Medical diagnosis is a process characterized by uncertainty and, as has been shown for many years, is also prone to biases in reasoning. Fryback and Thornbury, for example, demonstrated in an experiment more than 30 years ago that radiologists’ estimates of the probability of different diagnoses for space occupying lesions were inappropriately influenced by the importance of the diagnosis. Specifically, the probability of tumor was overestimated and that of benign lesions underestimated.1

Croskerry described more than 30 different types of errors and biases in diagnostic reasoning.2 “Anchoring,” for example, is the tendency to “lock into” clinical features in the initial presentation of a patient too early and fail to adjust this impression in light of later information. Another example is “search satisfying,” which is the tendency to call off a diagnostic search once something is found, with the result that other conditions may be missed.

Errors and biases in reasoning can also lead to errors in estimation of probability. Representativeness is defined as “an assessment of the degree of correspondence between a sample and a population, an instance and a category, an act and an actor, or, more generally, between an outcome and a model.”3

Representativeness can lead to an error known as the conjunction fallacy, defined by Tversky and Kahneman as incorrectly concluding that the probability of a joint event (such as a combination of clinical findings) is greater than the probability of any one of these events alone.1 If A and B represent events, and P(A) and P(B) are their associated probabilities, A∩B (A intersection B) is the “conjunction” or probability of both A and B occurring. According to the conjunction rule of probability: P (A∩B) ≤ P(A) and P (A∩B) ≤ P(B).

All types of people, including physicians, have been shown to be prone to the conjunction fallacy. Tversky and Kahneman introduced written vignettes of patients,
including one of a patient with an angiographically documented pulmonary embolism (PE), to different groups of Harvard-affiliated physicians and asked them to rank which symptoms or combination of symptoms she most likely presented with. For PE, these symptoms included hemiparesis (atypical of PE) and the combination of dyspnea (common in PE) and hemiparesis. For this and similar problems, physicians incorrectly identified the combination of symptoms (eg, dyspnea and hemiparesis) as more probable than the uncommon symptom alone (eg, hemiparesis) alone an average of 91% of the time. In the example above, dyspnea is highly representative of the population of patients with pulmonary embolism, and this representativeness resulted in errors in assessment of probability.

Work from fields outside of medicine suggests that those with expert knowledge and experience may actually be more vulnerable to the conjunction fallacy than less knowledgeable and experienced individuals. If this were true for medical decision making as well, inexperienced clinicians would commit the conjunction fallacy error less often than experienced clinicians. Among errors in diagnostic reasoning, the conjunction fallacy is relatively easy to study through the use of simple case scenarios.

The purpose of this study was to determine whether entering medical students are as vulnerable to the conjunction fallacy as the experienced physicians studied by Tversky and Kahneman a generation ago. If they are not, then something about medical training and experience may lead to the development of this and perhaps other biases and errors.

Methods
Subjects
The first-year class of medical students entering in 2008 at the University of Pittsburgh was comprised of 146 students, of whom 88 (60%) were men and 58 (40%) were women. All were asked to participate in the study during an introductory lecture in a mandatory course on clinical epidemiology and biostatistics during the first week of medical school. The students had little experience with basic clinical sciences and had not yet begun working with patients. Students’ participation and study methods were approved by the University of Pittsburgh Institutional Review Board.

Case Vignette
A case vignette was pilot tested with five physicians and other health care professionals for clarity and modified based on feedback from these individuals before presenting the vignette to the students. The vignette read as follows:

“Amelia is a 23-year-old medical student who comes to your office for help. You suspect she has a common cold. In the blank spaces below, based on your knowl-
edge and experience with the common cold, estimate the probability that Amelia would experience each of the following symptoms or symptom combinations. For example, if you believe Amelia has a 100% chance of experiencing “b” and a 90% chance of experiencing “c,” put 100% and 90% in the respective blanks.” Options given were (a) runny nose and diarrhea, (b) fatigue, (c) diarrhea, (d) ear pain and shortness of breath, (e) sore throat, and (f) headache.

The common cold was chosen for the vignette since entering medical students have little or no clinical experience but are assumed at one point or another to have suffered from the common cold and would have some knowledge of typical and atypical symptoms. Runny nose is widely known to be a common symptom; diarrhea is not.

Students were also asked to provide their gender, highest degree completed, major or area of concentration for their most recent degree, and indicate whether they had successfully completed one or more courses in statistics in the past. Majors or areas of concentration were then put into one of three categories: (1) physical sciences, engineering, or mathematics (eg, physics, chemistry, computer science), (2) biological sciences (eg, biology, botany), and (3) humanities (eg, psychology, history, philosophy).

Data Analysis
A violation of the conjunction rule (ie, conjunction fallacy) was recorded if diarrhea was assigned a lower probability than the combination of runny nose and diarrhea, regardless of the absolute assigned probability value or the values recorded for the other options. χ² statistics were calculated for comparisons of rates of violation of the conjunction rule between male and female students and among students with different educational backgrounds. All results were compiled and analyzed with SPSS version 13.0.

Results
A total of 134 first-year medical students (92% of first-year students) completed the exercise. Their characteristics are shown in Table 1. The sample was predominantly male, which was representative of the overall class. The majority of students had completed bachelor’s degrees. Majors/areas of concentration in the biological sciences were most common. A high proportion (70.1%) had completed at least one course in statistics in the past.

In the exercise, the mean estimate of the probability of diarrhea was 17.2% (standard deviation [SD]=14.7%), with a range of 0% to 65% and a median of 10%. The mean estimate of the probability of the combination of runny nose and diarrhea was 31.6% (SD=30.6%), with a range of 0% to 100% and a median of 15%. Overall, 64 or 47.8% of the students violated the conjunction
rule by assigning a higher probability to runny nose and diarrhea than to diarrhea alone.

