Improving the Healing Environment in University of Michigan Hospital through Noise Reduction and Masking Techniques

Final Report

Prepared For: Mr. Chris Schlaps, Planning and Development Project Manager
University of Michigan Health System

Prof. Harvey Bell, Co-Director of Multidisciplinary Program
University of Michigan

Dr. Amy Cohn, Arthur F. Thurnau Associate Professor
University of Michigan

Prepared By: Matthew DiTullio, Hospital Sound Analysis Team Member
Tori Ranger, Hospital Sound Analysis Team Member
Multidisciplinary Design Program

Project Team: Keegan Cisowski, Hospital Sound Analysis Team Member
Matthew DiTullio, Hospital Sound Analysis Team Member
Tori Ranger, Hospital Sound Analysis Team Member
Multidisciplinary Design Program

Date: December 13th, 2012

Table of Contents

List of Figures and Tables

Executive Summary

Outlined below is a summary of the Hospital Sound Analysis Team's noise reduction project.

Current Situation and Task

The University of Michigan Health System (UMHS) has consistently received below state and national average patient ratings of noise disruptions in the University of Michigan hospital. As such, the UMHS asked the University of Michigan College of Engineering (CoE) to assemble a team to reduce noise levels in units 7A/B of the University hospital. In response, the Multidisciplinary Design Program within the CoE assembled the Hospital Sound Analysis Team (HSAT). This team analyzed the task at hand and, through collaboration with the UMHS, altered this task. The HSAT discovered that what the UMHS actually wanted was an improved patient perception of noise levels, rather than just a reduced noise level. This realization came due to an analysis of the root causes of the desired reduction, both of which draw upon patient perception of noise, and not necessarily the actual noise levels. These root causes include: 1) A desire to improve patient ability to rest, which increases the healing rate and decreases hospital stay length, and in turn saves money and resources on behalf of the hospital, patient, patient's family, and insurance companies, and, 2) a desire to increase Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey scores.

The HCAHPS survey is a survey that allows public hospitals across the country to be compared to one another. As part of the Affordable Healthcare Act, hospitals – in the near future – will be penalized for receiving poor scores on the HCAHPS survey, and will receive incentives for receiving good scores. The UMHS ranks below both the national and state averages regarding the noise-related question on the HCAHPS survey.

Methods

Before attempting to improve patient perceptions of noise levels., the HSAT had to identify which noises patients found most disruptive to their ability to rest. To determine the "current" (pre-implementation) patient perceptions of noise, the HSAT first wanted to verify that there were no discrepancies between patient and staff perceptions of noise. Through the HSAT's administration of patient and staff surveys, the HSAT determined that no discrepancies existed. Furthermore, the patient surveys – which were administered to 83 patients – allowed the HSAT to identify the most disruptive sounds with regards to patient rest. The HSAT also conducted an extensive literature search and analysis to locate documentation that supported the HSAT project hypothesis that noise perception, rest, and recovery rate are all connected, and to identify preexisting methods to improve patient perception of noise. Benchmarking in St. Joseph Mercy hospital in Ann Arbor was also performed in order to develop further ideas for reducing patient perception of noise in UH 7A/B. Lastly, the HSAT conducted a sound inventory. This sound inventory consisted of the members of the HSAT spending half hour-long time periods in units 7A/B and recording all potentially disruptive noises. These noises were used in the previously mentioned patient survey in order to understand the patients' perceptions of these noises.

Through the use of sound inventories in units 7A/B and patient surveys in 7A/B, the HSAT determined that phones, alarms, beds rolling, doors, and support staff were the five most frequently occurring patient noise disruptions. Additionally, these top five disruptions combined to make up 69% of the total sound disruptions present. Furthermore, *Sleep Disruption Due to Hospital Noises: A Prospective Evaluation* – an article by Orfeu Buxton, Assistant Professor in the Harvard Medical School Division of Sleep Medicine – demonstrated a direct connection between improved patient rest and shortened recovery time. Another article, *Noisy hospitals need Rx for quiet as patients rest*, by Associated Press Medical Writer Lauran Neergaard, demonstrated the usefulness of quiet hours in patient rest. The main takeaway from the benchmarking was that the use of different wheels on any rolling equipment would likely be beneficial, as the wheels at St. Joseph Mercy were far quieter than those used within the UMHS.

After identifying the five top noise disruptions – phones, alarms, beds rolling, doors, and support staff – the HSAT conducted a design review of potential operational and design changes that could improve patient perception of these noises. This list of potential changes was narrowed to the three techniques that were the most feasible, implementable, and measureable: the use of a quiet hour from 1-2 PM, the use of signs to raise support staff awareness, and the use of white noise to mask problem noises.

The HSAT implemented the quiet hour, use of signs, and white noise for one month, from October 2012 through November 2012. Signs were posted on patient, equipment room, and hallway bathroom doors in 7A. The quiet hour was used in 7B, entailing the closing of doors at the end of the hall, the dimming of hallway lights, and the posting of signs to inform of the quiet hour. In addition to the quiet hour, the HSAT piloted the use of white noise machines in 7B. In late November, the HSAT administered post-implementation surveys to 31 patients. The results of these surveys were compared to the results from the pre-implementation surveys, and from these comparisons conclusions and recommendations were drawn.

Findings

In the post-implementation surveys, patients in 7A said that roommate- and family-related noise disruptions were improved by 47%. At the same time, these disruptions worsened by 25% in 7B, where signs were not posted. Also, 7A patients said that hospital staff-related noise disruptions were improved by 29% and 7B patients said that these same disruptions worsened by 51%. These results are all reported below, in Table 3 of Implementation Methods and Findings.

In 7B, 38% of patients noticed the quiet hour, and 83% of those who noticed said that the quiet hour had a positive impact on their ability to rest. The remaining 17% said that the quiet hour had no effect. Overall, the disruption of rest due to everyday noises decreased by 61%. Unfortunately, complications existed when collecting patient data regarding the white noise machines, such as lost machines and machines that were accidentally turned off. As such, the HSAT did not collect enough data to come to any definite conclusions. However, the HSAT did record positive patient comments that demonstrated the white noise machines' utility in patient sleep. Furthermore, patients who were interviewed after the machine was removed from their room admitted that they had more difficulty sleeping at night without the machine than they did with the machine.

Also, in 7A the number of patients who believe noisiness can be improved decreased by 24% from pre- to post-implementation. In 7B, this same metric decreased by 22%. These results show that patient perception of effort being made increased due to the implemented methods. Increased perception of efforts made to reduce noise by hospital staff will likely improve HCAHPS survey responses regarding noise. Conversely, disruption due to alarms and medical equipment increased by 49% and 150% in 7A and 7B respectively. This increase is largely because the methods implemented by the HSAT focused mainly on human-related noises.

Conclusions and Recommendations

From these results, the HSAT recommends that the UMHS continue the use of signs in 7A and expand the use of signs to other units. Simultaneously, the HSAT recommends that the quiet hour be lengthened to two hours in 7B and expanded to other units. Because of the discovered utility of the quiet hour, the length should continuously be increased and reviewed through surveys until patients' perception of noise reaches a plateau, as demonstrated in the survey results. Furthermore, the HSAT recommends an increased focus on white noise in the future of the project, as this will hopefully reduce disruptions due to non-human-related noises, while improving patients' abilities to sleep at night. The HSAT also recommends that the UMHS focus on equipment and wheel maintenance, a modified IV notification system, and the addition of a white noise channel to the TV system, all of which are expected improve perception of critical non-human-related noises discovered through the pre-implementation surveys.

Introduction

The noise conditions in Medicine Telemetry Units 7A/B of the University of Michigan Main Hospital (UH 7A/B) and the 5th Floor of the University of Michigan Cardiovascular Center (CVC5) are not conducive to patient healing, according to data provided by University of Michigan Health System (UMHS) patient satisfaction surveys. Therefore, UMHS wanted to know how patient healing could be improved through noise reduction/masking. UMHS asked the College of Engineering (CoE) to assemble a team to work on reducing noise levels in units 7A/B and CVC5 of the University hospital. In response the Multidisciplinary Design Program within the CoE assembled the Hospital Sound Analysis Team (HSAT).

The HSAT analyzed the task at hand and realized that what the UMHS actually wanted was an improved patient perception of noise levels. To improve this perception, the team developed and conducted pre-implementation patient and staff surveys, implemented noise reduction and masking techniques, and conducted post-implementation patient surveys to determine the effects of the noise reduction and masking implementations. From May 2012 through November 2012, the HSAT gathered and analyzed data through 114 patient surveys (Appendices A and B) and found that the most common problem noises were phones, alarms, beds, doors, and support staff, as demonstrated in the Pareto chart – Figure 1of Pre-Implementation Methods and Findings. These surveys were conducted both pre- and post-implementation of noise reduction and masking techniques, which allowed the HSAT to compare patient responses and determine the impact of implementation techniques. The pre-implementation patient surveys, along with staff observations, revealed the noise sources that impeded patient's ability to rest in the hospital. These observations confirmed results that were previously reported by the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) post-visit surveys – surveys given to patients after being discharged from the hospital – regarding patient opinions on how quiet their hospital room was at night. During October and November 2012, the HSAT implemented three techniques to improve patient rest with regards to the noises sources discussed previously. These techniques, and all data collected after August 2012, were only piloted in UH 7A/B due to the lost communication with CVC5 when the team's original contact person took a job elsewhere. This report presents the HSAT's data collection methods and findings, implementation methods and findings, conclusions, final recommendations, and expected impact for units 7A/B of the University of Michigan Hospital.

Background

The University of Michigan Hospital, specifically UH 7A/B, believe they have a noise problem based on the HCAHPS standardized survey. The HCAHPS conducted this survey to publicly compare and report internal customer services among all hospitals. One of the questions on the HCAHPS survey was: "During this hospital stay, how often was the area around your room quiet at night?" Results as of December 2011, showed that the percentage of University of Michigan Hospital patients who responded "Always" to this question was 45%; sample size greater than 300. This value is well below the national average of 59%.

The issue regarding noise in a hospital setting is important because noise can inhibit patients from receiving adequate rest, which in turn decreases their rates of recovery. As Dr. Orfeu Buxton demonstrates in his article *Sleep Disruption Due to Hospital Noises: A Prospective Evaluation* (Attachment A), improved rest conditions can help patients heal at a faster rate. According to the World Health Organization (WHO), the recommended decibel level for patient healing in hospitals is not to exceed 40 decibels; however, most hospitals far exceed this suggestion, averaging 72 decibels during daytime hours, and 60 decibels at night, which is not conducive to patient healing (Attachment B). As an added benefit, HCAHPS gives tax reimbursements to hospitals receiving the best ratings for their operational procedures and post-visit patient surveys. The operational procedures account for 70% of the rating, and the survey the other 30%. Noise levels and their effects are specifically addressed through questions on the patient survey. Previous attempts by hospital staff and administration at UMHS to address the noise issue, such as the installation of light-up sound meters and recording devices, have proven unsuccessful. These factors – the Buxton article, WHO recommendations, HCAHPS reimbursement, and failed attempts to address the noise issue – led to the team's investigation of the disruptive noises in UH 7A/B at the University of Michigan Hospital and the involvement of the College of Engineering HSAT.

Key Issues

The key issues driving the need for this project included:

- Patients reported that they had difficulties sleeping in the hospital due to noise
- Lack of patient rest in the hospital can lead to a slower patient recovery, prolonging patients' stays and costing the hospital, insurance companies, and patients more money
- Noise-reduction techniques that had previously been implemented were unsuccessful
- Tax-reimbursement policies from HCAHPS now consider patient survey responses regarding many aspects to the patient's hospital stay, including noise

Goal and Objectives

The primary goal of this project was to improve the healing environments in UH 7A/B by improving patient perception of noise levels. To achieve this goal, the HSAT addressed the following objectives:

- Recommended design changes to the five noise issues that were most disruptive to a patient's ability to rest
- Masked noise in UH 7A/B
- Implemented operational modifications to current procedures
- Improved the quality of rest patients received in the hospital

Project Scope

The HSAT recognized that many factors contributed to a patient's inability to rest in the hospital; this project only addressed noise-related issues. HSAT's implementation of noise-reduction/masking methods took place only in units UH 7A/B. However, for non-implementation tasks, the HSAT worked with additional units during the project. The HSAT conducted pre-implementation patient surveys in CVC5 and discussed "quiet hour" techniques with UH 5B. The HSAT also participated in meetings with nursing staff and patient/staff focus groups in the hospital and gathered the patient's/staff's opinions related to noise and ideas to improve patient perception of noise. In addition, benchmark data from St. Joseph Mercy Ann Arbor was included in the scope of this project. St. Joseph Mercy is another teaching hospital in the Detroit metropolitan area that received better patient noise ratings than UMHS. Lastly, the only noises that the HSAT addressed in this project were phones, beds, doors, support staff, and IV alarms.

Patient and staff responses unrelated to noise were outside of the scope of this project. The HSAT only focused on the noises listed above. The HSAT discussed broad noise-reduction/masking approaches in other units (outside of UH 7A/B), but quantifiable data was not gathered and noise-reduction/masking techniques did not take place in these other units.

