environment [26]. Internal interruptions may be advantageous because they are more likely to occur at natural boundary points in tasks when cognitive resources become available, mitigating the psychological cost of task switching. However, because internal interruptions originate from internal thought processes, reliance on these interruptions may result in untimely response to events that arise in the environment, especially when these events occur unpredictably. In such cases, external interruptions may facilitate a more timely response. For example, consider a hospital charge nurse who is responsible for staffing surgeries with nurses. If an assigned nurse becomes unavailable before a surgery, the charge nurse must find a replacement nurse for that surgery. This situation could be handled by posting changes to nurse schedules to a bulletin board, which the charge nurse must periodically check (an internal interruption). Because changes are likely to occur unpredictably, however, the charge nurse may fail to address the problem in time. Alternatively, the charge nurse could receive a page (external interruption) when a nurse becomes unavailable. She can then respond immediately to the scheduling problem, though this response may come at some cost to the activity being interrupted.

In critical environments such as hospitals, external interruptions often notify recipients of emergencies or urgent events. Consequently, these interruptions are more disruptive because people may need to respond immediately. In contrast, internal interruptions are less disruptive because people can negotiate when to respond to the event Recent research on how people respond to interruptions suggests that overall performance is improved when people can “negotiate” when to respond to the interruption than when the environment demands they attend to an event [27, 28]. McFarlane [28] also found that people who could negotiate interruptions switched tasks less frequently than people who had to respond immediately. However, he observed that giving people this control means that they may not handle interruptions in a timely way. When people are forced to handle interruptions immediately, they get the interruption task done promptly, but they make more mistakes and are less effective overall.

### 3.1 Research context and hypotheses

In this study we develop a role-playing game to simulate a master schedule of an operating room unit in a hospital. The game involves two tasks: a highly time-sensitive surgery scheduling task and a reading comprehension task. These tasks were chosen to represent (in a simplified context) the multi-tasking environment of actual hospital employees, which includes both collaborative and autonomous activities that must be allocated within a finite time period. Interruptions are operationalized as notifications that players receive during the game. Notifications are delivered in two ways: active notification (external interruption) and passive notification (internal interruption). Trajectories are operationalized as the frequency of task switches made by each player over the course of the game.

Based on the research cited above, we develop hypotheses about how certain types of interruptions will affect performance in the game. Consistent with McFarlane [28], we first hypothesize that the type of notification (interruption) will influence the frequency of task switches. Specifically,

- H1: Active notification (external interruption) will result in more frequent task switching as compared to passive notification (internal interruption)

Because active notifications alert players to problems associated with the master schedule, we expect that task switching prompted by these alerts will improve performance on the scheduling task. However, frequent task switching disrupts the cognitive processing required for the reading comprehension task and limits the amount of time players can spend on this task. Interrupting cognitively complex tasks has been shown to decrease performance [e.g. 29]. Thus,

- H2: Frequent task switching will lead to higher performance on the scheduling task
- H3: Frequent task switching will lead to lower performance on the reading task

## 4. Method

## 4.1 Observations of an operating room

To inform the design of simulation, we performed an ethnographic study of an OR unit at Southwest Medical Center (SMC). We conducted semi-structured interviews with OR professionals, observed OR activities, and consulted internal documents. We coded the qualitative material by identifying recurrent themes mentioned by the participants and situations in which coordination problems were associated with OR scheduling [30]. Three themes emerged: coordination across roles, competing tasks and objectives, and interruptions.

**4.1.1 Coordination across roles.** The members of different professional teams have multiple tasks to accomplish, requiring them to manage their own trajectories.

*"During the day, anesthesiologists do not work only in the OR. They are involved in academic and research activities, for example. They need to dedicate time to lectures, reading, classes, teaching, and clinical research projects. I am on the board of a medical journal. Then there are other meetings, the visits to patients on the floor, and so on."[A2]*

The trajectory of every professional also intersects with the trajectories others (e.g., during surgery, the trajectory of an anesthesiologist intersects with the trajectory of a surgeon) or fails to do so (e.g., the anesthesiologist needs to postpone a surgery because the surgeon is late). As we noted earlier, the effective coordination of these activities is performed by the charge nurse. According to one surgeon talking about the charge nurse,

*"The charge nurse is responsible for controlling the schedule on the day of surgery and for assuring the routine activities to follow. She communicates with the anesthesiologist in charge and with the surgeons to be sure that everything is ready for surgery." [S1]*

The coordination is performed through face-to-face interactions, phone calls and the use of visual artifacts. The main visual artifact is the master schedule, a whiteboard that represents all the surgeries that are scheduled for that day. For example, the master schedule is used by nurses to know when they need to perform their activities.

