Title
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Journal
ACS Chemical Health & Safety, 23(1)

ISSN
1871-5532

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Publication Date
2016

DOI
10.1016/j.jchas.2015.03.001

Peer reviewed

RESEARCH ARTICLE

Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers

A survey on laboratory safety, conducted in 2012, provided the basis for comparing safety culture attributes of respondents from academic ($n = 991$), government ($n = 133$) and industry ($n = 120$) laboratories. There were institutional differences in risk assessment methods conducted before carrying out an experiment, for which fewer researchers from academia (18%) used forms issued by their organization as compared to government and industry researchers (51% and 43%, respectively). Safety training in all three institutions was reported to be similar; however, about 25% of all researchers were not trained on the specific hazard with which they worked. Risk perceptions were similar between respondents from all three institutions with respondents generally believing their personal risk to be significantly lower than what they assumed was predicated by their institution. The most striking difference between institutions was observed with self-reported PPE compliance behavior; respondents from industry labs were significantly more compliant with wearing a lab coat (87%) and eye protection (83%) than respondents from academic (66% and 61%, respectively) and government labs (73% and 76%, respectively). PPE compliance was highly associated with researchers' perception of the level of risk in their lab; PPE compliance generally declined with lower perceived risk. In contrast to industry and government labs, PPE compliance of researchers in academia was significantly positively influenced when their safety behavior was monitored. Active safety involvement of the principal investigator (PI) or laboratory supervisor also correlated significantly with lower numbers of accidents reported by students and postdoctoral fellows in academic labs. The data support the view that laboratory safety is positively impacted by active involvement of the PI or a dedicated laboratory supervisor in academic institutions.

By Imke Schröder, Debbie Yan Qun Huang, Olivia Ellis, James H. Gibson, Nancy L. Wayne

INTRODUCTION

Recent accidents in academic laboratories have raised the question whether adequate safety is provided to students, postdoctoral fellows and staff in research labs at colleges and universities.[1,2] Stringent safety policies present in government and industry facilities suggest that these institutions

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1871-5532
http://dx.doi.org/10.1016/j.jchas.2015.03.001

place a higher value on employees' safety relative to other priorities.[3] However, near misses with potentially dangerous consequences in government facilities have questioned safety practices in government labs.[4] Many studies have demonstrated a positive impact of organizational safety climate and safety culture on safety outcomes,[5–9] however, little is known how researchers in academic, governmental and industry laboratories compare in their safety perception and practices. Safety climate is described as the perceptions of safety shared by the workers and the management of a facility or organization at a given time. It can be considered a temporal phenomenon and subject to change. Safety culture refers to an organization's commitment to safety, in which safety sets priority over other processes that might be important to the organization. Both safety climate and safety culture are placed in perspective in a review by Guldenmund[10] and Wiegmann et al.[11]

Research scientists often include a broad variety of hazardous substances or equipment in their experiments that can place them at risk of injury if safety measures are not followed. It could be expected that laboratories in academic institutions generally use smaller volumes of hazardous substances as compared to laboratories in industrial facilities, which often manipulate larger amounts of hazardous material for the development of scaled-up manufacturing processes. Laboratories operated by the federal government often conduct research on highly hazardous materials such as explosives, radioactive substances, and highly pathogenic organisms.

Institutions operating research labs generally protect their workers on four levels if hazards cannot be eliminated or substituted: (1) isolation by preventing access to personnel who do not work with the hazard; (2) engineering controls to provide a safe, well ventilated work space that often include chemical fume hoods or biosafety cabinets for working with hazardous chemicals and pathogens, respectively; (3) administrative controls to provide safety training, access to information on hazardous substances, and laboratory inspections by institutions' health and safety experts to ensure a safe working environment; (4) personal protective equipment (PPE) such as a lab coat, eye protection and gloves that offers a direct protective layer to researchers.[12,13] Dependent on the hazard additional PPE is often required. PPE is generally regarded as the last barrier to protect against harm from laboratory hazard if engineering and administrative controls fail or are ignored.[13] Wearing required PPE can be considered a proxy for how well researchers comply with safety policies.[14]