Pre-Implementation Methods and Findings

The HSAT team used findings from a literature search, discoveries from benchmarking, observations through sound inventories, and responses from patient and staff surveys (Appendices A and C, respectively) to determine ideal noise-reduction/masking techniques. The parties involved in this project included hospital administration, as well as UH 7A/B nurses, doctors, support staff, clerks, and patients. The quantitative and qualitative data gathered by the HSAT through a literature search, benchmarking, sound inventories, and patient survey allowed the team to isolate the main noise issues in UH 7A/B. These findings allowed the team to develop implementations and recommendations to improve the healing environment in these units. The Hospital Sound Analysis Team separated the data collection portion of this project into four phases: a literature search, benchmarking, sound inventories, and patient surveys.

Literature Search

The HSAT performed a literature search from May until August 2012, to gather additional information and enhance the team's background on possible solutions to noise related issues in a hospital setting. The noise issue is important because noise can inhibit patients from receiving adequate rest, which in turn decreases their rates of recovery. In addition, the team performed this literature search to find articles that showed how improved rest conditions could help patients heal faster. Based on the information the HSAT gathered from this literature search, the team proved the correlation between noise in the hospital and recovery rate and received ideas on how to reduce the noise issues in a hospital setting.

The first article used by the HSAT showed the correlation between the quality of patient rest in the hospital and recovery rates was *Sleep Disruption Due to Hospital Noises: A Prospective Evaluation* (Attachment A). This article discussed the positive relationship between patients receiving better rest and having a faster recovery. Another article used by the team was *Noisy hospitals need Rx for quiet as patients rest* (Attachment C). This article demonstrated the use of quiet hours during a specific time each day. In this article, hospital staff conducted these quiet hours by minimizing overhead paging, dimming the lights and only entering patient's rooms when absolutely necessary. In addition, the team discovered literature regarding the use of acoustic sound absorbing materials and images/sounds of nature. Even though these ideas to reduce/mask noise in the hospital were not implemented by the HSAT, recommendations regarding such topics were given to UH 7A/B.

Benchmarking

The HSAT researched other teaching hospitals in the metro-Detroit area that received better patient noise ratings according to HCAHPS data available on the hospital comparison website (http://www.hospitalcompare.hhs.gov). The team planed to gather benchmarking data from three hospitals: 1) St. Joseph Mercy, Ann Arbor, 2) Sinai Grace, Detroit, and 3) Harper Hospital, Detroit. The purpose of this benchmarking was to identify noise reduction methods used at these hospitals that lead to their improved ratings. After various efforts via telephone and email were made to contact these three hospitals, the HSAT was only established contact with only St. Joseph Mercy hospital in Ann Arbor. As such, benchmarking data for this project was only collected from St. Joseph Mercy.

In October 2012, the HSAT visited St. Joseph Mercy and met with hospital staff to discuss noise reduction and masking techniques with them. This discussion was beneficial to the HSAT as the discussion confirmed that similar ideas to reduce and mask noise developed by the team were also being implemented at St. Joseph. An additional finding from this benchmarking was related to the wheels that St. Joseph Mercy was using on their equipment – beds, carts, and IVs. In contrast to the wheels currently used at UMHS, the wheels at St. Joseph Mercy produced less noise when rolled across the floor. The team was not able to gather benchmarking data through patient interviews at this time because the team did not receive approval from the Institutional Review Board (IRB). However, the HSAT plans to continue with benchmarking at St. Joseph Mercy next semester pending IRB approval.

Sound Inventories

The HSAT observed the current state of UH 7A/B in May of 2012. During these observations of the current state, HSAT members performed four sound inventories. Sound inventories consisted of a team member standing at each of the satellite nurse stations in 7A/B and creating a list of all the different noises that occurred during a half hour period, two hours in total. For each noise on the list, the team member manually tallied each time a specific noise occurred. The noises that occurred most frequently became the response choices for the following question on the patient survey: “Please rate the following noises on a scale of 0 to 5 on how disruptive they are to your rest (0 is no effect, 5 is extremely disruptive)” (Appendix A).

The observations of UH 7A/B through sound inventories revealed the most frequently occurring noises during the day in these units. The HSAT learned that the most frequent noises in UH 7A/B were:

Table 1: Average frequencies of 12 main noise sources in UH 7A/B discovered through sound inventories

Noise Source	**Average Frequency**
Alarms	7.5
Beds/carts rolling down the hall	14
Beeps (constant beeping on monitor)	8.5
Cabinet doors being opened/closed outside of patient room doors	12
Clean suits (plastic suits staff puts on before entering patient rooms)	1
Doors	17
Elevator	1.5
IV rolling	3
Pager	1.5
Phone	5
Maintenance equipment	2.5
Floor cleaner (Zamboni)	0*

* This noise source did not occur during the daytime when sound inventories were performed; noise source was added to patient survey due to high response as an additional noise source in original patient survey

Collected through four half-hour sound inventories conducted by the HSAT (5/2012)

As Table 1 shows, The HSAT calculated the average frequency of the four sound inventories. The team then used these frequently occurring noises on the patient survey to determine the noises patients found most disruptive to their rest in the hospital.

Patient Surveys

In March of 2012, the HSAT developed a patient survey (Appendix A) that addressed patient’s opinions and ideas for improvement regarding noise in the hospital setting. This survey consisted of 13 questions and was conducted in person by the HSAT members. The HSAT patient survey was updated four times during the project. In addition, the HSAT combined results from all of these surveys, but results were only combined on the questions that were consistent in each version of the HSAT patient survey. Therefore, changes made to the HSAT patient survey did not have an effect on any of the survey results reported by the team. The purpose of these changes was to shorten the patient survey by removing questions that were not beneficial to the project. For example, the HSAT learned that certain noises (i.e. elevator) heard at the nurse satellite stations during sound inventories were not heard by patients in their rooms, and therefore these noises were removed from the survey. In addition, the HSAT developed a hospital staff survey (Appendix C) that consisted of 12 questions.

The HSAT members conducted 77 staff surveys from May until June 2012. The staff survey was used to gather preliminary opinions from hospital staff members on noise issues in the hospital. The HSAT conducted the first round of patient surveys, called pre-implementation surveys, from May until August 2012, 83 patients were surveyed. The purposes of the patient surveys were to 1) identify discrepancies between patients' opinions and hospital staff's opinions regarding noise-related issues and, 2) identify the most disruptive noises with regards to patient rest, according to the patients.

The HSAT entered data collected through these pre-implementation surveys into Excel spreadsheets. To identify trends in data, formulae were written in Excel. Also, responses from these patient surveys qualified the patient opinions of the noise issues in UH 7A/B. The HSAT created a Pareto chart, Figure 1 below, to identify the noises that were most disruptive to patient rest and show what noises the HSAT should reduce or mask.

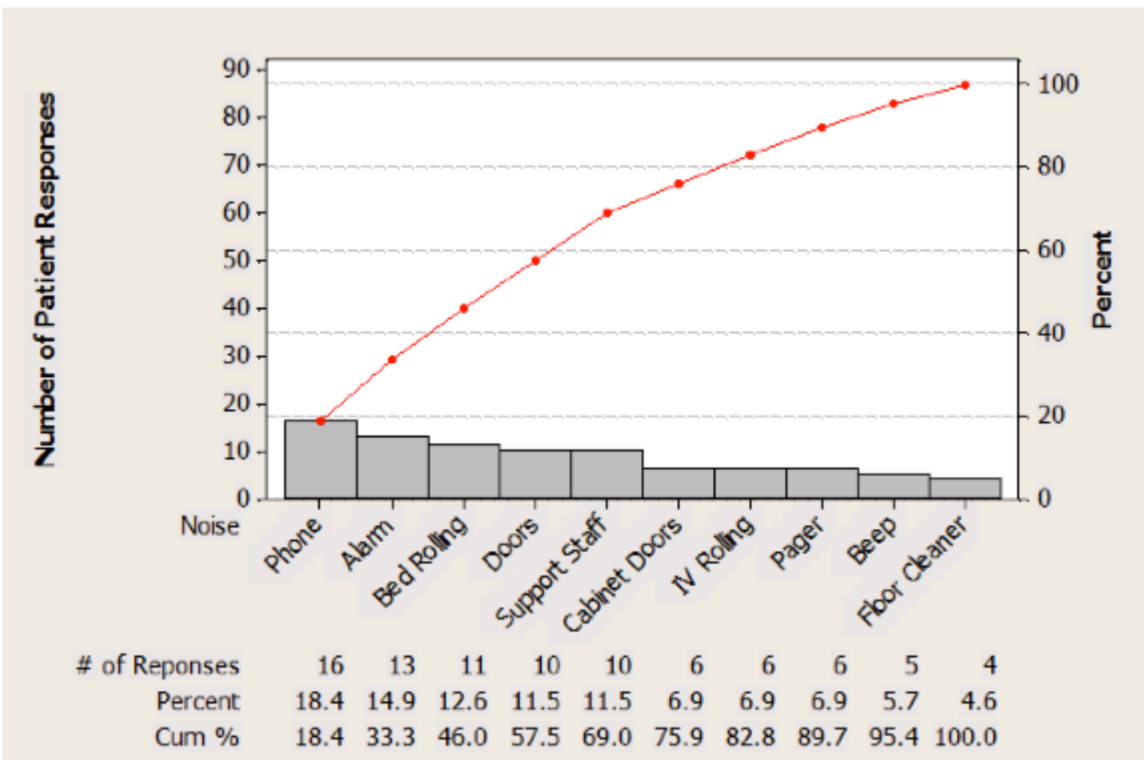


Figure 1: The top five noise sources in UH 7A/B according to HSAT patient surveys
Sample Size: 83 patients, Collected through patient surveys administered by the HSAT (5/2012-6/2012)

As Figure 1 shows, the five noises that are most disruptive to patient rest, had the greatest number of patient responses, in UH 7A/B are phones, alarms, beds, doors, and support staff. These five noise sources account for 69% of the total noise in the unit. Therefore, the HSAT determined that reducing or masking these noises would increase patient satisfaction measured in the hospital's discharge surveys. From these five noise sources the HSAT developed techniques to reduce/mask these specific noises, improving patient perception of noise in the hospital. These implementations were divided in two categories: 1) operational changes and 2) design changes, which can be seen in Table 2:

Table 2: Operational and design implementations for the top five noise issues developed by the HSAT

	Operational Changes	**Design Changes**
Phones	Close patient's doors Designate areas for cell phone use (by elevators) Turn down ringer volume at night and during quiet hours*	Play white noise in patients' rooms (through headphones or white noise machines)* Place sound absorbing materials on ceilings and walls
Alarms		Modify the notification method (alarm only at nurse station, send page, turn on call light) Play white noise in patients' rooms (through headphones or white noise machines)*
Beds	Maintain equipment (oil wheels)	Play white noise in patients' rooms (through headphones or white noise machines)*
Doors		Change latches on door Put windows in doors Play white noise in patients' rooms (through headphones or white noise machines)* Place sound absorbing materials on ceilings and walls
Support Staff	Maintain equipment (oil wheels) Dim lights during night/quiet hours* Close patient's doors	Put "Shhhh" signs on all doors*

* These techniques were implemented by the HSAT in UH 7A/B

As Table 2 shows, the HSAT has developed implementations that address the 5 main noise sources. The implementation section of this report further describes the implementations that the team piloted.

Implementation Methods and Findings

Through the HSAT patient surveys the team learned that the most frequently identified noise sources were phones, alarms, beds, doors, and support staff. Based on these noise sources and patient/staff suggestions gathered in the data collection phase of this project, the HSAT developed implementation methods to reduce/mask noise issues in UH 7A/B. In November of 2012, the HSAT performed post-implementation patient surveys, 33 patients were surveyed. These patient surveys were developed by the HSAT (Appendix B). Post-implementation surveys were conducted using the same methods described in the pre-implementation survey section.

The purpose of the post-implementation surveys was to provide the ability to compare qualitative patient data from after implementing the HSAT's perception-improving methods to the pre-implementation patient data. The data showed improvement or a positive outlook in many areas, but was inconclusive for other aspects. The HSAT's implementation methods consisted of three techniques, which were feasible, implementable, and measureable: 1) quiet hours, 2) support staff awareness, 3) white noise.

Quiet Hours

In the HSAT pre-implementation patient survey, patients reported that they received better rest during the daytime hours of their hospital stay. As a result, in October 2012, the HSAT recommended the implementation of a one-hour block of quiet time, from 1 PM to 2 PM, in UH 7B to the nurse manager on this unit. The idea of a quiet hour was previously piloted in UH 5B, and results collected by the UH 5B nursing staff showed that simply dimming the lights served as a mental cue for hospital staff and visitors to keep noise levels to a minimum. During the quiet hour in UH 7B lights were dimmed, doors at the ends of the unit were closed, and ringer volumes on the nurse station phones were turned down by the clerk on the unit.

From the HSAT's post-implementation surveys, the implementation of the 1-2 PM quiet hour in 7B positively affected patients' perceptions of noise. While only 38% of patients actually noticed the quiet hour, an overwhelming 83% of those who noticed the quiet hour gave a positive response when questioned about this implementation. The remaining 17% who noticed the quiet hour said that the quiet hour had "no effect," which shows optimism, as the quiet hour did not have a negative effect. The only complaint the HSAT received regarding the quiet hour was in response to a visitor who had trouble visiting a patient. This complaint was because the exterior doors connecting the patient quarters to the seventh floor entry hallway, where the elevators are located, do not have an "automatic door open" button to make them accessible to those in wheelchairs. Adding such a button to the exterior doors is predicted to solve this accessibility issue.

