Since the 1999 report by the Institute of Medicine, a great deal of public attention has focused on errors in medicine. In that report, it was estimated that more than 7,000 deaths per year were caused by medication errors alone, and it called for a reduction in errors by 50% within five years. One of the most basic steps in addressing this issue is to seek and identify associations between specific types of errors and potentially remediable factors. The fatigue and sleep deprivation experienced by on-call physicians during the night and the day after call can be substantial, and may contribute to prescribing errors.

The causes of physician error have not been extensively studied, but the effect of sleep deprivation on human performance has been studied in other fields. Many have reported that sleep deprivation has detrimental effects on mood, cognition, vigilance, reaction time, and complex decision making. Most research on the effects of sleep deprivation on physician performance has focused on simple cognitive tests or simulated procedural tasks, rather than actual clinical measures during real-time patient care. Although there are conflicting reports, it appears that errors are more likely on routine, repetitive tasks and those that require sustained vigilance.

Ordering medications is an integral part of inpatient medicine. Although it is a routine task, it is fraught with risk. Medication errors can lead to significant morbidity or mortality, and the most frequent and preventable culprit in the chain of events is the step of prescribing. Being on call is a fact of life for many physicians, especially during residency training. The fatigue and sleep deprivation experienced by physicians on call at night and during the following day can be substantial. We sought to determine whether there was a relationship between errors in medication orders and the work schedule of the physicians who wrote them. Our study objective was to compare the rate of errors in medication orders, as written by resident physicians who were postcall versus those who were not.

METHODS

Study Design. We conducted a retrospective review of all inpatient medication orders written by resident physicians and all errors detected by the pharmacy over a one-month period in April 2000. The institutional review board approved the study.

Study Setting and Population. The setting was a university-affiliated, community teaching hospital inpatient medication orders, pharmacy records, and resident physician work schedules in a university-affiliated community teaching hospital with residency programs in emergency medicine, family practice, internal medicine, obstetrics, pediatrics, and surgery. The authors calculated error rates, odds ratios (ORs), and 95% confidence intervals (95% CIs) for physicians during April 2000. Results: In 8,195 medication orders, there were 177 errors (2.16% overall error rate). There was an increased error rate for overnight and postcall orders (2.71%, OR 1.44, 95% CI = 1.06 to 1.95) in comparison to orders written by off-call physicians (1.90%). Error rates were significantly higher on the medical/surgical wards during the overnight (3.91%, OR 1.89, 95% CI = 1.22 to 2.92) and postcall (3.41%, OR 1.64, 95% CI = 1.10 to 2.43) periods compared with the off-call (2.11%) period, and postgraduate year 1 (PGY1) physicians had a higher overnight error rate (4.23%, OR 2.28, 95% CI = 1.44 to 3.61). Error rates were also higher on the medical/surgical wards compared with critical care units (2.62% vs. 1.22%, OR 2.17, 95% CI = 1.48 to 3.18). The PGY1 physicians had error rates similar to those of the PGY2–5 physicians when off call, but were significantly higher on overnight call (4.23% vs. 0.52%, OR 8.47, 95% CI = 2.00 to 35.82).

Conclusions: Medication-ordering error rates were higher for overnight and postcall physicians, particularly on the general medical/surgical wards, and in PGY1 physicians during the overnight period. Key words: medication errors; education, medical, graduate; sleep deprivation; internship and residency. ACADEMIC EMERGENCY MEDICINE 2005; 12:629–634.
with 12,000 annual inpatient admissions. We studied physicians in the adult medical/surgical wards and critical care areas, which included the medical and surgical intensive care units, the burn unit, the transitional care area, and telemetry units.

The study population consisted of all resident physicians rotating on inpatient services with in-hospital, overnight call during the study period. Physicians ranged from the postgraduate year 1 (PGY1) to PGY5, and were training in internal medicine, surgery, emergency medicine, family practice, pediatrics, obstetrics and gynecology, and transitional internship.

All inpatient medication orders written by residents on the above services were included. Four of the 61 residents eligible for the study were excluded because they were primarily assigned to another hospital and were on call less than twice during the study period at the study hospital. We also excluded orders written by physician assistants or attending physicians, and telephone orders from home. The final study population consisted of 57 resident physicians and every inpatient medication order they wrote during the study period.

Study Protocol. Orders on the wards were handwritten by physicians, and faxed by the ward clerk to the pharmacy for review and completion by a pharmacist. The faxed copies were retained in the pharmacy records. In the critical care areas, orders were generally reviewed by nurses prior to faxing. When a pharmacist detected an error or needed clarification, the ordering physician was contacted. If the order was changed, the pharmacist recorded the new order in the medical record and retained a copy for the pharmacy log.