*"Nurses are in charge of cleaning up the OR, preparing the patients and assisting during operations. They typically do not need inputs by surgeons, anesthesiologists or the charge nurse. In fact they organize their work autonomously, looking at the master schedule." [CN1]*

**4.1.2 Competing tasks and objectives.** Because professional groups have varying priorities, experience, and backgrounds, there are bound to be conflicts [3, 31]. We observed conflicts between all members of the OR unit. Surgeons were often perceived as uncaring, or "cutters." As one anesthesiologist put it:

*"Surgeons don't know too much about the general conditions of patients. They are more focused on the specific procedure and that is it."[A1]*

One charge nurse told us:

*"I believe that reassuring patients and families and offering them a relaxing and comfortable place is an important part of my job. It is fundamental to give the impression that patients are not just bodies to be processed."*

In contrast, nurses are perceived by anesthesiologists and surgeons as being not flexible in responding to interruptions or to special needs. A surgeon, for example, told us that when he is "nasty and scary," the charge nurse will "give you the best staff."

Moreover, the different work schedules and incentives that are given to the professional groups can create an atmosphere of conflict and misunderstanding. One surgeon made this point:

*"Nurses work for the first shift, until 3 pm. So when it is 2:30, they do not want to begin another case because it will put them over their shift. There are no incentives if they stay longer. Surgeons are paid with a different logic. They are given a certain salary that corresponds to a certain number of cases and after that they are paid extra. This means that they are willing to add cases and stay longer." [S2]*

These different attitudes, values, and behaviors translate into different objectives and priorities in the execution of work and thus add to the cost of coordination. of a more cumbersome process.

In spite of the differences, the people we talked with in the OR agree that the overall effectiveness of the unit should be measured by patient safety, that is, that all surgeries are performed without harm to the patients.

*"At the end of the day, the operations in the ORs are considered successful if no harm has been done to the patient. Patient safety is the bottom line to judge the performance of the teams. Even nurses are willing to stay over time if patient safety is at risk." [A2]*

**4.1.3 Interruptions.** Clinical work in the operating room begins with the arrival and health assessment of the patient. When a patient arrives, the charge nurse contacts the anesthesiologist in charge so the patient can be moved the pre-operating room. The charge nurse also informs the surgeon that the patient is in the unit. These two examples of the charge nurse giving information to others may, in turn, interrupt the current trajectories of the anesthesiologist and surgeon. Interruptions can originate within the OR unit as they relate to the scheduling process (internal), or they can originate from outside the unit, as when a patient unexpectedly arrives from the emergency room.

*"The scheduling [of work activities on the day of surgery] is complicated by night emergencies. If an anesthesiologist has*

*been working all night on a heart transplant, he cannot be available the next day. It is necessary to reschedule." [A1]*

If an interruption concerns a conflict or problem with a surgery, medical professionals in the OR need to agree on how to update the master schedule. Such updates, however, may affect other professionals in the unit who are scheduled for that day. One charge nurse we interviewed identified some recurrent interruptions in the OR unit where she worked (see also [12]). They include not sufficient staff available, health of the patient requiring surgery to be rescheduled, surgeries taking longer than expected, adding a patient due to an emergency condition, and surgical equipment or instruments not being available when needed.

Because different professional groups have varying priorities, experience, and backgrounds, some conflict arose among all OR professionals. Their work schedules, attitudes, and incentives can engender an atmosphere of misunderstanding, and can thus add to the cost of coordination. Yet in spite of their differences, the professionals we interviewed all voiced the importance of ensuring patient safety so that all surgeries are performed without harm to the patients. This objective overrode adherence to the master schedule.

## 4.2 Design of the OR Simulation

The observations and interviews we conducted in the OR, as well as the field studies and observations from the literature [e.g. 10, 12] informed the design of our simulation. We drew upon the themes discussed in the previous section to guide the design of the game structure. Figure 1 shows how we incorporated the themes we identified into the characteristics of the simulation. Each of these characteristics is described further below.