Support Staff Awareness

In late October 2012, the HSAT strategically placed additional "Shhhh" signs on all equipment/patient room doors in UH 7A, 27 signs in total. These signs served as a constant reminder to support staff to keep noise to a minimum, without directly singling out support staff members. In addition, these signs were targeted to support staff managers to remind support staff members to maintain the wheels on carts, beds, and IVs in the unit.

To determine the effectiveness of the signs, the HSAT asked patients about the same potentially problematic noises and sound categories that were asked about in the pre-implementation survey. Upon comparison of these data, the signs reduced not just noises attributed to support staff, but all human-related noises. As indicated by the post-implementation surveys conducted by the HSAT, disruption due to roommates and their families was reduced by 47% and disruption due to hospital staff was reduced by 29% in unit 7A, where the signs were utilized. At the same time, disruption due to roommates and their families increased by 25% and disruption due to hospital staff increased by 51% in unit 7B, where signs were not utilized. Furthermore, disruptions attributed to alarms and medical equipment increased by 49% and 150% in units 7A and 7B, respectively. These results can be seen in Table 3 below:

Table 3: Differences between pre- and post-implementation noise categories in UH 7A/B

Noise Category	7A - Before*	7A - After*	7A - Change
Roommates/Families	25.0%	13.3%	-47.0%
Hospital Staff	37.5%	26.7%	-29.0%
Alarms/Medical Equipment	31.3%	46.7%	49.0%
Everyday Noises	6.3%	33.3%	433.0%
Noise Category	**7B - Before***	**7B - After***	**7B - Change**
Roommates/Families	10.0%	12.5%	25.0%
Hospital Staff	29.0%	43.8%	51.0%
Alarms/Medical Equipment	10.0%	25.0%	150.0%
Everyday Noises	48.0%	18.8%	-61.0%

*These are percentages of patients who said that each category caused disruption(s) in their ability to rest
Sample Size: 33 patients, Collected through patient surveys administered by the HSAT (11/2012)

Table 3 shows that signs would not alter the disruptions due to non-human factors (alarms/medical equipment). These findings were verified through analysis of patient ratings of specific noises, which can be seen in Figure 2 below. While alarms, beeps, and IVs rolling all were deemed more disruptive (an average higher rating on the 0-5 scale during the 7A post-implementation surveys than the pre-implementation patient surveys) beds rolling, cabinets, doors, pagers, phones, trash cans, and floor cleaners were all seen as less disruptive. These findings again demonstrate that, aside from IVs rolling and pagers, the human-related noise factors improved while the non-human factors got worse.

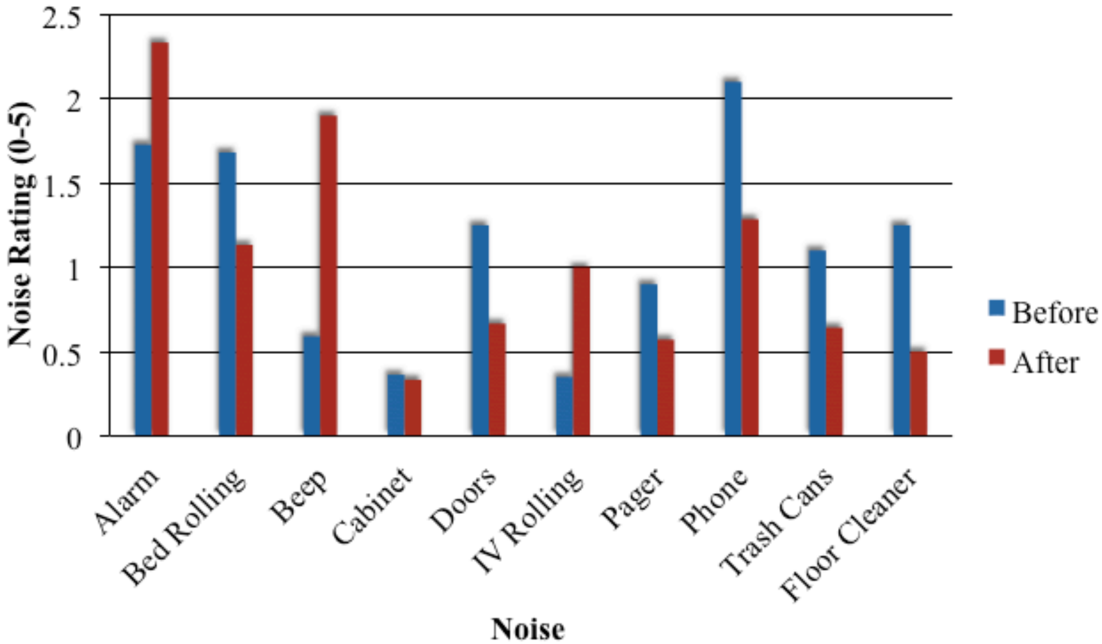


Figure 2: Differences between pre- and post-implementation noise sources in UH 7A
Sample Size: 33 patients, Collected through patient surveys administered by the HSAT (11/2012)

White Noise

In October and November 2012, the HSAT tested the use of white noise generators to mask the constant background noise in UH 7B. White noise is noise consisting of many frequencies with equal intensities, which is used to mask other noises. White noise machines were placed in patient rooms to effectively mask any of the noise issues coming from outside of the room. These machines were placed in an unoccupied patient room and turned on. When a patient was admitted to a room with a white noise generator, he/she was not informed that this machine was in their room. In addition, the HSAT had asked the nurses and other staff on the unit to only discuss the white noise generator with a patient if the patient asked about the white noise generator. The purpose behind the use of white noise in this method was to expose the patient to one day in the hospital in which noises issues were masked and then one day in which noise issues were not masked. HSAT members conducted patient surveys on the first and second day of each patient's stay to determine if the white noise generator affected the patient perceived noise levels. However, the team did not receive enough data on this implementation method due to three reasons: 1) white noise machines being removed from patient rooms, 2) patients being asleep or out of the room when the HSAT member went to survey them, and 3) number of white noise generators available was limited to one machine.

As discussed previously, the HSAT had trouble collecting data regarding white noise's impact on patient perception of noise; however, the HSAT did receive positive comments regarding the white noise machine. For example, one patient said he "really [appreciated] the machine...it [drowned] and [mellowed] out everything...5 on a scale of 0 to 5 of being good." Furthermore, he said that he was awake for most of the following night due to removal of the white noise machine from his room. Another patient said he “loved the white noise machine” because this machine “helped a lot.” He was very upset when the machine was taken away, and he claimed his sleep was also worse the night after the white noise machine was removed. He said that they should “put them in every room.” A third patient said that she also slept worse the night after the machine was removed, that the white noise machine “was great” and she wanted the machine back a second day. White noise will be a main focus of the HSAT project next semester.

Conclusions

From the HSAT’s implementation findings, the team learned that both the quiet hour and usage of signs helped to improve patient perception of noise. White noise appears to be helpful, but more data is necessary to verify this conclusion. However, because the HSAT implemented these methods separately (usage of signs in 7A, quiet hour in 7B) a study should be conducted that utilizes both the quiet hour and the use of signs to verify that a negative interaction will not take place. The HSAT believes, however, that due to the nature of the methods implemented, there will not be a strong interaction effect, let alone a negative one. As will be discussed further in recommendations, the use of signs and expanded quiet hours would improve patient perception of noise.

Recommendations

To address the noise issues in UH 7A/B, the HSAT recommends continuing and expanding the three piloted noise reduction/masking techniques. The team has seen positive results from both the quiet hours and the “Shhhh” sign noise reduction techniques. As a result, the team recommends the signs be added in UH 7B and the quiet hours be implemented in UH 7A. In addition, the HSAT recommends that the quiet hour be lengthened to a two-hour block of time, 1-3 PM. As mentioned previously, the noise masking technique with the white noise machines should be piloted further to determine the effect this technique is having on patient responses to noise.

In addition to the implementations performed by the HSAT, the team recommends additional noise reduction/masking techniques. The implementations performed by the team addressed the noise concerns of phones, doors, and support staff, but did not solve the noise issues concerned with alarms and beds. The HSAT recognized that these noise issues are still problematic and therefore brainstormed additional noise reduction/masking techniques. In response to beds, carts, and IVs rolling through the hallways, the team recommends implementing wheel checks on equipment to ensure that all wheels are oiled and roll quietly. These noises weren’t addressed in the HSAT’s implemented methods due to the vast changes necessary to quell them.

For the alarms, the HSAT recommends a new notification method where alarms do not sound in the patient rooms. Instead, the alarm would only sound at the nurse station and send a message directly to the nurse’s pager. This change would address the patients’ complaints regarding many of the alarms and beeps. Lastly, the HSAT recommends adding a white noise channel to the TV, allowing patients to plug their ear-buds directly into their remote. This capability would be similar to the white noise machines technique in masking background noise, but would allow one patient in a semi-private room to listen to the white noise without the roommate having to listen to the white noise. The HSAT believes that if UH 7A/B implements these recommendations, the patients in these units will receive better rest and in turn recover faster.

Expected Impact

As a result of the improved healing environment in UH 7A/B, the HSAT projects:

- Reduced patient-perceived noise disruptions, allowing patients to sleep better
- Increased patient satisfaction regarding hospital stay
- Increased patient throughput as average length-of-stay decreases
- Reduced cost for insurance providers, hospitals, and patients
- Increased HCAHP tax reimbursements through more favorable survey results

Appendix A: Pre-Implementation HSAT Patient Survey

Intro:
We are seniors in the College of Engineering at the University. We are currently working on a multidisciplinary engineering design project. Our overarching goal is to improve the stay of University Hospital patients. We appreciate your taking the time to answer a few brief questions and hopefully help future patients. Thank you!

Patients/Families:

1. How long have you been a patient here?
   a) 1 night or less
   b) 1 < nights ≤ 3
   c) 3 < nights ≤ 7
   d) Over 1 week
2. On a scale of 0 to 5 (0 being the worst, 5 the best) rate your hospital stay.
3. Do you consider yourself a light sleeper when you are sleeping at home? Rate yourself on a scale of 0 to 5 (0 being everything awakes you, 5 you can sleep through anything)

4 a) Do you rest and sleep well in the hospital? (Yes or No)
b) Explain.

5a. On a scale of 0 to 5 (0 being quiet, 5 excessive noise) how noisy do you think your room here is on a daily basis?
b. How disruptive to your sleep is the amount of light in your room here on a scale of 0 to 5? (0 is not at all, 5 is extremely disruptive)

6. Does noise impede your ability to rest? (Yes or No)
   (If yes, go continue to question 7, if no, skip to question 13)

7. What is the loudest time or times of day in the hospital?
8. What noises do you believe impede your ability to rest?
   (leave open ended when asking patients, use options for sorting results)
   a) Roommate and their family
   b) hospital staff
   c) alarms/medical equipment
   d) everyday noises (ie doors, cleaning, maintenance)
   e) other (please be specific)
9. Please rate the following noises on a scale of 0 to 5 on how disruptive they are to your rest (0 is no effect, 5 is extremely disruptive)

CVC5:
b) IV Alarm
c) Bed
d) Bed Rolling
e) Cart
g) Doors
h) Pager
i) Phone
j) Printer
k) Trash Cans
l) Floor cleaner/zamboni

Appendix A: Pre-Implementation HSAT Patient Survey (continued)

7A/7B:

a) Alarm
b) Bed Rolling
c) Beep
d) Cabinet
f) Doors
h) IV Rolling
i) Pager
j) Phone
k) Trash Cans
l) Floor cleaner/zamboni

10a. On a scale of 0 to 5 (0 being the worst, you can't hear anything, 5 the best, you hear everything) how good would you say your hearing ability is?
10b. Is there a difference in hearing between your right and left ear? (If so, please rate your right ear on the previous scale)
10c. Please rate your left ear on the previous scale.
10d. Do you use a hearing aid?
11a. Have you ever been awakened by admissions of a roommate?
11b. Have you ever been awakened by hospital staff for procedures such as getting blood drawn?
11c. What noises, if any, have prevented you from getting back to sleep?
12a. Have you ever complained to a healthcare provider about sound level? (yes or no)
12b. If so, what was the complaint?
12c. How did the nurse/doctor/staff go about handling your complaint?
12d· Was the "fix" satisfactory (scale of 0 to 5, 0 = very unsatisfactory, 5 = very satisfactory)?

13a. Do you perceive noisiness as an issue that can be improved in the hospital?
13b. Why or why not?
13c. If so, do you have any recommendations as to how noise can be improved?

Appendix B: Post-Implementation HSAT Patient Survey

Intro:

We are seniors in the College of Engineering at the University. We are currently working on a multidisciplinary engineering design project. Our overarching goal is to improve the stay of University Hospital patients. We appreciate your taking the time to answer a few brief questions and hopefully help future patients. Thank you!