Laboratory safety is generally regulated by Occupational Safety and Health Administration (OSHA) policies setting exposure limits to hazardous substances.[15] Many states, including California, have developed their own job safety and health programs, which are approved and monitored by OSHA. Additional regulatory policies exist for radiation and biohazards.[16,17] However, safety practices differ extensively between institutions as each facility generally develops its own safety policies that are based on state and federal regulatory requirements and best practices addressing the specific hazards and risk levels in their workspaces. These site-specific policies often vary between academic, government, and industry research facilities, and even between labs of the same facility.[18] However, despite regulatory oversight, sometimes catastrophic accidents happen.[19] Incited by recent accidents in academic labs,[2] the National Research Council of the National Academies recently released recommendations for an improved safety culture at colleges and universities.[18]

The focus of this study is to compare safety perception and practices of researchers from academic government and industry labs, and the extent to which they adhere to safety measures required for their respective research environments. Our results are based on the analysis of data of a recently performed comprehensive laboratory safety survey.[20] The survey was designed by the UC Center for Laboratory Safety, BioRAFT, and Nature Publishing Group. Survey questions were not developed to answer hypotheses, but intended to inform about lab safety knowledge and tools for safe experimentation, researcher's and organizational risk safety atmosphere, compliance behavior, and injury or incident experiences. Participants included laboratory researchers at various professional levels from academia, private industries, government laboratories, and medical schools mainly in the United States, but also in the United Kingdom, Japan, China, and other countries. The initial analysis of the survey was conducted by Nature Publishing Group, who highlighted that researchers generally have mixed attitudes toward lab safety standards, and that especially younger researchers underestimate the risk in their laboratory.[21]

The goal of this study is to examine the laboratory safety survey with focus on similarities and differences of perceptions of safety climate and self-reported safety compliance behavior between researchers working in academic, government, and industry laboratories. An optimal safety climate describes an organization's safety perception atmosphere, where employees and management place the same value on safety at a particular moment in time. Safety climate is recognized as a robust leading indicator or predictor of safety outcomes.[22] To reduce heterogeneity based on cultural and country-dependent regulatory differences, only participants from the United States were included in this analysis.

For the comparison of researchers from academic, government and industry laboratories understanding the following questions were of particular interest:

1. What is researchers' experience of their lab safety training?
2. How do researchers assess risks associated with their work?
3. How safe do researchers feel in laboratories?
4. What are researchers' attitudes toward compliance with PPE regulations?
5. Does monitoring of safety activities by the PI or safety manager impact PPE compliance and accidents in the lab?

METHODS

This study was derived from a single questionnaire, the Laboratory Safety Culture Survey, developed by the UC Center for Laboratory Safety, BioRAFT and Nature Publishing Group, and has been approved by UCLA's Institutional Review Board.[20,21]

Participants

The laboratory safety survey was broadly distributed via the Internet to universities and colleges, medical school and hospital laboratories, research institutions operated by the federal government, and industry research laboratories including pharmaceutical and chemical industries. For the purpose of this analysis, only U.S. researchers from academic (universities and colleges), government and industry laboratories ($N = 1{,}244$) were included in the study.

Measures

We analyzed 42 questions grouped into the following categories: demographics (11), risk perception and assessment (7), safety training (6), safety behavior (10), safety attitude (5), and injuries (3). The questions were similar to previously developed safety climate questionnaires.[9,23,24] While many questions required a yes or no answer, other items were categorized as year increments such as 5–10 years research experience or <65 years of age. Thirteen items were scored on a five-point Likert scale and three items on a four-point scale. The reliability of all Likert scale items was high with a Cronbach alpha coefficient of 0.848. Where relevant, questions had an "I don't know" option.

Statistical Analysis

Associations between pairs of factors were analyzed using the Chi-square test of independence. Post hoc pairwise comparisons were conducted for significant correlations by partitioning the Chi-square. Multiple logistic regression and multinomial logistic regression were used to adjust for age. The difference in perceived individual risk and perceived organizational risk was compared using the analysis of variance procedure. Statistical significance was evaluated at the 0.05 level and the Bonferroni correction was used to account for multiple testing. Data management and analyses were performed in SAS® 9.3.