We defined a “medication error” as any time the pharmacist perceived an error in a medication order, contacted the physician, received a change in that order, and entered the change into the medical record. Examples include incorrect drug dose, route, or schedule; drug interaction; or allergy. One order could receive only one error designation. Simple clarifications without a resulting change were frequent, and were not entered into the error log or counted as errors. A common example of a pharmacist–physician interaction that did not result in a change and was not considered an error was a clarification of poor handwriting.

For the purpose of the study, we defined “overnight” orders as those written from 0000 hours (midnight) to 0700 hours (7:00 AM) by a physician scheduled for overnight call. Orders written prior to 0700 by physicians who were not on call the night before were likely written by physicians who were beginning their workday, and were classified as “off-call” orders. We defined a “postcall” order as any order written after 0700 on the day after an overnight call period. All other orders were defined as “off-call.”

For example, if the physician began working at 0700 on April 5, orders written during that day were classified as “off-call.” If that physician stayed overnight on call, orders written between midnight and 0700 were “overnight,” and those written after 0700 on April 6 were “postcall.” Another physician who was not on call, but worked from 0700 to 1700 on April 6, wrote ten hours of “off-call” orders. During the study period, physicians were typically on call every three to five days and left the hospital at approximately 1500 on the postcall day, after 32 hours of duty, and wrote many orders in all three categories.

Measurements. Two research assistants underwent standardized training that included medication-order identification, signature identification, timing of orders, and a video on research methods. They were blinded to the study hypothesis as well as to pharmacy-identified errors and call schedules. Data were tabulated using standardized collection forms that included a template of study physicians’ signatures to aid in identification. A pharmacy technician and one of the authors (BEB) reviewed unclear orders or signatures for identification. Both abstractors reviewed the orders written on an overlapping 20% of the days to determine their interrater agreement. One hundred percent of error log entries were matched to their corresponding order in the medical record to verify the ordering physician, date, and time. All medication orders were entered into a database (Microsoft Access, Microsoft Corp., Redmond, WA) where they were correlated with the call schedules and pharmacy-identified errors.

Data Analysis. Based on pilot data, we assumed a baseline error rate of 1%, and estimated that a sample size of approximately 16,000 orders would be required to detect an absolute difference of 1% in the error rates (assuming alpha = 0.05 and power = 0.80). We estimated that a one-month period would provide a sufficient number of orders.

The main outcome measures were the medication-ordering error rates calculated for the physicians when they were off call, on overnight call, or postcall. We performed subgroup analyses to determine error rates based on time of day, level of training, and acuity level of the unit where the order was written.

All medication orders were counted and recorded for each calendar day, as were the errors recorded in the pharmacy log. Error rates were determined for orders classified as off-call, overnight, and postcall. The medication-ordering error rates were calculated by dividing the number of the pharmacy-detected medication errors by the number of orders written by the study physicians.

We calculated descriptive statistics as well as the medication-ordering error rates as described above. Error rates were compared using chi-square testing with Yates’ correction as appropriate. Odds ratios
(ORs) and 95% confidence intervals (95% CIs) were also calculated. We also examined error rates as a function of the time of day, level of training, and hospital ward. A statistician reviewed all statistical analyses.

**RESULTS**

There were 8,195 orders written by the 57 study physicians during the month. Physicians wrote a mean of 144 orders each (range 1–634) over the course of the month. The pharmacy documented 177 medication-order errors written by these physicians during the study period, for an overall error rate of 2.16% (range 0% to 9.72%), or 3.4 errors per physician per month (range 0 to 14).

The 177 medication-order errors were classified into five categories (Figure 1). Seventy-four (42%) orders required a change in the dosage or route of administration, 30 (17%) required a change in the frequency of administration, 60 (34%) resulted in a medication change or discontinuation, four (2%) were changed because of an allergy, and nine (5%) were changed for other or undetermined reasons.

The study physicians wrote 5,575 off-call orders, 1,025 overnight orders, and 1,595 postcall orders. Error rates for off-call, overnight, and postcall orders are reported in Table 1. The error rate was significantly higher for the combined overnight and postcall orders in comparison to the off-call orders. However, when the time periods were analyzed separately, the trends toward increased error rates for overnight and postcall orders were not statistically significant. On the medical/surgical wards, error rates were significantly higher during the overnight and postcall periods, but not for orders written by off-call physicians.