Patients/Families:

1. On a scale of 0 to 5 (0 being the worst, 5 the best) rate your hospital stay.
2. Do you consider yourself a light sleeper when you are sleeping at home? Rate yourself on a scale of 0 to 5 (0 being everything awakes you, 5 you can sleep through anything)
3. a) Do you rest and sleep well in the hospital? (Yes or No)
   b) Explain.
4. a) On a scale of 0 to 5 (0 being quiet, 5 excessive noise) how noisy do you think your room here is on a daily basis?
   b) How disruptive to your sleep is the amount of light in your room here on a scale of 0 to 5? (0 is not at all, 5 is extremely disruptive)
5. What is the loudest time or times of day in the hospital?
6. What noises do you believe impede your ability to rest?
   a) Roommate and their family
   b) hospital staff
   c) alarms/medical equipment
   d) everyday noises (ie doors, cleaning, maintenance)
   e) other (please be specific)
   f) None of the above
7. Please rate the following noises on a scale of 0 to 5 on how disruptive they are to your rest (0 is no effect, 5 is extremely disruptive)
   a) Alarm
   b) Bed Rolling
   c) Beep
   d) Cabinet
   f) Doors
   h) IV Rolling
   i) Pager
   j) Phone
   k) Trash Cans
   l) Floor cleaner/zamboni
8. On a scale of 0 to 5 (0 being the worst, you can't hear anything, 5 the best, you hear everything) how good would you say your hearing ability is?
9. a) Have you ever complained to a healthcare provider about sound level? (yes or no)
   b) If so, what was the complaint?

Appendix B: Post-Implementation HSAT Patient Survey (continued)

c) How did the nurse/doctor/staff go about handling your complaint?

d) Was the "fix" satisfactory (scale of 0 to 5, 0 = very unsatisfactory, 5 = very satisfactory)?

10. a) Do you perceive noisiness as an issue that can be improved in the hospital?
    b) Why or why not?
    c) If so, do you have any recommendations as to how noise can be improved?

For 7B only:
One technique the hospital is piloting to improve your rest is a "quiet hour" from 1-2 PM.

11. a) Did you notice this "quiet hour"?
    b) If yes, what was your perception of it?

Appendix C: HSAT Staff Survey

Intro:

We are juniors in the College of Engineering at the University. We are currently working on a multidisciplinary engineering design project. Our overarching goal is to improve the stay of University Hospital patients by assessing noise. We appreciate your taking the time to answer a few brief questions and hopefully help future patients. Thank you!

Hospital Staff:

1. How long have you been working in a hospital setting?
   a) 1 year or less
   b) 1 < years ≤ 2
   c) 2 < years ≤ 5
   d) 5 < years ≤ 10
   e) Over 10 years
2. How long have you been at this particular unit?
   a) 1 year or less
   b) 1 < years ≤ 2
   c) 2 < years ≤ 5
   d) 5 < years ≤ 10
   e) Over 10 years

3a. What hospital(s) did you work at before?

3b. How does this hospital compare to them relative to noise levels (quieter or louder)?

4. What shifts do you work?

a. Day (7 am to 3:30 pm)
   b. A (7 am to 7:30 pm)
   c. Eve (3 pm to 11:30 pm)
   d. N (11 pm to 7:30 am)
   e. P (7 pm to 7:30 am)

5. What type of sound(s) do you think on your particular unit impedes a patient's ability to rest?
   a) Roommate and their family
   b) hospital staff
   c) alarms/medical equipment
   d) everyday noises (ie doors, cleaning, maintenance)
   e) other (please be specific)
6. What do you think is the loudest time of day?
   a) Midnight-6am
   b) 6am-noon
   c) noon-6pm
   d) 6pm-midnight

7a. Think of a shift that is quieter than your shift. What is the loudest noise contributor(s) during that shift? Please rank if there is more than one.
   a) Roommate and their family
   b) hospital staff
   c) alarms/medical equipment

d) everyday noises (ie doors, cleaning, maintenance)
e) other (please be specific)

7b. Think of a shift that is louder than your shift. What is the loudest noise contributor(s) during that shift? Please rank if there is more than one.

a) Roommate and their family
b) hospital staff
c) alarms/medical equipment
d) everyday noises (ie doors, cleaning, maintenance)
e) other (please be specific)

8. Recall the time(s) that a patient has complained to you about noise. What action did you most commonly take to address the complaint?

9. On a scale of 0 to 5 (0 = lowest noise, 5 = excessive noise), how noisy do you think the hallways are on a daily basis?

10. On a scale of 0 to 5 (0 = lowest noise, 5 = excessive noise), how noisy do you think the patient's rooms are on a daily basis

11a. On a scale of 0 to 5 (0 = no effort, 5 = great effort), are you aware of any efforts that have been taken by hospital staff to reduce the level of noise?

11b. On a scale of 0 to 5 (0 = not effective, 5 = very effective), how effective are these efforts?

12. **Do you have any ideas as to how noise can be reduced in your environment?** (important!)

MAKE SURE TO THANK THEM FOR THEIR TIME!

Annals of Internal Medicine | Original Research

Sleep Disruption Due to Hospital Noises

A Prospective Evaluation

Orfeu M. Buxton, PhD; Jeffrey M. Ellenbogen, MD; Wei Wang, PhD; Andy Carballeira, BM; Shawn O'Connor, BS; Dan Cooper, BS; Ankit J. Gordhandas, SB; Scott M. McKinney, BA; and Jo M. Solet, PhD

Background: Sleep plays a critical role in maintaining health and well-being; however, patients who are hospitalized are frequently exposed to noise that can disrupt sleep. Efforts to attenuate hospital noise have been limited by incomplete information on the interaction between sounds and sleep physiology.

Objective: To determine profiles of acoustic disruption of sleep by examining the cortical (encephalographic) arousal responses during sleep to typical hospital noises by sound level and type and sleep stage.

Design: 3-day polysomnographic study.

Setting: Sound-attenuated sleep laboratory.

Participants: Volunteer sample of 12 healthy participants.

Intervention: Baseline (sham) night followed by 2 intervention nights with controlled presentation of 14 sounds that are common in hospitals (for example, voice, intravenous alarm, phone, ice machine, outside traffic, and helicopter). The sounds were administered at calibrated, increasing decibel levels (40 to 70 dBA [decibels, adjusted for the range of normal hearing]) during specific sleep stages.

Measurements: Encephalographic arousals, by using established criteria, during rapid eye movement (REM) sleep and non-REM stages 2 and 3.

Results: Sound presentations yielded arousal response curves that varied because of sound level and type and sleep stage. Electronic sounds were more arousing than other sounds, including human voices, and there were large differences in responses by sound type. As expected, sounds in non-REM stage 3 were less likely to cause arousals than sounds in non-REM stage 2; unexpectedly, the probability of arousal to sounds presented in REM sleep varied less by sound type than when presented in non-REM sleep and caused a greater and more sustained elevation of instantaneous heart rate.

Limitations: The study included only 12 participants. Results for these healthy persons may underestimate the effects of noise on sleep in patients who are hospitalized.

Conclusion: Sounds during sleep influence both cortical brain activity and cardiovascular function. This study systematically quantifies the disruptive capacity of a range of hospital sounds on sleep, providing evidence that is essential to improving the acoustic environments of new and existing health care facilities to enable the highest quality of care.

Primary Funding Source: Academy of Architecture for Health, Facilities Guidelines Institute, and The Center for Health Design.

Ann Intern Med. 2012;156. www.annals.org
For author affiliations, see end of text.
This article was published at www.annals.org on 12 June 2012.

Sleep is essential for the restoration of health and well-being (1). However, in hospitals, where healing is paramount, noise frequently disrupts patients' sleep. In a recent national survey, patients identified the noise levels in and around rooms at night as the quality-of-care factor with the most need for improvement (2). Acoustic measurements from a major urban hospital document a crescendo of nighttime hospital noise over the last 45 years from an average level of 42 dBA [decibels, adjusted for the range of normal hearing] to more than 55 dBA in 2005 (3). Hospitals are exposed to external noise sources known to disrupt sleep, such as traffic and airplane sounds (4), with documented dose-related consequences for next-day cognitive performance (5). Patient care also produces noise specific to treatment and protection, such as intravenous and cardiac monitor alarm signals (6). Improving acoustics in environments of care to protect sleep and enhance outcomes for the more than 37 million patients who are hospitalized annually in the United States (7) has become a transdisciplinary priority (8–11).

The goal of this study was to provide essential information about the effect of sound on sleep to guide architectural, technological, and programmatic advances to facilitate sleep and improve clinical outcomes for patients who are hospitalized. We hypothesized that the capacity for sleep disruption varies by the type of sound and increases for each type as the sound level increases. We further hypothesized that the stages of sleep, characterized by diverse cortical activity patterns, are differentially vulnerable to disruption by noise. Sleep stages cycle through the night and vary in their relative proportions with age (12), medications (13), and certain medical and psychiatric disorders (14), among other factors. Therefore, a useful exploration of the responses of sleep to noises must include sleep stage during noise exposure.

Sleep stages include 2 brain state categories: rapid eye movement (REM) sleep and non-REM (NREM) sleep stages. The range of NREM sleep stages includes progressively deepening levels from drowsiness to deep sleep, termed *N1*, *N2*, and *N3* (15): N1 is the brief transition between wakefulness and sleep, N2 is typically the most

See also:

Print
Summary for Patients

Context

The negative effects of hospital noise on sleep are among the most common concerns of inpatients and their families.

Contribution

During sleep laboratory studies of healthy volunteers, investigators found that the disruptive effect of recorded hospital noises varied by the type and level of sound emitted and by the volunteer's stage of sleep. Electronic sounds designed to be alerting were most disruptive, as were staff conversations and voice paging.

Caution

Volunteers were young and healthy. Sounds were not administered together.

Implication

Reduction of hospital noise through policies, procedures, and building design may lead to improved patient sleep and, thus, quality of care.

—The Editors

abundant stage of sleep in adults, and N3 (or slow-wave sleep) is the deepest level. These REM and NREM brain states seem to be driven by different nuclei and neurotransmitters (16). They can be readily discerned through distinct patterns appearing on electroencephalograms (EEGs) (15) and neuroimaging (17). In addition, behavioral evidence demonstrates that the sleeping brain responds to auditory stimuli differently during REM than during NREM sleep (18). We sought to elaborate on this evidence by examining differential responses to hospital noise exposures between REM and NREM states and exploring variability in sleep disruption within the deepening stages of NREM.

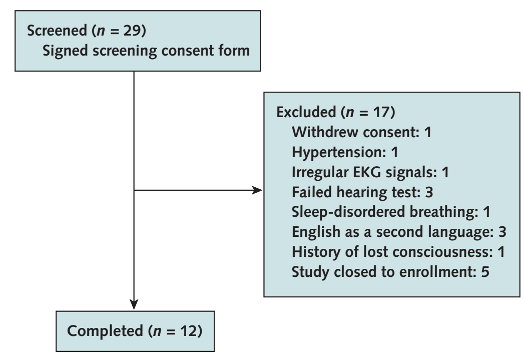
We designed a protocol to examine the influence of graded noise exposures during all stages of sleep, through polysomnographic (PSG) assessments (combined EEG, electrooculogram, and electromyogram), a standard (19, 20) and sensitive (21, 22) system to measure sleep strongly correlated with awakenings (21). Because elevations in heart rate (HR) are known to occur during full EEG-documented awakenings from sleep (23), we used the electrocardiogram to detect the presence of clinically relevant HR responses to noise-induced arousals. We predicted HR elevations during these EEG-documented sleep arousals in participants who were exposed to common hospital sounds.

METHODS

Design Overview

All study procedures were approved by the human research committees of the involved institutions. The design is a 3-day PSG study, beginning with a baseline (sham) quiet night followed by 2 noise exposure intervention nights, during which EEG arousals and electrocardiogram HR accelerations were documented.

Figure 1. **Study flow diagram.**



EKG = electrocardiogram.

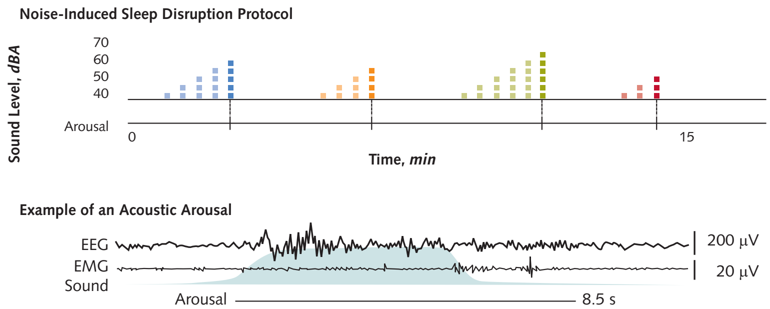
Participants and Setting

Participants were recruited through flyers, Web site postings, and word of mouth and then screened by questionnaire, physical examination, and laboratory testing. Participants who reported medical or psychiatric conditions or use of substances or medications that potentially affect sleep were excluded from the study. Criteria for exclusion included history of drug or alcohol abuse; depression; anxiety; posttraumatic stress and obsessive compulsive disorders; neurologic or sleep disorders; infectious diseases; diseases of the cardiovascular system; or treatment with antidepressants, neuroleptics, or major tranquilizers. Urinalysis confirmed the absence of caffeine, nicotine, and alcohol. Standard audiometric screening confirmed normal hearing (that is, exceeding 20 dBA in both ears). The first 12 eligible and available participants were enrolled (**Figure 1**).