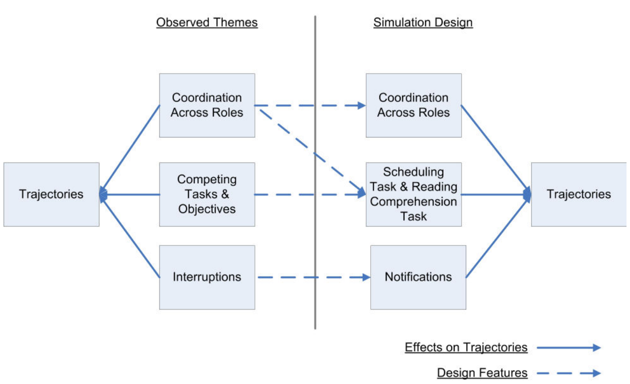


**Figure 1. The link between the themes identified through interviews and observations and the characteristics of the simulation**

**4.2.1 Coordination across roles.** The simulated game includes three players who take on the role of the Charge Nurse (CN), the Anesthesiologist in Charge (AIC), and the Surgeon Coordinator (SC). They are responsible for coordinating the Master Schedule of an OR, as well as for working individually to respond to questions on a reading comprehension task. Players schedule surgeries during a single 8-hour work shift, and are each responsible for a subset of resources (e.g. the CN is responsible for nurses, the AIC is responsible for anesthesiologists, and the SC is responsible for surgeons). To successfully schedule surgeries over the course of the simulation, interaction among the players is required. (Game time moves at an accelerated pace: 8 hours of game time are simulated in 1 hour of real time.) One goal of the simulation is to ensure that surgeries are scheduled and conducted within the 8-hour shift. To do that, players need to coordinate their activities to respond to unexpected events (depicted by warning icons). In addition to this goal, each player has the individual objective of completing a reading comprehension exercise. The scheduling task and the reading comprehension task are described further below.

**4.2.2 The scheduling task.** The scheduling task requires management of a dynamic master schedule of a 4-room operating unit. The simulation begins with an initial master schedule containing scheduled surgeries for an 8 hour work shift. Figure 2 shows an initial master schedule containing information about the surgeries that will be performed during the game shift. Each surgery includes a surgeon, two nurses, an anesthesiologist, and equipment. The initial master schedule is modified during the course of the game as players receive notifications of unexpected events (e.g., a surgery is going to be 30 minutes late due to complications), and then make the appropriate changes (e.g., move the surgery that follows the late one) The initial master schedule was constructed based on the document data we obtained from an actual OR unit.

Each player in the game is responsible for a subset of resources and must manage these available resources. Since not all players control the same resources, the players share responsibility for the master schedule and must interact with the other members of their medical team.

The simulation is designed so that the three players can complete both schedule surgeries and read the cases within the 8-hour shift. If, however, interruptions are not managed in time, surgeries have to be moved in ways that often result in problems later on. This may necessitate rescheduling yet other surgeries, resulting in potential scheduling conflicts or overtime requirements. Errors such as these affect the score for the scheduling task, which is described further in section 4.5.