Error rates as a function of hospital location are noted in Table 2. There were 5,499 orders written on the medical/surgical wards and 2,696 orders written in the critical care units. The overall error rate was significantly higher on the medical/surgical wards than in the critical care units. The error rates were significantly higher on the medical/surgical wards during the overnight and postcall periods, but not for orders written by off-call physicians.

Error rates as a function of level of training are reported in Table 3. Thirty-one (54%) of the study physicians were PGY1, and they wrote 61% of the orders during the study period. The error rate for the PGY1 physicians was not different from that of the PGY2–5 physicians during the off-call period, but the PGY1 error rate was significantly higher during the overnight period.

Both data abstractors reviewed an overlapping six days of orders. The correlation coefficient between the two data abstractors for agreement when determining the ordering physician, date, and ward was $r = 0.89$ ($p < 0.001$).

**TABLE 1. Medication Orders, Errors, and Error Rates for Off-call, Overnight, and Postcall Physicians**

<table>
<thead>
<tr>
<th></th>
<th>Errors</th>
<th>Orders</th>
<th>Error Rate</th>
<th>OR (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>106</td>
<td>5,575</td>
<td>1.90%</td>
<td>1.0</td>
</tr>
<tr>
<td>Off-call</td>
<td>29</td>
<td>1,025</td>
<td>2.83%</td>
<td>1.50 (0.99, 2.28)</td>
</tr>
<tr>
<td>Overnight call (0000-0700 hours)</td>
<td>42</td>
<td>1,595</td>
<td>2.63%</td>
<td>1.40 (0.97, 2.00)</td>
</tr>
<tr>
<td>Postcall</td>
<td>71</td>
<td>2,620</td>
<td>2.71%</td>
<td>1.44 (1.06, 1.95)‡</td>
</tr>
<tr>
<td>Overnight and postcall</td>
<td>1117</td>
<td>2,620</td>
<td>2.71%</td>
<td>1.44 (1.06, 1.95)‡</td>
</tr>
<tr>
<td>Medical/surgical wards</td>
<td>77</td>
<td>3,645</td>
<td>2.11%</td>
<td>1.0</td>
</tr>
<tr>
<td>Off-call</td>
<td>29</td>
<td>741</td>
<td>3.91%</td>
<td>1.89 (1.22, 2.92)‡</td>
</tr>
<tr>
<td>Overnight call</td>
<td>38</td>
<td>1,113</td>
<td>3.41%</td>
<td>1.64 (1.10, 2.43)‡</td>
</tr>
<tr>
<td>Postcall</td>
<td>67</td>
<td>1,854</td>
<td>3.61%</td>
<td>1.74 (1.25, 2.42)‡</td>
</tr>
<tr>
<td>Overnight and postcall</td>
<td>1117</td>
<td>2,620</td>
<td>2.71%</td>
<td>1.44 (1.06, 1.95)‡</td>
</tr>
<tr>
<td>Critical care units</td>
<td>29</td>
<td>1,931</td>
<td>1.50%</td>
<td>1.0</td>
</tr>
<tr>
<td>Off-call</td>
<td>1</td>
<td>284</td>
<td>0.40%</td>
<td>0.23 (0.03, 1.70)</td>
</tr>
<tr>
<td>Overnight call</td>
<td>4</td>
<td>481</td>
<td>0.83%</td>
<td>0.55 (0.19, 1.57)</td>
</tr>
<tr>
<td>Postcall</td>
<td>4</td>
<td>765</td>
<td>0.52%</td>
<td>0.35 (0.12, 0.98)‡</td>
</tr>
<tr>
<td>Overnight and postcall</td>
<td>1</td>
<td>284</td>
<td>0.40%</td>
<td>0.23 (0.03, 1.70)</td>
</tr>
<tr>
<td>Postgraduate year 1</td>
<td>64</td>
<td>3,372</td>
<td>1.90%</td>
<td>1.0</td>
</tr>
<tr>
<td>Off-call</td>
<td>27</td>
<td>639</td>
<td>4.23%</td>
<td>2.28 (1.44, 3.61)‡</td>
</tr>
<tr>
<td>Overnight call</td>
<td>30</td>
<td>1,038</td>
<td>2.89%</td>
<td>1.54 (0.99, 2.39)</td>
</tr>
<tr>
<td>Postcall</td>
<td>57</td>
<td>1,677</td>
<td>3.40%</td>
<td>1.82 (1.27, 2.61)‡</td>
</tr>
<tr>
<td>Postgraduate years 2–5</td>
<td>42</td>
<td>2,203</td>
<td>1.91%</td>
<td>1.0</td>
</tr>
<tr>
<td>Off-call</td>
<td>2</td>
<td>386</td>
<td>0.52%</td>
<td>0.27 (0.07, 1.11)</td>
</tr>
<tr>
<td>Overnight call</td>
<td>12</td>
<td>557</td>
<td>2.16%</td>
<td>1.13 (0.59, 2.17)</td>
</tr>
<tr>
<td>Postcall</td>
<td>14</td>
<td>943</td>
<td>1.48%</td>
<td>0.78 (0.43, 1.43)</td>
</tr>
</tbody>
</table>