Participants slept at home on a regular schedule for at least 4 days before participation in the study. They reported sleeping a mean of 7.72 hours (SD, 0.27) over a mean of 6.5 days (SD, 1.1) through a time-stamped phone-answering system that was confirmed through wrist actigraphy (AW-64, Philips Respironics, Murrysville, Pennsylvania), which demonstrated a mean of 7.16 hours (SD, 0.29) of sleep over a mean of 6.7 monitored days (SD, 0.9).

Participants stayed at the Massachusetts General Hospital Sleep Laboratory for 3 days. Each night, participants were given an 8.5-hour sleep opportunity, which began at their normal bedtimes. Continuous video observation and wrist actigraphy confirmed that participants did not nap during the day. Light levels were maintained at less than 1 lux (darkness) during sleep periods and approximately 90 lux (ordinary daylight in room) during waking periods. Because of continuous air exchange (required in health care

Figure 2. **Schematic diagram of study protocol.**



Top. The solid vertical lines along the *x*-axis indicate stimuli evoking EEG arousals, and a sample of 4 noises is shown. Each color represents a different sound type. Ten-second noises were evaluated for their probability to induce a cortical arousal at increasing sound levels in varying stages of sleep and presented once per 30-second sleep epoch (while sleep stage was stable) until an arousal occurred, sleep stage changed, or the 70-dBA maximum was reached. *Bottom.* Shown here is a typical sound-induced arousal from stage N2 sleep, as measured by polysomnography. Arousals are defined by their appearance on the EEG (the right frontal lead F3 shown here), characterized by an abrupt shift of frequency that lasts at least 3 seconds. Arousals during REM sleep require a concurrent increase in submental EMG activity. This transient arousal lasted for approximately 8.5 seconds before sleep resumed. dBA = decibels, adjusted for the range of normal hearing; EEG = electroencephalogram; EMG = electromyogram.

facilities), background ambient sound levels averaged between 34 and 35 dBA ($LA_{EQ,\ 10\text{-}s}$ [equivalent continuous A-weighted scale {adjusted for the range of normal human hearing} sound pressure level, averaged over the 10-second stimulus duration]). On the first night, participants slept undisturbed to allow adaptation to the PSG equipment and laboratory environment, confirm absence of sleep disorders (including sleep apnea), and establish baseline sleep recordings. On the second and third nights, recorded hospital sounds were presented to participants throughout sleep.

Intervention: Acoustic Stimuli

Recordings of hospital sounds were captured on a medical unit of Somerville Hospital, Cambridge Health Alliance, Somerville, Massachusetts. Each sound stimulus fit within 1 or more of the categories identified as salient in the American Institute of Architects Guideline on Sound and Vibration in Healthcare Facilities: external to building, within hospital, and within or outside patient rooms (8). Fourteen noise stimuli were selected: "good" conversation, which was defined as 1 male and 1 female voice discussing a positive patient outcome; "bad" conversation, which was defined as the same voices discussing a negative patient outcome; male voice from an overhead paging system calling a physician by name; door closing; telephone ringing; toilet flushing; ice machine disgorging; IV alarm sounding; laundry cart rolling; automatic paper towel machine dispensing; helicopter takeoff; jet engine flyover; and outside traffic flow. To control for differences in duration across stimuli, sounds were normalized to 10 seconds (**Appendix Table 1**, available at www.annals.org).

Hospital noises were presented as stimuli with 2-dimensional verisimilitude (for example, airplane sounds moved across space) through use of 4 studio monitor loudspeakers (PS6, Event Electronics, Silverwater, Australia) arrayed about the head of the sleeping participants (a modified pattern from the ITU-R BS 775-1 Recommendation, omitting the center loudspeaker). Sound levels in the participants' room were logged in 1-second increments by using an environmental sound monitor (NL-31, with type 1 microphone [Rion, Tokyo, Japan]) installed roughly 10 inches above the head of the sleeping participants and programmed to output a direct current voltage proportional to the A-weighted fast-response sound level.

Once a steady sleep stage of at least 90 seconds was recorded, as assessed in real time by a technician, stimuli were systematically presented once per 30-second sleep epoch, starting at an exposure level ($LA_{EQ,\ 10\text{-}s}$) of 40 dBA in increasing steps of 5 dBA (**Figure 2**, *top*) until either sleep was disrupted by an arousal (**Figure 2**, *bottom*), sleep stage changed, or the 70-dBA maximum exposure level was reached. Because both the equivalent sound level and the duration of the noise stimuli were held constant, all stimuli were normalized to deliver an equal "noise dose," an integration of sound intensity over time (24). All stimuli were presented in a computer-generated random order within each sleep stage on both exposure nights for every participant.

Outcomes

Standard PSG recordings (Comet XL, Grass Technologies, West Warwick, Rhode Island) were collected on all 3 nights through skin surface electrodes. Sleep stages and arousals were identified by using current criteria (15). **Figure 2** (*top panels*) depicts a standard arousal, as defined by an abrupt shift of EEG frequency lasting at least 3 seconds. Arousals during REM sleep also require a concurrent increase in submental electromyogram activity (**Figure 2**). Body position was scored from infrared video to allow for statistical adjustment based on whether either ear was occluded, potentially attenuating arousal responses. Body position (supine or not) was assessed continuously by a sleep technician viewing the infrared video on the same screen as the EEG signals they were using to score sleep stages in real time at the initiation of each acoustic stimulus.

Experimental tasks were coordinated by 2 researchers; a sleep technician maintained PSG signal quality classification of sleep stages and identification of cortical arousals indicating sleep disruption (25), along with documentation of body position. A second technician or investigator maintained the acoustic equipment and initiated the programmed, semiautomatic presentation of escalating noise stimuli. Discrepancies with the real-time scoring were resolved by a board-certified sleep physician.

Statistical Analysis

The probability of arousal by stimulus, sound level and type, and sleep stage was examined descriptively (graphically). Generalized linear mixed models were applied to evaluate the effects of hospital noises on the binary outcome (arousal from sleep) with a logit link, by using PROC GLIMMIX in SAS software, version 9.2 (SAS Institute, Cary, North Carolina), for determining differences by sleep stage, with factors of study night and body position. Because of large inter-person differences, the participant was treated as a random effect, incorporating participant-specific intercepts into the model. We assume that, between 2 adjacent presented stimuli levels (for example, 50 and 55 dBA), the arousal probability increases linearly for the intervening stimuli levels (for example, 51 to 54 dBA). Because an ear against the pillow could attenuate the administered sound level, body position served as a covariate in the model where supine position (reference category) corresponded to having both ears exposed. This model was used to estimate the probability of arousal while accounting for stimulus, sound level, sleep stage, and body position. We separately estimate the additional effect of the night of study (see the Results section).

To assess the effects of noise on HR during sleep by sleep stage, we calculated the profile of instantaneous HR during each arousal relative to the average HR during the 10 seconds preceding each corresponding sound onset. To quantify the temporal dynamics of the HR response, we calculated the median durations from the sound onset to the time of peak HR during each arousal and to the time of arousal onset.

Role of Funding Source

Nonprofit entities, the American Architects Health Foundation, Facilities Guidelines Institute, and The Center for Health Design, contributed resources to this investigator-initiated study. They did not play a role in the study design, conduct, or reporting, or the decision to submit a manuscript.

RESULTS

Twelve healthy, white participants (8 women; mean age, 27 years [SD, 7]; mean BMI, 21.8 kg/m^2 [SD, 3.7]) successfully completed this study.

As expected, louder sounds were more apt to cause sleep disruption (see **Figure 3**). Effects varied by the type of sound stimulus (for example, IV alarm vs. voices) and by the stage of sleep during which the sound stimulus was presented (for example, REM vs. N3).

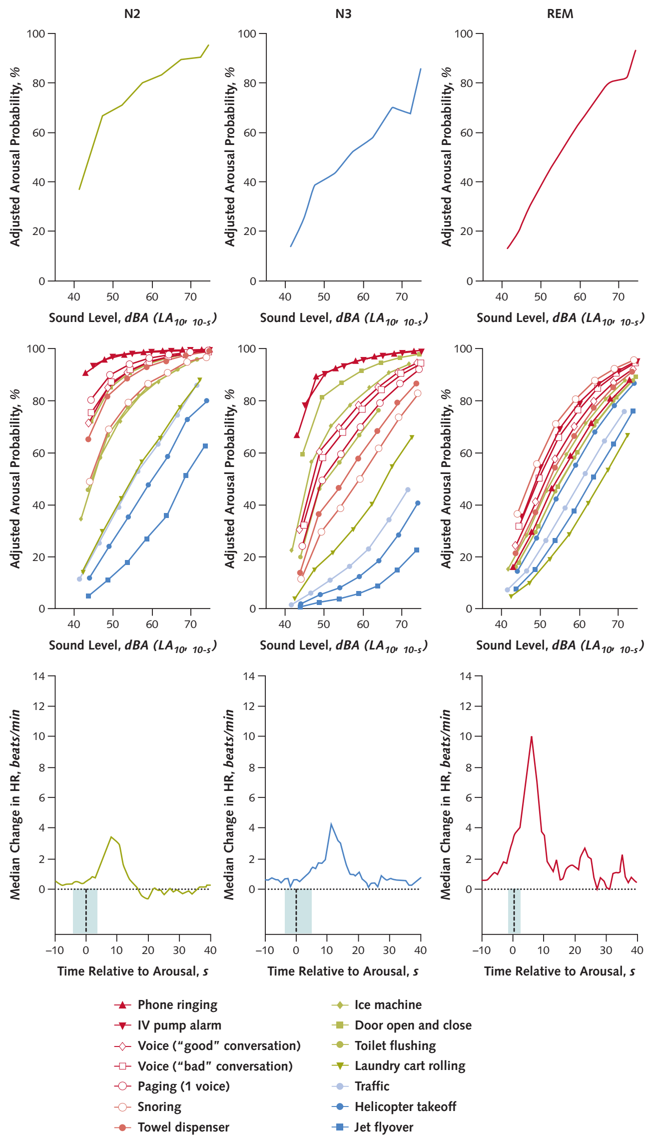
We saw an effect of sleep stage on sound stimulus–evoked arousal probability (**Figure 3**, *top panels*); N2 differed from N3 and REM (both $P < 0.001$, Bonferroni-adjusted), but N3 and REM did not differ overall, using model-based probability estimates. The pattern of arousal probabilities from stages N2 to N3 were relatively consistent in terms of sound stimulus order from most to least arousing, but shifted to overall lower arousal rates during N3 compared with N2 (**Figure 3**, *middle panels*). In marked contrast, arousals from REM sleep revealed a more homogeneous and monotonic pattern across sounds presented than NREM stages (**Figure 3**, *middle panels*) not readily apparent from the mean curves alone (**Figure 3**, *top panels*). Arousals occurred at lower sound levels on the third study night compared with the second study night ($P < 0.001$). Testing for the stage–by–study-night interaction only showed a slight difference across nights among sleep stages ($P = 0.020$, adjusted for sound levels [**Appendix Table 2**, available at www.annals.org]; body position was not significant and was not included in the final interaction model). The significant interaction suggests that the arousal probability was lower on the third night for all sleep stages, but the magnitude of the difference varied across stages and may reflect some degree of sensitization of arousals to sound presentation. Depiction of arousal probabilities for individual sound stimuli by stage and sound level revealed considerable heterogeneity in the responses to the various stimuli (**Figure 4**).

We studied the change in HR during stimulus-induced arousals by subtracting the instantaneous HR from the average HR of the 10 seconds preceding the sound onset. The stage in which the arousal occurred substantially predicts the magnitude of the HR increase ($P < 0.0001$); the greatest responses occurred during REM, followed by N3 and N2 (**Figure 3**, *bottom panels*). All pairwise comparisons are significant at an α level of $0.05/3 = 0.017$. Baseline (pre-arousal) HR does not predict the magnitude of the response ($P = 0.94$). Study night is not significant ($P = 0.83$), reflecting a lack of habituation of the electrocardiogram HR response.