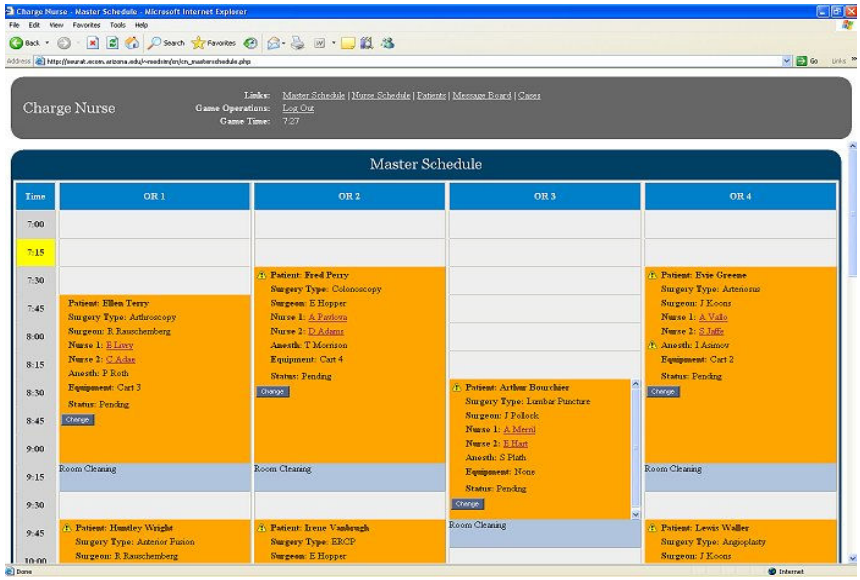


**Figure 2. The master schedule**

**4.2.3 The reading comprehension task.** The reading comprehension task consisted of 3 reading passages followed by 4 multiple choice questions per passage, for a total of 12 questions. We chose reading cases, since many of the professionals we interviewed often had to read hospital documents, medical journals, and patient charts. Reading passages were taken from sample graduate entrance examinations such as the Graduate Management Admission Test (GMAT). We chose cases that had an average level of difficulty. Pilot tests revealed that students could complete both tasks in sufficient time.

Participants viewed the reading passages and multiple choice questions on a single scrollable web page. Answers could be changed until the game time expired, at which point all answers were recorded in the game database. Once a question had been answered, it could not be changed back to an unanswered status. Scoring for the reading comprehension task is described further in section 4.5

**4.2.4 Notifications.** During the game, all players receive 8 notifications, of which 6 require changes to the master schedule and 2 are unrelated to the master schedule (see Table 1). In addition, the CNs receive 10 notifications informing them that a patient has arrived. (When a patient arrives, the CN moves the patient to the pre-op, and then must inform the AIC, so that the AIC can move the patient from the pre-op to the OR.) The timing of the notifications was designed so that players could not anticipate when they would occur. All notifications occur in the same order and at the same time across games.

**Table 1. Game notifications**

| Notification text | Delivery time (elapsed time) |
|---|---|
| Anesthesiologist I Asimov is sick for the rest of the day | 0 min |
| Surgery for Evie Green has complications. It will take 30 minutes longer than expected. The master schedule has been updated, but please check staff schedules. | 6 min |
| Cart 1 needs maintenance. It has been sent to the materials management department. It will not be available during the shift. | 15 min |
| Nurse P Legnani has gone home sick for the rest of the day. | 19 min |
| Notice: the 3rd floor cafeteria will be closed for remodeling for the next 4 weeks. | 23 min |
| The surgery for Irene Vanbrugh is going very well. It will take 1 hour less than expected. The master schedule has been updated. | 28 min |
| Anesthesiologist T Morrison is not feeling well. She will go home for the rest of the day. | 39 min |
| The hospital will be hosting its annual spring social on March 24. Please come and join us for good food and festivities. Families are welcome. | 51 min |

To examine the effect of interruptions on trajectories and performance, we present players with the following types of notifications: In the active notification condition, players are interrupted by pop-up messages that notify them of problems or events. In the passive notification condition, interruptions are posted on an electronic message board, which the players must remember to check periodically. These notification delivery methods represent a simplified abstraction of active/passive notification methods found in actual hospitals, such as pagers and bulletin boards. A control group without interruptions was not included, since without interruptions the scheduling task would become too simple and the player would spend almost all of her time on the reading task.

## 4.3 Participants

Thirty-nine participants were recruited from a business course designed to instruct students about scheduling dynamics. We chose to begin our data collection with business students to observe their ability to play the game without a medical background. We assumed that if business students could play the game, then the expense of using medical professionals in subsequent games would be warranted. The 16 graduates (41%) and 23 undergraduates (59%) received course credit for their participation in the experiment. There were 13 three-person games, with 7 games in the active notification condition and 6 games in the passive notification condition. We randomly assigned teams to conditions and players to roles. In all but four games, teams were made up of either an all graduates or all undergraduates. Of the 6 teams in the passive notification condition, there were three teams of all graduates and one team of all undergrads. In the 7 teams in the active notification condition, there were one all graduate team and four all undergraduate teams. There were no differences in performance between teams with all graduates or all undergraduate. Most of the participants were male (69%). Both graduates and undergraduates and males and females were about 24 years old. Only two students had any amount of previous hospital work (both minimal), and computer game experience was fairly evenly distributed across the participants.

## 4.4 Procedure

Participants were brought to the computer laboratory where they randomly drew the role they would play from a cardboard box. They were then asked to sit in the seat labeled with their role, where they were instructed about their tasks and how to play the game. The instructions involved a demonstration, where participants were guided through an example surgery in which they resolved scheduling conflicts so that the surgery could take place. Various types of scheduling problems were deliberately included in the example surgery, and all participants could see the computer screens and responsibilities of the other players. After working through the scheduling task, participants were shown how to access the reading task and were briefly instructed on how to complete it. Next to each player's computer was a written summary sheet outlining the objectives of the game and specific guidelines to follow for the role they were assigned to play. Participants were told to that their overall performance would depend equally on how well they met their objectives and followed the guidelines in both the scheduling task and the reading task.