*Odds ratios (ORs) and 95% confidence intervals (95% CIs) are reported for each variable in relation to the baseline error rate for off-call physician orders.
†The actual error rate was 0%, but one error was reported to make statistical calculations possible.
‡Statistically significant.

Figure 1. Types of errors in the medication orders ($n = 177$).
DISCUSSION

In our study, physicians were significantly more likely to make an error in ordering medications during overnight call and postcall than when they were off call. The differences were most pronounced in PGY1 physicians and on the general medical/surgical wards.

Although the PGY1 physicians comprise less than one-third of all resident physicians at our institution, they wrote most (61%) of the orders during the study period. Interestingly, the first-year physicians and the more senior residents had equivalent error rates when they were off call, but the PGY1 physicians had much higher error rates during the overnight hours. It is possible that the fatigue and sleep deprivation may be more severe among first-year physicians. Alternatively, the more experienced physicians may have learned better coping strategies, such as reviewing their orders more cautiously.

A particular strength of the study is that each physician wrote orders in all three categories and, in a sense, acted as his or her own control. It is possible that the differences we found between the overnight and daytime hours were due to differences in the nursing and pharmacy staffing. However, during the off-call and postcall periods, the same physicians wrote orders in the same hospital with the same nursing and pharmacy personnel. Some possible explanations for the higher overnight error rates include: 1) less supervision during the night, 2) the onset of fatigue during the middle of the night, 3) verbal orders after awakening from brief sleep, and 4) degradation in performance associated with natural circadian nadirs.

There was a significantly higher error rate on the medical/surgical wards by postcall physicians, though the opposite effect was noted in the critical care areas. It seems unlikely that the actual physician error rate varies by hospital ward, but the differences may have been due to increased surveillance or supervision in different locations. Nurses in the critical care units tend to be more highly trained and experienced, while caring for fewer patients. In our facility, they also examine orders before they are sent to the pharmacy, thereby providing an additional layer of error surveillance. There may also be more physician supervision in these areas. Another possibility is that physicians were less likely to make an error because they were more familiar with their patients after being at the bedside overnight.

Most studies of the effects of sleep deprivation on resident physicians have used surrogate markers such as written tests or simulated work tasks as outcome measures, and many have shown no detriment in performance. However, Friedman et al. determined that sleep-deprived medical residents made more errors in interpreting electrocardiograms and had worse moods. Taffinder et al. showed that sleep-deprived surgical residents were more likely to make errors on a laparoscopy simulator and took longer to complete the task. Gottlieb et al. demonstrated a reduction in medication errors after eliminating night call and implementing a night float system, but did not assess the call status of the physicians who made errors. We know of only one other study that examined actual clinical performance in postcall physicians. Haynes et al. found a 45% increase in postoperative complications by postcall surgeons, though the effect lost statistical significance after eliminating emergent surgeries.

LIMITATIONS

There were several limitations in our study. Although we postulate that the difference in error rates is at least partly due to sleep deprivation, we did not measure the amount of sleep obtained. Others have

TABLE 2. Error Rates as a Function of Hospital Location

<table>
<thead>
<tr>
<th></th>
<th>Medical/Surgical Wards</th>
<th>Critical Care Units</th>
<th>Chi-square, p-value</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall error rate</td>
<td>2.62%</td>
<td>1.22%</td>
<td>$\chi^2 = 16.00$, p &lt; 0.001</td>
<td>2.17 (1.48, 3.18)</td>
</tr>
<tr>
<td>Off-call error rate</td>
<td>2.11%</td>
<td>1.50%</td>
<td>$\chi^2 = 2.21$, p = 0.14</td>
<td>1.42 (0.92, 2.18)</td>
</tr>
<tr>
<td>Overnight error rate</td>
<td>3.91%</td>
<td>0.40%*</td>
<td>$\chi^2 = 7.99$, p = 0.005</td>
<td>11.57 (1.57, 85.32)</td>
</tr>
<tr>
<td>Postcall error rate</td>
<td>3.41%</td>
<td>0.83%</td>
<td>$\chi^2 = 7.75$, p = 0.005</td>
<td>4.22 (1.50, 11.88)</td>
</tr>
</tbody>
</table>

*The actual error rate was 0%, but one error was reported to make statistical calculations possible.