Heart rate responses are aligned by their peaks in **Figure 3** (*bottom panels*). The stage in which the arousal occurred significantly predicts the duration of time from the start of the arousal to the peak of the HR increase ($P < 0.001$); the fastest response times to peak were found during REM, then during N2 and N3. The median time from

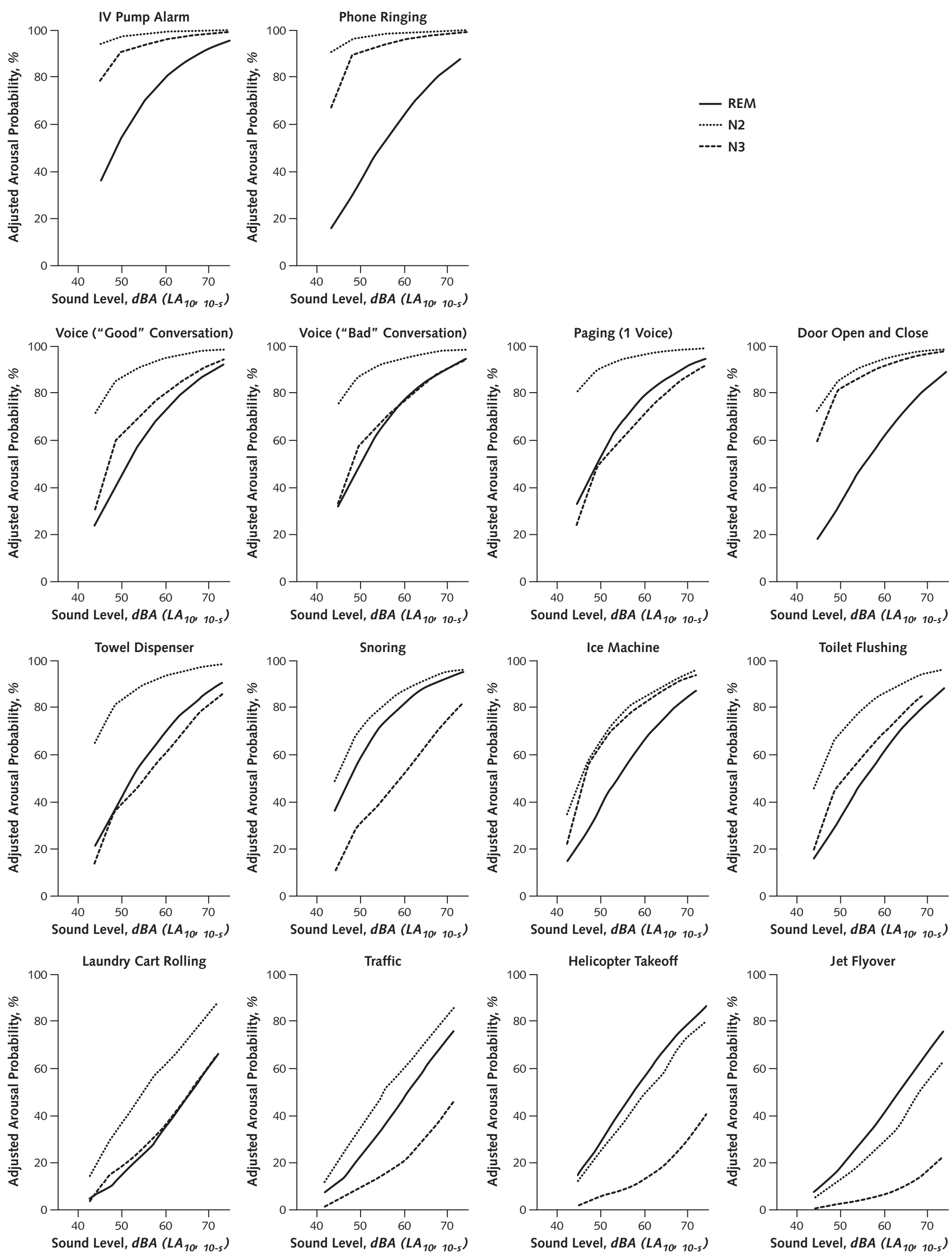
Attachment A: Buxton Article (continued)

Figure 3. **Sleep disruption due to noise stimuli presented during sleep, by stage of sleep.**



Arousal probability of sound stimuli presented in sleep stages N2, N3, and REM. Ten-second noises were introduced during sleep stages N2, N3, and REM to evaluate their propensity to disturb sleep. Once a stable stage of at least 90 seconds was reached, noises were initiated at sound levels of 40 dBA (equivalent continuous A-weighted [adjusted for the range of normal human hearing] sound pressure level, averaged over the 10-s stimulus duration) and presented every 30 s in 5-dBA increments until an arousal occurred or the 70-dBA exposure level was reached. *Top panels:* Mean arousal probabilities (with 95% CIs) are depicted for stimuli presented during stages N2, N3, and REM versus presented sound level and adjusted for stimulus and body position (see Methods section). *Middle panels:* Mean arousal probabilities for individual noise stimuli by sleep stage, adjusted for body position. *Lower panels:* Changes in the median HR during nonspontaneous, noise-induced arousals are aligned by the time of the peak HR response and expressed relative to the average HR in the 10 seconds preceding the arousals in stages N2, N3, and REM. The vertical lines represent the median time of arousal onset (with CIs) before that peak. dBA = decibels, adjusted for the range of normal hearing; HR = heart rate; $LA_{10,\ 10\text{-s}}$ = sound pressure level, averaged over the 10-second stimulus duration, exceeded 10% of the time; N2 = non-REM sleep stage 2; N3 = non-REM sleep stage 3; REM = rapid eye movement.

Figure 4. **Electroencephalogram arousal probabilities for noise stimuli presented, adjusted for body position (see Methods section).**



dBA = decibels, adjusted for the range of normal hearing; $LA_{10,\ 10\text{-}s}$ = sound pressure level, averaged over the 10-second stimulus duration, exceeded 10% of the time; N2 = non-REM sleep stage 2; N3 = non-REM sleep stage 3; REM = rapid eye movement.

the start of the arousal to peak HR in REM is significantly shorter than N2 and N3; N3 is not significantly different from N2 adjusted for several comparisons at an α level of 0.017. No differences were seen in baseline HR across sleep stages ($P = 0.53$).

Discussion

This study systematically quantifies the disruptive capacity of hospital-recorded sounds on sleep. Sound presentations during sleep yielded arousal response curves that varied because of sound type and level and sleep stage. As predicted, for each stimulus, higher sound levels led to a greater probability of sleep disruption. Electronic sounds, such as an IV alarm designed to alert medical staff, were consistently more arousing than other sounds at the same noise dose. Overall, the effect of sound level and type were modified by sleep stage physiology, producing unique arousal probability profiles for each sleep stage. We further demonstrate that the arousal effects of noise on sleep include HR elevations, even when disruptions are brief and frequent. Heart rate effects may be particularly relevant to critical care settings, in which monitor alarms are very frequent (6). These arousal probability profiles have the potential to drive needed innovation in design, construction, engineering, building materials, monitoring and communication equipment, and care-giving protocols to preserve sleep and enhance environments for healing. Improved acoustic environments consistent with current guidelines in the United States (8) and European Union (26) could deliver several clinical benefits, including reduced sedation and shorter hospital stays (4, 9, 10, 21, 27–29).

Disrupted sleep is known to be associated with hypertension (30), incidence of cardiovascular and coronary heart disease (31), impaired immune function (32), elevated stress hormone responses (33), attention and memory deficits (34), and depressed mood (35). Preservation of patients' sleep should be a priority for contributing to improved clinical outcomes for patients who are hospitalized (36). Spontaneous arousals are known to accelerate HR (36–39). Full awakenings evoked by noise lead to HR elevations of approximately 10 beats/min (36). We demonstrate that evoked arousals elicit HR acceleration from all stages of sleep, but a greater magnitude (10 beats/min) and faster onset of HR accelerations from REM, with lesser magnitude and less rapid accelerations in stages N2 and N3. Our data demonstrate that the effect of noise on sleep includes HR elevations, even when the disruption is brief and frequent, as might be seen in an intensive care unit setting. A recent synthesis of hospital soundscape surveillance data described a pattern of intensive care unit noise exceeding a "peak" of 60 dBA more than 50% of the time at night (40) and, thus, the frequency of sleep disruptions may be high in typical intensive care or other inpatient units, as described by patient self-reports (2), and in other units, such as the neonatal intensive care unit (41). A study of patients in the cardiac intensive care unit demonstrated that adverse acoustic environments are associated with higher pulse amplitude at night and elevated use of β-blockers. The patient group exposed to the acoustically unmodified environment also demonstrated higher rates of rehospitalization and poorer ratings of quality of care (29).

Looking more broadly across the hospital, patients who are hospitalized frequently have delirium with immediate and long-term consequences, including an association with increased mortality rates. Sleep disruption has been proposed as a modifiable target for delirium interventions (42). A prospective and multifaceted delirium intervention study of older patients on a general medical ward—a study that included a sleep component and noise reduction—successfully reduced delirium symptoms and the rate of sleep medication use (43). Sleep is a cyclic orchestration of stages that alters with aging and can vary from person to person with specific medical, psychiatric, and situational differences (44). Older persons tend to have less N3 sleep (12, 45), and various medications can influence stage distributions (for example, antidepressants suppress REM sleep) (46). Our data provide a framework for implementing targeted strategies to mitigate noise-induced sleep disruption, which potentially contributes to delirium among patients who are hospitalized.

Approaches to mitigating noise for sleeping patients include eliminating or controlling the sound source or blocking the sound path. The first approach, controlling sound at the source, includes public-policy restrictions on acceptable night noise, such as aircraft flyovers (9); substitution with quieter technologies, such as personal digital assistants in place of overhead paging; and telemetry from nurses' stations to limit intrusive oversight (11, 47). The night-care intervention study at 1 hospital established a "quiet time" period, altered intrusive medication routines, and reduced sound level exposures from staff voices. This protocol resulted in a 25% reduction of unit-wide sedative medication use and improved patient satisfaction ratings (10). The second approach to mitigation focuses on "blocking" or attenuating sound along the transmission path, including hospital unit design configurations; application of advanced construction materials, such as acoustic surfaces (48); closing doors; and even supplying earplugs to patients.

As expected, the most potent sleep disruptors were electronic sounds intentionally designed to be alerting (49, 50). The arousal probability curves in **Figure 4** corresponding to these sounds (that is, phone ringing and IV alarm) reveal that these devices may not be suitably attenuated to spare sleep, even at their quietest settings: within the lowest tested ranges in this study, these sounds produced sleep disruption more than 50% of the time. Alarm signals have proliferated in health care settings. Monitor alarms could be better managed through enhanced algorithms, more careful patient assignment and clinically relevant configuration standards, and targeting intended responders with technologies using nonauditory channels (6).

Staff conversations and voice paging were also found to be highly alerting, producing a 50% chance of arousal at 50 dBA (sound level exceeded 10% of the time) in N2 and REM sleep. Voice transmission can be modified behaviorally (10) and diminished through design and construction solutions. Simple strategies include planning for and directing conversation to designated consulting spaces. In many health care settings, policy still includes keeping patient doors open to allow for visual monitoring and easy accessibility by caregivers, which exposes patients to excess noise from the nurses' station and other sources. Centralized patient-monitoring technology may help minimize the need for this policy—at least at night—while still addressing patient-safety concerns. Proper door hardware and gasketing could decrease the sounds generated by door closing and limit sound transmission from halls.

Other tested hospital sounds (for example, ice machines, laundry carts, and overhead paging) that emanate from sources external to patient rooms (51–53) were, as a group, arousing at relatively low sound levels. Ice machines should be architecturally isolated from patient areas or reengineered. Modifying procedures and equipment, such as selection and maintenance of carts and organizing the schedule of use and routing, is a low-tech, low-cost contribution to reducing noise. Exterior-to-building noises (jet, helicopter, traffic, etc.) were the least arousing among our group of stimuli, and our findings were consistent with other studies of sleep and airplane flyovers (21). The previous work determined that statistical description of average sound level ($LA_{EQ,\ 10\text{-}s}$) over 24 hours is an inadequate measure for describing the sleep-disruptive effects from noise. Examining disruption at different sound levels is the more appropriate exposure metric (9), especially for sounds with broad ranges that peak. It is, therefore, not surprising that we determined that continuous stimuli (for example, traffic noise) are less arousing than intermittent stimuli (for example, phone ringing or IV alarm). At the same adjusted noise dose, higher transient sound levels and faster rise times are more likely to induce cortical arousals. In considering our findings, broad sleep-preserving steps should include changes in the design of health care facilities, construction materials chosen for acoustic properties, improved monitoring and alerting technology, sleep-protective night-care routines, and education and retraining of health care personnel on the effect of noise on patient arousal and cardiac responses to such sleep disruptions (4, 9, 10, 21, 27–29).

During REM sleep, we saw a narrower range of cortical arousals, relative to NREM stages of sleep, and given a wide range of sounds administered in this experiment. This may demonstrate that the brain, during REM sleep, has less capacity to differentiate among sounds compared with NREM sleep. This finding is unexpected because REM sleep has an abundance of cerebral activity relative to stage N3 sleep, including in auditory areas of the brain (17). Auditory-evoked potentials elicited by saying a participant's name during REM sleep also seem similar in morphology to those seen during wakefulness (18), implying that there is some higher-order processing in REM sleep. This supports the broader notion that, in REM sleep, cerebral resources are dedicated to internal processing, such as dream content, rather than to differentiating external sound sources.

Although ecologically valid in many aspects, this experiment has some limitations that may cause an underestimation of the effects of noise on sleep. We presented noises individually for up to 10 seconds and halted if arousal occurred. This procedure minimized full awakenings and increased sleep time available for more stimulus presentations. In a hospital setting, sounds often last longer than 10 seconds and several sounds occur simultaneously. We do not account for relative proportion or intermittency of stimuli in a hospital setting; our data are intended to provide a framework by which a specific unit could assess the sleep-disrupting effects of a specific hospital environment. We studied only 12 young, healthy adults. The typical patient who is hospitalized is older, with generally less of the most protected deep sleep, N3 (54). Medical and psychiatric conditions, as well as pain and medication use, compromise sleep in patients who are hospitalized, presumably rendering deep sleep, N3, more difficult to achieve. Noise can be expected to interact with these other sleep-disrupting stressors associated with hospitalization (55). Therefore, we judge our arousal probability profiles for N2 sleep to be most relevant for predicting acoustic disruption of sleep in inpatient populations. Future studies should assess the effect of noise on sleep disruption and HR changes in older participants to confirm generalizability and document effects on sleep stage proportions and architecture. Together, these limitations may cause our data to underestimate the effects of noise on sleep for patients who are hospitalized. Our data should be viewed as providing reference points that demonstrate sleep disruption caused by these common hospital noises, across a range of sound levels, and should be used to set a minimum for noise-attenuating standards.