After completing the instructions, the experimenter began the simulation. A continuous game clock was displayed at the top of the screen and 15-minute game time intervals were shown in the rows of the Master Schedule, with the current period highlighted. Participants' actions were monitored by the system as they moved from screen to screen, and the game automatically ended after one hour. Participants were then asked to complete a post-game questionnaire, after which they were debriefed.

## 4.5 Measures

*Scheduling Task Performance.* Performance on the scheduling task was measured by subtracting points for each scheduling mistake a group made (i.e. failure to meet an objective or follow a guideline) from a 100-point target score. Points were deducted based on the gravity of each mistake as explained to the players in the instructions. Since each individual player had their own objectives, points were additionally deducted for individual mistakes. For example, the charge nurse was instructed to avoid calling in an off-shift nurse from home to cover a surgery. The objectives for individual players varied by role, so we transformed the performance measure into a normalized z-score for each player by role. Mistakes and associated point deductions are given in the Table 2 below.

**Table 2. Scheduling mistakes and deductions**

| Mistake | Points Deducted | Who is Responsible |
|---|---|---|
| A surgery does not start during the shift due to a scheduling error and is not rescheduled for overtime | 10 | Group |
| A surgery is scheduled to start in overtime, but all resources are in place | 6 | Group |
| A surgery starts during the shift, | 4 | Group |

| | | |
|---|---|---|
| but goes into overtime | | |
| A surgery is rescheduled during the shift due to a scheduling error | 2 | Group |
| An off-shift nurse is called in from home to cover a surgery | 2 | CN |
| An anesthesiologist is called in from a lecture, a meeting, or visiting time to cover a surgery | 2 | AIC |
| A surgeon is called from a lecture, a meeting, or visiting time to cover a surgery | 2 | SC |

*Reading Task Performance.* Performance on the reading task was measured as the percentage of correct responses to the reading case questions.

*Trajectories.* As mentioned above, we measured player trajectories by assessing how frequently players switched from one task to another, i.e., the number of times they switched from working on the master schedule to working on the reading case.

## 5. Results

*Manipulation Checks.* As expected, the participants in this study spent significantly more time on the master schedule (M=45:21 minutes), as compared to time on the reading task (M=14:38 minutes), $F(1,38)=152.1$, $p<.001$. To make sure players noticed differences in notification types, we asked players to respond to the question, "It was easy to know when notifications of events occurred." Players in the active notification condition found it significantly easier to know when notifications occurred during the game (M=4.35) as compared to players in the passive notification condition (M=3.17), $F(1,37)=9.0$, $p<.01$. We then asked players to allocate percentages to the amount of time they spent scheduling nurses, anesthesiologists, and surgeons, Charge Nurses said they allocated 98% of their time to scheduling nurses, $F(2,37)=87.7$, $p<.001$. Anesthesiologists allocated 89% of their time scheduling anesthesiologists, $F(2,37)=53.9$, $p<.001$), and Surgeon Coordinators allocated 87% of their time to scheduling surgeons, $F(2,37)=40.1$, $p<.001$.

We report the findings for our main hypotheses below. We first hypothesized that the frequency of task switching would be influenced by the types of interruptions players received (active vs. passive). Table 3 shows no support for H1. In fact, we found the opposite effect: Task switching was significantly higher in the passive notification condition (M=23.1) than in the active condition (M=12.3), $F(1,38)=9.4$, $p<.01$. Table 3 also shows no difference between notification types and performance on either the scheduling task or the reading task. The average time spent in each condition also did not reveal differences between active and passive notifications.

We then hypothesized that the shape of the trajectory would influence group and individual performance. Based on correlation coefficients, we found support for H2, in that task switching is positively related to performance on the master schedule ($r=.66$, $p<.001$). We thought that frequent task switching would be disruptive and so would lower performance in the reading task (H3), however, frequent task switching is also significantly related to individual performance ($r=.41$, $p<.01$). Perhaps not so surprising, the less time you spend in the master schedule, the lower the performance on the scheduling task ($r=-.79$, $p<.001$).