TABLE 3. Error Rates as a Function of Level of Training

<table>
<thead>
<tr>
<th></th>
<th>Postgraduate Year 1</th>
<th>Postgraduate Years 2–5</th>
<th>Chi-square, p-value</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall error rate</td>
<td>2.40%</td>
<td>1.78%</td>
<td>$\chi^2 = 3.20$, p = 0.07</td>
<td>1.36 (0.98, 1.87)</td>
</tr>
<tr>
<td>Off-call error rate</td>
<td>1.98%</td>
<td>1.91%</td>
<td>$\chi^2 = 0.00$, p = 1.0</td>
<td>1.0 (0.67, 1.48)</td>
</tr>
<tr>
<td>Overnight error rate</td>
<td>4.23%</td>
<td>0.52%</td>
<td>$\chi^2 = 10.72$, p = 0.001</td>
<td>8.47 (2.00, 35.82)</td>
</tr>
<tr>
<td>Postcall error rate</td>
<td>2.89%</td>
<td>2.16%</td>
<td>$\chi^2 = 0.51$, p = 0.48</td>
<td>1.35 (0.69, 2.66)</td>
</tr>
</tbody>
</table>
reported that resident physicians sleep from zero to five hours while on call. 
Likewise, we did not include any measurement of supervision. The difference in errors we found could have been a function of fatigue, decreased supervision, or some other factor, rather than sleep deprivation. We counted only errors that were discovered by pharmacists, and many errors may have gone undetected. While this would have caused us to underestimate the error rates, it should not have biased the results in one direction or the other. The prescribing error rates in our study are similar to those in other published reports. 
Also, it is possible that last-minute changes to the call schedule resulted in erroneous calculations of postcall error rates. We verified the call schedules by contacting each department, the hospital page operator, and individual physicians. If such misclassification of data occurred, it is unclear in which direction the results might have changed.

The error rates and the differences between groups were small, and we did not attempt to determine the clinical significance of the errors. We could have included a blinded panel review to determine the potential seriousness of the errors. While some judgments might have been straightforward, many would have been fraught with estimation and hypothetical predictions. Most of the errors in our study were trivial and would have likely caused no harm, but any error has the potential to be harmful in a given clinical setting. Bates and colleagues reported that approximately 1% of medication errors led to an adverse drug event, with 13% being life-threatening or fatal. Also, because we performed multiple subgroup comparisons, it is possible that some of the differences were due to chance alone. Finally, it is unclear whether we can extrapolate the results of this study to other types of medical decision making. We did not examine any of the complexities of diagnostic and therapeutic decision making. It is possible that error rates in complex clinical scenarios follow the pattern that we found for medication orders, but it is also possible that error rates are lower in high-acuity situations due to increased vigilance.

Our sample size was smaller than we planned according to our estimations and power calculation. However, the error rates and effect sizes were also higher than we estimated based on pilot data. Therefore, we found statistically significant differences despite a smaller sample than we anticipated during one month of data collection.

Our study took place before the July 1, 2003, implementation of the Accreditation Council for Graduate Medical Education (ACGME) duty-hour standards that limit resident work hours to 80 per week, with a maximum continuous duty period of 24 hours (plus time for transfer of care). It would be interesting to repeat our study with the new standards in place, to determine whether limitations on duty hours effectively reduce errors during the overnight and postcall periods.

This study provides another piece in the puzzle of error reduction. Available interventions that might reduce errors include using dedicated “night float” physicians, implementation of the ACGME duty-hour standards, increasing the supervision of junior physicians, and implementing computer-based systems to decrease order-entry errors and increase error detection. 
Our study suggests that the higher rate of errors in postcall physicians is multifactorial, and is associated with the time of day, hospital location, and level of training. Questions remain regarding the relative importance of the many potential contributing causes, such as fatigue due to long duty hours, sleep deprivation, or differences in the level of supervision.

CONCLUSIONS

We found that physicians were more likely to make an error in ordering medications during the overnight and postcall periods. Although the errors were minor and the overall error rates were low, the differences were greatest during overnight call, on the general medical/surgical wards, and in PGY1 physicians. Further research is needed into the etiology, detection, and prevention of errors.

The authors thank their research coordinator, Brandy Snowden, research assistants Damara Ortiz and Lily Lou, Ron Imoto and the staff of University Medical Center Pharmacy, as well as Anamarie Graf, Ronna Mallios, and Mike Tilden in the UCSF Fresno Medical Education Program statistics and graphic arts departments.

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