In summary, protecting sleep from acoustic assault in hospital settings is a key goal in advancing the quality of care for inpatient medicine. We characterized the vulnerability of sleep to commonly encountered hospital sounds by deriving unique arousal probability profiles to enable customized target thresholds and interventions to limit noise-induced sleep disruption. This research has already informed the first acoustic standards in the Guidelines for the Design and Construction of Health Care Facilities (8). With the leading edge of baby boomers turning 66 this year and an aging health care infrastructure, billions of dollars in health care facility renovation and new construction are anticipated in the coming decade (7). Improving the acoustics in health care facilities will be critical to ensuring that these environments enable the highest quality care and the best clinical outcomes.

From Harvard Medical School, Brigham and Women's Hospital, Massachusetts General Hospital, and Berklee College of Music, Boston; Cambridge Health Alliance, Cambridge; and Cavanaugh Tocci Associates, Sudbury, Massachusetts.

Note: Drs. Buxton and Ellenbogen contributed equally to this manuscript.

Acknowledgment: The authors thank Jenny Lai Olsen, Margaret Merlino, Karen Gannon, Leah Rondon, Vanessa Castro, Carolina Smales, Deirdre McLaren, and James Porter for technical assistance, Peg Toro, audiologist, for consultation on screening for normal hearing, and Dean M. Hashimoto, MD; John W. Cronin, MD; and Matt Travis Bianchi, MD, PhD, for helpful comments on the manuscript.

Grant Support: This study was funded by investigator-initiated grants (Dr. Solet) from the Academy of Architecture for Health, the Facilities Guidelines Institute, and The Center for Health Design. Sleep laboratory work was completed through the generosity of Massachusetts General Hospital and with acoustic consultation by Cavanaugh Tocci Associates.

Potential Conflicts of Interest: Disclosures can be viewed at www.acponline.org/authors/icmje/ConflictOfInterestForms.do?msNum=M11-1159.

Requests for Single Reprints: Orfeu M. Buxton, PhD, 221 Longwood Avenue, BLI438-K, Boston, MA 02115; e-mail, orfeu_buxton@hms.harvard.edu.

Reproducible Research Statement: *Study protocol, data sets, and statistical code:* Available from Dr. Buxton (e-mail, orfeu_buxton@hms.harvard.edu). Execution of a materials transfer agreement is required by the institution for the transfer of data.

Current author addresses and author contributions are available at www.annals.org.

References

1. **Colten HR, Altevogt BM, eds; Committee on Sleep Medicine and Research.** Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem. Washington, DC: National Academies Pr; 2006.
2. **Jha AK, Orav EJ, Zheng J, Epstein AM.** Patients' perception of hospital care in the United States. N Engl J Med. 2008;359:1921-31. [PMID: 18971493]
3. **Busch-Vishniac IJ, West JE, Barnhill C, Hunter T, Orellana D, Chivukula R.** Noise levels in Johns Hopkins Hospital. J Acoust Soc Am. 2005;118:3629-45. [PMID: 16419808]
4. **Griefahn B, Bröde P, Marks A, Basner M.** Autonomic arousals related to traffic noise during sleep. Sleep. 2008;31:569-77. [PMID: 18457245]
5. **Elmenhorst EM, Elmenhorst D, Wenzel J, Quehl J, Mueller U, Maass H, et al.** Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose-response relationships in laboratory and field. Int Arch Occup Environ Health. 2010;83:743-51. [PMID: 20143082]
6. **Solet JM, Barach P.** Managing alarm fatigue in cardiac care. Prog Pediatr Cardiol. 2012;33:85-90.
7. **Carpenter D, Hoppszallern S.** Proceed with caution. Lean year expected for hospital construction. Health Facil Manage. 2010;23:11-8. [PMID: 21638945]
8. Facilities Guidelines Institute. Guidelines for Design and Construction of Health Care Facilities. Chicago: American Society for Healthcare Engineering of the American Hospital Association; 2010.
9. **Basner M, Samel A, Isermann U.** Aircraft noise effects on sleep: application of the results of a large polysomnographic field study. J Acoust Soc Am. 2006;119: 2772-84. [PMID: 16708935]
10. **Bartick MC, Thai X, Schmidt T, Altaye A, Solet JM.** Decrease in as-needed sedative use by limiting nighttime sleep disruptions from hospital staff. J Hosp Med. 2010;5:E20-4. [PMID: 19768797]
11. **Montague KN, Blietz CM, Kachur M.** Ensuring quieter hospital environments. Am J Nurs. 2009;109:65-7. [PMID: 19704239]
12. **Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV.** Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. Sleep. 2004;27: 1255-73. [PMID: 15586779]
13. **Schweitzer PK.** Drugs that disturb sleep and wakefulness. In: Kryger MH, Roth T, Dement WC, eds. Principles and Practice of Sleep Medicine, 5th ed. St. Louis: Elsevier Saunders; 2010:542-60.
14. **Witmans M.** Systematic review of the efficacy and safety of drug treatments and combination treatments in the management of chronic insomnia in adults. J Clin Sleep Med. 2005;1:e488-95.
15. **Iber C, Ancoli-Israel S, Chesson A, Quan SF.** The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications. Darien, IL: American Academy of Sleep Medicine; 2007.
16. **Siegel JM.** REM sleep. In: Kryger MH, Roth T, Dement WC, eds. Principles and Practice of Sleep Medicine. 5th ed. St. Louis: Elsevier Saunders; 2010:92-111.
17. **Braun AR, Balkin TJ, Wesenten NJ, Carson RE, Varga M, Baldwin P, et al.** Regional cerebral blood flow throughout the sleep-wake cycle. An H2(15)O PET study. Brain. 1997;120 (Pt 7):1173-97. [PMID: 9236630]
18. **Perrin F, García-Larrea L, Mauguière F, Bastuji H.** A differential brain response to the subject's own name persists during sleep. Clin Neurophysiol. 1999;110:2153-64. [PMID: 10616121]
19. **Bonnet MH, Arand DL.** EEG arousal norms by age. J Clin Sleep Med. 2007;3:271-4. [PMID: 17561594]
20. **Basner M.** Arousal threshold determination in 1862: Kohlschütter's measurements on the firmness of sleep. Sleep Med. 2010;11:417-22. [PMID: 20223705]
21. **Basner M, Glatz C, Griefahn B, Penzel T, Samel A.** Aircraft noise: effects on macro- and microstructure of sleep. Sleep Med. 2008;9:382-7. [PMID: 17870661]
22. **Halász P, Terzano M, Parrino L, Bódizs R.** The nature of arousal in sleep. J Sleep Res. 2004;13:1-23. [PMID: 14996030]
23. **Basner M, Griefahn B, Berg M.** Aircraft noise effects on sleep: mechanisms, mitigation and research needs. Noise Health. 2010;12:95-109. [PMID: 20472955]
24. **De Gennaro L, Casagrande M, Violani C, Di Giovanni M, Herman J, Bertini M.** The complementary relationship between waking and REM sleep in the oculomotor system: an increase of rightward saccades during waking causes a decrease of rightward eye movements during REM sleep. Electroencephalogr Clin Neurophysiol. 1995;95:252-6. [PMID: 8529555]
25. **Bonnet MH, Doghramji K, Roehrs T, Stepanski EJ, Sheldon SH, Walters AS, et al.** The scoring of arousal in sleep: reliability, validity, and alternatives. J Clin Sleep Med. 2007;3:133-45. [PMID: 17557423]
26. World Health Organization Regional Office for Europe. Night Noise Guidelines for Europe. Copenhagen, Denmark: World Health Organization; 2010.
27. **Cmiel CA, Karr DM, Gasser DM, Oliphant LM, Neveau AJ.** Noise control: a nursing team's approach to sleep promotion. Am J Nurs. 2004;104:40-8. [PMID: 14767379]
28. **Johnson AN.** Adapting the neonatal intensive care environment to decrease noise. J Perinat Neonatal Nurs. 2003;17:280-8. [PMID: 14655788]
29. **Hagerman I, Rasmanis G, Blomkvist V, Ulrich R, Eriksen CA, Theorell T.** Influence of intensive coronary care acoustics on the quality of care and physiological state of patients. Int J Cardiol. 2005;98:267-70. [PMID: 15686777]
30. **Cappuccio FP, Stranges S, Kandala NB, Miller MA, Taggart FM, Kumari M, et al.** Gender-specific associations of short sleep duration with prevalent and incident hypertension: the Whitehall II Study. Hypertension. 2007;50:693-700. [PMID: 17785629]
31. **Hoevenaar-Blom MP, Spijkerman AM, Kromhout D, van den Berg JF, Verschuren WM.** Sleep duration and sleep quality in relation to 12-year cardiovascular disease incidence: the MORGEN study. Sleep. 2011;34:1487-92. [PMID: 22043119]
32. **Cohen S, Doyle WJ, Alper CM, Janicki-Deverts D, Turner RB.** Sleep habits and susceptibility to the common cold. Arch Intern Med. 2009;169:62-7. [PMID: 19139325]
33. **Buxton OM, Pavlova M, Reid EW, Wang W, Simonson DC, Adler GK.**

Sleep restriction for 1 week reduces insulin sensitivity in healthy men. Diabetes. 2010;59:2126-33. [PMID: 20585000]
34. **Drummond SP, Brown GG.** The effects of total sleep deprivation on cerebral responses to cognitive performance. Neuropsychopharmacology. 2001;25:S68-73. [PMID: 11682277]
35. **Ancoli-Israel S, Cooke JR.** Prevalence and comorbidity of insomnia and effect on functioning in elderly populations. J Am Geriatr Soc. 2005;53:S264-71. [PMID: 15982375]
36. **Basner M, Griefahn B, Müller U, Plath G, Samel A.** An ECG-based algorithm for the automatic identification of autonomic activations associated with cortical arousal. Sleep. 2007;30:1349-61. [PMID: 17969469]
37. **Catcheside PG, Chiong SC, Mercer J, Saunders NA, McEvoy RD.** Non-invasive cardiovascular markers of acoustically induced arousal from non-rapid-eye-movement sleep. Sleep. 2002;25:797-804. [PMID: 12405616]
38. **Sforza E, Chapotot F, Lavoie S, Roche F, Pigeau R, Buguet A.** Heart rate activation during spontaneous arousals from sleep: effect of sleep deprivation. Clin Neurophysiol. 2004;115:2442-51. [PMID: 15465431]
39. **Sforza E, Jouny C, Ibanez V.** Cardiac activation during arousal in humans: further evidence for hierarchy in the arousal response. Clin Neurophysiol. 2000;111:1611-9. [PMID: 10964073]
40. **Ryherd EE, Waye KP, Ljungkvist L.** Characterizing noise and perceived work environment in a neurological intensive care unit. J Acoust Soc Am. 2008;123:747-56. [PMID: 18247879]
41. **Williams AL, van Drongelen W, Lasky RE.** Noise in contemporary neonatal intensive care. J Acoust Soc Am. 2007;121:2681-90. [PMID: 17550168]
42. **Weinhouse GL, Schwab RJ, Watson PL, Patil N, Vaccaro B, Pandharipande P, et al.** Bench-to-bedside review: delirium in ICU patients–importance of sleep deprivation. Crit Care. 2009;13:234. [PMID: 20053301]
43. **Inouye SK, Bogardus ST Jr, Charpentier PA, Leo-Summers L, Acampora D, Holford TR, et al.** A multicomponent intervention to prevent delirium in hospitalized older patients. N Engl J Med. 1999;340:669-76. [PMID: 10053175]
44. **Dang-Vu TT, McKinney SM, Buxton OM, Solet JM, Ellenbogen JM.** Spontaneous brain rhythms predict sleep stability in the face of noise [Letter]. Curr Biol. 2010;20:R626-7. [PMID: 20692606]
45. **Landolt HP, Dijk DJ, Achermann P, Borbély AA.** Effect of age on the sleep EEG: slow-wave activity and spindle frequency activity in young and middle-aged men. Brain Res. 1996;738:205-12. [PMID: 8955514]
46. **Mayers AG, Baldwin DS.** Antidepressants and their effect on sleep. Hum Psychopharmacol. 2005;20:533-59. [PMID: 16229049]
47. **Kahn DM, Cook TE, Carlisle CC, Nelson DL, Kramer NR, Millman RP.** Identification and modification of environmental noise in an ICU setting. Chest. 1998;114:535-40. [PMID: 9726742]
48. **Berg S.** Impact of reduced reverberation time on sound-induced arousals during sleep. Sleep. 2001;24:289-92. [PMID: 11322711]
49. **Bruck D, Ball M, Thomas I, Rouillard V.** How does the pitch and pattern of a signal affect auditory arousal thresholds? J Sleep Res. 2009;18:196-203. [PMID: 19302343]
50. **McNeer RR, Bohórquez J, Ozdamar O, Varon AJ, Barach P.** A new paradigm for the design of audible alarms that convey urgency information. J Clin Monit Comput. 2007;21:353-63. [PMID: 17973195]
51. **Yinnon AM, Ilan Y, Tadmor B, Altarescu G, Hershko C.** Quality of sleep in the medical department. Br J Clin Pract. 1992;46:88-91. [PMID: 1457316]
52. **Topf M, Bookman M, Arand D.** Effects of critical care unit noise on the subjective quality of sleep. J Adv Nurs. 1996;24:545-51. [PMID: 8876415]
53. **Southwell MT, Wistow G.** Sleep in hospitals at night: are patients' needs being met? J Adv Nurs. 1995;21:1101-9. [PMID: 7665774]
54. **Dijk DJ, Duffy JF, Czeisler CA.** Age-related increase in awakenings: impaired consolidation of nonREM sleep at all circadian phases. Sleep. 2001;24:565-77. [PMID: 11480654]
55. **Topf M, Thompson S.** Interactive relationships between hospital patients' noise-induced stress and other stress with sleep. Heart Lung. 2001;30:237-43. [PMID: 11449209]

Current Author Addresses: Dr. Buxton: 221 Longwood Avenue, BLI438-K, Boston, MA 02115.
Dr. Ellenbogen: Wang ACC 720, Massachusetts General Hospital, 55 Fruit Street, Boston, MA 02114.
Dr. Wang: 221 Longwood Avenue, BLI438-M, Boston, MA 02115.
Mr. Carballeira: 10 Upton Street, Cambridge, MA 02139.
Mr. O'Connor: 3535 Market Street, Room 1514, Philadelphia, PA 19104.
Mr. Cooper: 221 Longwood Avenue, BLI 2-230, Boston, MA 02115.
Mr. Gordhandas: 15 Parkman Street, WACC 7, Boston, MA 02114.
Mr. McKinney: ICME, Suite 053B, Huang Engineering Center, 475 Via Ortega, Stanford, CA 94305.
Dr. Solet: 15 Berkeley Street, Cambridge, MA 02138.