Female and male students violated the conjunction rules at rates that were not statistically significant (41.2% and 51.8%, respectively; \( P = .23 \)). Differences in rates of violation by educational background (physical sciences, engineering, or mathematics (33.0%), humanities (42.9%), and biological sciences (54.4%)) also were not statistically significant \( (P = .14) \). There were also no statistically significant differences among students with different degree levels \( (P = .78) \) or among students who had or had not completed a statistics course \( (P = .43) \).

### Discussion

This is the first study of the frequency with which beginning medical students are susceptible to the conjunction fallacy. Though 47.8% of students violated the conjunction rule, this is a much lower proportion than the 91% of physicians who violated the conjunction rule in Tversky and Kahneman’s earlier study. This result is consistent with Frederick and Libby’s observations that under certain circumstances, experienced accounting auditors are more prone to the conjunction fallacy than accounting students.\(^4\) The rate of violation of the conjunction rule by the medical students is also similar to rates of violation by undergraduate students in previous studies.\(^5\)

The vignette used in this study was designed to be similar in structure to those used by Tversky and Kahneman. Their vignettes, however, asked physicians to rank symptoms and combinations of symptoms in terms of probability rather than assign percentages. Pilot testing for this study revealed that asking for percentages instead of ranks made the problem easier to understand. The reported percentages were also useful because the mean reported probability that the patient experienced diarrhea was just 17.2%, confirming that, despite their lack of clinical experience, the students understood diarrhea to be an uncommon symptom of the common cold.

The conjunction fallacy has been shown repeatedly to demonstrate that the human mind does not always follow logical rules in forming judgments about probability. As a source of flawed judgment, however, it has been criticized for various reasons. For example, errors in violation of the conjunction rule have been shown to some extent to be dependent on how problems are worded. The use of the word “and,” in particular, is interpreted by some people not to imply conjunction but temporal or causal relationships (eg, Amelia has runny nose and then developed diarrhea).\(^6\) It has also been shown that replacing the word “probability” (which people interpret in different ways) with “frequency” reduces rates of the conjunction fallacy.\(^7\)

Over or underestimation of pre-test probability can potentially have profound implications for diagnostic testing and treatment. It is difficult to know, however, whether there is a relationship between a tendency to violate the conjunction rule and incorrect interpretation of diagnostic tests used for medical decision making. But, it is easier to imagine situations in which representativeness results in simple errors in judgment. For example, if a clinical case is slightly more representative of disease A than disease B, even if disease B is much more common than disease A, representativeness is likely to result in an incorrect diagnosis of A, because the base rates or probabilities of A and B have been ignored.

Our results show that neither prior educational background nor previous statistics coursework significantly influenced rates of violation of the conjunction rule, though the sample size was limited. By contrast, Tversky and Kahneman showed that graduate students with a strong statistics background were less likely to violate the rule than undergraduates without such a background, albeit at a still high rate of 36%.\(^3\) Comparisons with the physicians studied by Tversky and Kahneman, however, should be made cautiously. It is not clear if today’s practicing physicians would perform the same as those in Tversky’s and Kahneman’s study from the 1980s, nor if they would perform worse than the medical students in our study. And, it is possible that the medical students may also not have been representative of medical students as whole. The sample was predominantly male, and the vast majority of students had taken some statistics classes. Nevertheless, it is interesting that beginning medical students violated the conjunction rule less often than a previously studied group of practicing physicians. It is possible that with increasing clinical experience, physicians instinctively rely more on representativeness and less on the rules

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**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th># (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>83 (61.9%)</td>
</tr>
<tr>
<td>Highest degree completed</td>
<td></td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>117 (87.3%)</td>
</tr>
<tr>
<td>Master’s degree</td>
<td>14 (10.4%)</td>
</tr>
<tr>
<td>PhD</td>
<td>2 (1.5%)</td>
</tr>
<tr>
<td>Other/professional degree</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Area of concentration</td>
<td></td>
</tr>
<tr>
<td>Biological sciences</td>
<td>79 (59.0%)</td>
</tr>
<tr>
<td>Humanities</td>
<td>28 (20.9%)</td>
</tr>
<tr>
<td>Physical sciences/engineering/mathematics</td>
<td>27 (20.1%)</td>
</tr>
<tr>
<td>Completed statistics course</td>
<td>94 (70.1%)</td>
</tr>
</tbody>
</table>
of probability in making diagnosis. As noted above, though in theory this could result in serious judgment errors, it is unknown if it actually does.

**Conclusions**

Making clinicians aware of cognitive errors in diagnostic reasoning could be an important strategy for reducing those errors. Many medical schools now incorporate courses in evidence-based medicine (EBM) into their curricula. Teaching medical students about the conjunction fallacy and other biases in assessment of probability has, in theory at least, the potential to improve students’ decision making.

Consider this one-session curricular strategy: A case similar to the vignette of Amelia could be introduced to medical students who could be asked to complete the exercise individually. This could be followed by a discussion of the conjunction fallacy, making students aware of this error if it is committed. A discussion of other types of cognitive errors in diagnosis could follow. The objective would be to introduce the idea and raise awareness of cognitive errors in diagnosis in general. Given that many EBM curricula for medical students and residents emphasize journal clubs, whose value in improving knowledge and decision making has not been shown, devoting some time instead to a session on the conjunction fallacy and other cognitive errors might be a worthwhile investment.

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**References**