**Table 3. Descriptive statistics for passive and active notifcations**

| Notifications | No. of Task Switches (Trajectory) | Scheduling Task Performance (z-score) | Reading Task Performance (% correct) | Mean Time |
|---|---|---|---|---|
| **Passive (n=18)** | 23.1 (13.5) | 0.23 (0.77) | 34% (0.26) | 6:00 (9:00) |
| **Active (n=21)** | 12.3 (8.2)** | -0.19 (1.10) | 26% (0.21) | 12:03 (17:16) |
| **Mean (n=39)** | 17.3 (12.2) | 0.00 (1.00) | 30% (0.23) | 9:15 (14.14) |

** $p<.01$

## 6. Discussion

In this experiment, we tested the idea that the types of interruptions players received would influence individual trajectories and performance. Our findings did not support our original hypothesis (H1) that players who were actively notified of interruptions through screen pop-ups would be more disrupted by external events and would therefore switch their tasks more frequently than players who were passively interrupted. Rather, we found the opposite effect: players in the passive condition, where interruptions can be "negotiated," switched more frequently between the master schedule and the reading task over the course of the game. Moreover, more task switching improved performance on the surgery scheduling task (H2) and, surprisingly, also improved performance on the reading task (H3).

The findings suggest, as McFarlane [28] does, that the player's ability to "negotiate" when they wanted to switch from the master schedule to the reading case may have lead to better performance than players who had to respond immediately to interruptions. Contrary to McFarlane, however, the results also seem to suggest that players who switch tasks often perform better, and though players in the passive condition switch tasks more, there is no direct relationship between the type of notification and performance. Although not conclusive, the data suggest that interruptions affect performance through player's work trajectories.

The finding that frequent task switching led to improved performance may have emerged because passive notification condition players had to be much more aware of their activities in both the master schedule and the reading task, making it more challenging for them to perform well, but perhaps accounting for their frequent switching. When we asked participants after the game about their perceptions of task difficulty (on scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree), participants in the passive notification condition found the task to be much more difficult (M=2.1) than those in the active notification condition (M=2.7), $F(1,37)=4.7$, $p<.05$.

Surprisingly, we did not expect frequent switching to lead to an improved performance on the secondary reading task. We thought that switching tasks would improve scheduling task performance but reduce reading task performance because of reduced attention to the latter task [27]. The finding can perhaps be explained by the fact that, although players in the passive condition switched tasks more often, they may have been able to interrupt their reading activity at more opportune times, leading to improved performance.

As in all experiments, there were some limitations to this study. Our measure of trajectories was simplified so that we could observe how the notifications players received affected the way they moved from one task to another. In addition, the use of business school students as subjects may limit the generalizability of our findings to actual hospital contexts. Although an experimental study cannot capture all of the complexity inherent in managing trajectories in critical work environments, this study represents a valuable start in that direction. Our next set of experiments will seek to build upon this research by (1) improving external validity with the recruitment of medical workers as study participants, (2) creating a second task that will make it harder for players to switch to the master schedule immediately, and (3) having interruptions affect team players differently, so that not everyone receives the same interruption at the same time.

We foresee that conducting our experiment with medical workers, while strengthening the external validity of the study, will introduce particular challenges. First, the clinical expertise of medial professionals may cause them to manage their activity switching differently than business students. They may, for example, feel more personal investment in the surgery scheduling task, causing them to ignore the reading case. Consequently we have considered substituting for the reading case another individual exercise that has more face validity in a medical context, such as arranging the schedule for the next day's surgeries. Second, because medical professionals are generally less accessible than students, participant recruitment may pose a challenge. We are currently working with our university's nursing school and several medical centers who have expressed interest in participating in the simulation experiment. We are therefore optimistic about our opportunities to test our hypotheses with medical professionals as game players.

## 7. Conclusions

We made significant inroads in our understanding of how interruptions affect trajectories and performance in a 3-player role-playing simulation game involving the coordination of a master schedule in an operating room. We feel that the simulation experiment represents an innovative HCI design for several reasons. The game is complex and engaging, but allows for experimental control and measurement of multiple effects. We introduced the idea of trajectory management by measuring task switching over time. Finally, we show that how interruptions are delivered significantly affects how people move between tasks, and their subsequent performance. This finding adds to the literature about the effects of interruptions and better explains the temporal dynamics of different types of interruption notification systems.

## 8. References

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