Author Contributions: Conception and design: O.M. Buxton, A. Carballeira, J.M. Solet.
Analysis and interpretation of the data: O.M. Buxton, J.M. Ellenbogen, W. Wang, A. Carballeira, A. Gordhandas, S.M. McKinney, J.M. Solet.
Drafting of the article: O.M. Buxton, J.M. Ellenbogen, S. O'Connor, D. Cooper, S.M. McKinney, J.M. Solet.
Critical revision of the article for important intellectual content: O.M. Buxton, J.M. Ellenbogen, A. Carballeira, S. O'Connor, D. Cooper, J.M. Solet.
Final approval of the article: O.M. Buxton, A. Carballeira, S. O'Connor, D. Cooper, A. Gordhandas, J.M. Solet.
Provision of study materials or patients: O.M. Buxton, J.M. Ellenbogen, D. Cooper, J.M. Solet.
Statistical expertise: W. Wang.
Obtaining of funding: O.M. Buxton, J.M. Ellenbogen, J.M. Solet.
Administrative, technical, or logistical support: O.M. Buxton, J.M. Ellenbogen, A. Carballeira, S. O'Connor, J.M. Solet.
Collection and assembly of data: O.M. Buxton, J.M. Ellenbogen, A. Carballeira, S. O'Connor, D. Cooper, J.M. Solet.

Appendix Table 2. **Time Spent in Stages of Sleep and Wakefulness During 8.5-Hour Sleep Periods**

Variable	Night 1	Night 2	Night 3
Mean sleep stage (SD), *min*			
N1	58.0 (16.7)	63.6 (16.9)	59.3 (22.3)
N2	232.3 (26.3)	247.3 (36.3)	238.4 (28.7)
N3	90.5 (37.2)	69.2 (30.9)	80.5 (33.6)
REM	99.1 (23.6)	104.6 (19.2)	101.0 (18.7)
Mean wakefulness (SD), *min*	28.2 (14.9)	23.5 (18.9)	30.8 (14.9)

N1 = non-REM sleep stage 1; N2 = non-REM sleep stage 2; N3 = non-REM sleep stage 3; REM = rapid eye movement.

Appendix Table 1. **Acoustic Descriptors of Sound Stimuli***

Acoustic Descriptor	Voice ("Bad" Conversation)	Voice ("Good" Conversation)	Door Open and Close	Helicopter Takeoff	Ice Machine	IV Pump Alarm	Jet Flyover	Laundry Cart Rolling	Overhead Paging (1 Voice)	Phone Ringing	Snoring	Toilet Flushing	Towel Dispenser	Traffic
L_{01}	76	78	78	76	73	76	74	73	77	73	74	75	74	72
L_{10}	74	74	74	74	72	75	74	72	74	73	74	74	73	71
L_{50}	67	68	67	69	70	66	69	71	67	71	68	69	67	70
L_{90}	52	56	55	54	69	47	52	60	46	35	35	45	45	57
L_{99}	50	41	36	36	46	42	36	36	35	35	35	35	37	35
L_{max}	76	78	79	76	73	76	74	74	78	73	74	76	74	72
L_{min}	35	35	35	35	35	35	35	35	35	35	35	35	35	35
L_{EQ}	70	70	70	70	70	70	70	70	70	70	70	70	70	70
$L_{10}–L_{EQ}$	4	4	4	4	2	5	4	2	4	3	4	4	3	1
$L_{max}–L_{EQ}$	6	8	9	6	3	6	4	4	8	3	4	6	4	2
$L_{01}–L_{EQ}$	6	8	8	6	3	6	4	3	7	3	4	5	4	2
$L_{10}–L_{90}$	22	17	20	20	3	28	22	13	28	38	39	28	29	14
$L_{01}–L_{99}$	26	37	42	40	26	34	38	37	42	38	39	40	37	37

L_{01} = sound level exceeded 1% of the time; L_{10} = sound level exceeded 10% of the time; L_{50} = sound level exceeded 50% of the time; L_{90} = sound level exceeded 90% of the time; L_{99} = sound level exceeded 99% of the time; L_{max} = maximum A-weighted root-mean square sound level; L_{min} = minimum A-weighted root-mean square sound level; L_{EQ} = equivalent continuous sound level.
* Sound stimuli = 70 dBA (adjusted for the range of normal human hearing).

Attachment B: World Health Organization Article

The Daily Briefing

High hospital noise levels hinder patient recovery

Study finds peak noise levels rivaled a chainsaw

January 11, 2012

Higher-than-recommended hospital noise levels may cause patients to lose sleep and impede their ability to heal, according to a new study in the *Archives of Internal Medicine*.

The **World Health Organization** recommends that average patient room noise levels remain around 30 decibels. According to *Medscape Medical News*, the recommended maximum noise level is 40 decibels.

But the average sound level at hospitals, according to a recent study: 48 decibels.

Study methodology
Researchers from the **University of Chicago's Pritzker School of Medicine** evaluated the sleep quality of 106 patients between April 2010 and May 2011. They used sound level monitors to record beside noise levels and wrist activity monitors for objective sleep data.

The findings showed that the the peak noise level rivaled that of a chainsaw and reached more than 80 decibels. In addition, the researchers found that hospital noise levels reached 67 decibels in the ICU and 42 decibels in surgical wards. The most common sources of noise reported by patients were staff conversation, roommates, alarms, intercoms, and pagers.

According to the study, 42% of patients reported being woken up by noise and many reported sleeping significantly less than normal while in the hospital. Patients exposed to the loudest average nighttime noises slept an average of 76 minutes less than patients exposed to the quietest noises.

"Despite the importance of sleep for recovery, hospital noise may put patients at risk for sleep loss and its associated negative effects," the authors write. However, they add that hospitals can make modifications to reduce overall noise levels. "Hospitals should implement interventions to reduce nighttime noise levels in an effort to improve patient sleep, which may also improve patient satisfaction and health outcomes" (Garcia, *Medscape Medical News*, 1/9; Pittman, *Reuters*, 1/11).

Attachment B: World Health Organization Article (continued)

More from the Daily Briefing

Preventing presenteeism: State is nation's first to mandate paid sick leave

Behind the scenes: Taking a Mayo idea to the Mall of America

Meet the three new members of the NLRB

CBO: Hiking Medicare eligibility age to 67 would save $148B

Study: Nurses using EHR systems report better patient outcomes

Walgreen updates stores with eye on health services expansion

How losing a loved one can break your heart

View all

Attachment C: Neergaard Article

Noisy hospitals need Rx for quiet as patients rest

By LAURAN NEERGAARD | Associated Press – Tue, Jun 12, 2012

WASHINGTON (AP) — Anyone who's had a hospital stay knows the beeping monitors, the pagers and phones, the hallway chatter, the roommate, even the squeaky laundry carts all make for a not-so-restful place to heal.

Hospitals need a prescription for quiet, and new research suggests it may not be easy to tamp down all the noise for a good night's sleep.

In fact, the wards with the sickest patients — the intensive care units — can be the loudest.

"It's just maddening," says Dr. Jeffrey Ellenbogen, sleep medicine chief at Massachusetts General Hospital. He pointed to one study that found the decibel level in ICUs reaches that of a shout about half the time.

Patient satisfaction surveys are packed with complaints that the clamor makes it hard to sleep. Yet remarkably little is known about exactly how that affects patients' bodies — and which types of noises are the most disruptive to shut-eye. So

Ellenbogen and researchers from Harvard and the Cambridge Health Alliance recorded different kinds of hubbub in a community hospital in Boston's suburbs to try to find out.

Since it wouldn't be appropriate to experiment on sick people by disrupting their sleep, 12 healthy volunteers were enlisted. They spent three nights in Mass General's sleep lab, slumbering as recorded hospital sounds blared from nearby speakers at increasing volumes.

Sure, a toilet flushing, voices in the hallway or the ice machine woke people once they were loud enough. But electronic sounds were the most likely to arouse people from sleep — even at decibel levels not much above a whisper, the researchers reported Monday in the journal Annals of Internal Medicine.

What electronic sounds? Particularly troublesome was the beep-beep-beep from IV machines that signals someone needs more fluid or medicine, one of the most common machines in a hospital. They're just one of a variety of alarms.

Those alarms are meant to alert hospital workers, of course, so the finding raises a conundrum. But some hospitals are testing ways to make at least some monitors flash signals at the nurses' stations rather than sound loudly at the bedside.

The other surprises: The sleepers' heart rates temporarily jumped as much as 10 beats a minute as they were aroused, the researchers reported. And they didn't remember most of the disruptions even though brain recordings clearly showed their sleep was interrupted, which suggests that patients' complaints are underestimating the problem.

"My God, we delivered 100 sounds to this person and woke them up 40 times and they're reporting to us just a couple" of awakenings, Ellenbogen says with disbelief.

If healthy young adults had a pronounced change in heart rate, imagine the stress of alarms sounding all night long in an ICU full of frail, older patients with weakened hearts, he says.

"It clearly has a big impact," agrees Dr. Ivor Berkowitz of Johns Hopkins University in Baltimore. He's a pediatric ICU specialist and wasn't involved with the research but calls it compelling and would like to see children studied in the same way.

Attachment C: Neergaard Article (continued)

Regularly getting too little sleep plays a role in a number of health troubles, from drowsy driving to high blood pressure, obesity, depression, memory problems and a weakened immune system. There's been far less research on how much sleep disruption interferes with recovery from illness. But some studies show patients in noisier wards require more medications and sedatives. Delirium — a dangerous state of confusion and agitation — is linked to sleep deprivation and the loss of normal sleep-wake cycles during certain hospitalizations, especially among older people, Ellenbogen notes.

Noise isn't the only challenge. He says sometimes patients are awakened for a blood test or blood pressure check simply because the overnight nurse assigned the task goes off duty at 7 a.m.

Acoustical engineers from Johns Hopkins helped sound an alarm about hospital noise several years ago, reporting that the average level at night has risen dramatically over the past few decades. Now a number of hospitals have begun taking steps to muffle the noise.

Hopkins recently opened a new building constructed for quiet, and Berkowitz says the difference in the new pediatric ICU is stunning. Before, eight children's beds were grouped together in two rooms linked by an opening — the sound of ventilators and machine alarms and conversation all bouncing around the area, he recalls. Now, every patient room is private.

Sound-absorbing materials line ceilings. There's a rubber floor in the neonatal unit. There's no overhead paging — workers' phones vibrate when they're needed.

"People have a sense, I think, of being calmer," Berkowitz says. He doesn't have any medical records to show it, but "my gut sense is that it's better for patients."

Existing hospital buildings, especially those without private rooms, require different techniques. For example, Mass General has posted "quiet hours" in the afternoon and at night on certain wards. The lights are dimmed, patients' room doors are closed wherever possible, overhead paging is minimized, and health workers lower their voices and try not to enter rooms unless it's really necessary, says Rick Evans, the hospital's senior director for service.

In his office sits a gadget that looks like a traffic light, flashing yellow or red when the decibel level gets too high. Evans says the hospital is evaluating whether to start using some type of noise sensor for further help.

Until hospitals dampen more noise, Ellenbogen advises families to advocate for quiet:

—If an IV alarm repeatedly sounds, "tell the nurse this has got to stop," he says.

—Ask if it's OK to close the room door.

—Request a fan in the room to be "white noise" that muffles the electronics.

—Speak up if hallway conversations are too loud.