RESULTS

Description of Respondents

Respondents from academic ($n = 991$), government ($n = 133$) and industry ($n = 120$) laboratories participating in the survey were 18 years and older. Respondents from academia were generally younger with approximately 60% being between 21 and 40 years old (Table 1). In contrast, the majority of respondents from government and industry labs were 41 years or older. Because of the age difference between academic respondents, and respondents from government and industry labs, potential for age bias was examined for each item where the three groups differed significantly. If not stated explicitly, no age bias was identified. More than half of the respondents from academic labs reported 15 or fewer years of combined lab experience (Table 1); of these, 71% constituted undergraduate, graduate, and postdoctoral fellows. The majority of researchers from government and industry labs have 16 or more years of total lab experience. The majority of respondents from academia had spent four or fewer years in their current lab (Table 1).

Respondents at all levels of employment were included in the analysis as long as they spent time inside their lab rather than being engaged solely in administrative work (Supplementary Table 1). Participants listed a variety of science and industry related research fields as their work area (Supplementary Table 2). Researchers working 40 hours or longer in their lab per week constituted the largest group of respondents from academic institutions (45%). Since 45% of all researchers in academia consisted of students and postdoctoral fellows (Supplementary Table 1), we examined how much time this sub-population spent in the lab. Students and postdoctoral fellows generally spent long hours working in the lab with 64% exceeding 40 hours per week, 24% worked 21–40 hours, and 12% worked 1–20 hours per week. Forty-four percent of respondents from government laboratories spent 1–20 hours every week in their labs (Table 1). Forty-three percent of the respondents from industry worked 1-20 hours and 40% worked 20–40 hours per week in their labs.

The majority of all respondents (71%) worked in labs with a group size of 1–10 researchers (Table 1).

Laboratory Safety Training

Researchers generally receive some type of formalized training in laboratory safety as mandated by OSHA regulations.[15] The survey was analyzed for responses to when researcher received training, and who trained them. About 70% of researchers in both academic and industry laboratories received safety training before they were allowed to carry out an experiment, and 26% and 19% of researchers, respectively, were trained within 30 days of starting experiments (Figure 1A). While a larger number of researchers from government labs (80%) were trained before starting experiments, the differences between the lab environments were non-significant after adjusting for differences in age. On the other hand, government researchers have significantly lower odds of being trained within 30 days of beginning their experiments than academic researchers, even after adjusting for age (Odds Ratio, $OR = 0.52$; $p = 0.012$). Training 30 days after start of experimentation was not widely practiced, and also training upon request or notification was reported by less than 10% of all respondents regardless of their research environment. Nearly every researcher indicated that laboratory safety training was required, and only a small percentage of respondents claimed that safety training was not mandatory at their institution (Figure 1A).

Overall, most researchers in all three institutions were trained by Environment, Health and Safety (EH&S) staff. With almost 100% participation, EH&S staff training was pointedly highest for government laboratory researchers ($\chi^2 = 6.53$, $df = 2$,

Table 1. Demographic Overview of Respondents.

		Academic labs ($n = 991$)		Government labs ($n = 133$)		Industry labs ($n = 120$)	
		#		#		#	
Respondents' age (years)	18–20	11	1%	0	0%	1	1%
	21–25	105	11%	3	2%	10	8%
	26–30	243	25%	10	8%	11	9%
	31–35	149	15%	27	20%	14	12%
	36–40	94	9%	17	13%	14	12%
	41–50	159	16%	29	22%	34	28%
	51–60	149	15%	31	23%	26	22%
	>60	81	8%	16	12%	10	8%
Total lab experience (years)	<1–4	148	15%	4	3%	12	10%
	5–10	306	31%	24	18%	19	16%
	11–15	162	16%	30	23%	24	20%
	16–20	98	10%	21	16%	15	12%
	21–25	81	8%	14	10%	19	16%
	>25	196	20%	40	30%	31	26%
Years in current lab	<1–4	538	54%	49	37%	69	58%
	5–10	223	23%	34	25%	28	23%
	11–15	86	9%	25	19%	14	12%
	16–20	50	5%	9	7%	5	4%
	21–25	45	4%	5	4%	1	1%
	>26	49	5%	11	8%	3	2%
Hours/week spent in lab	1–20	318	32%	58	44%	51	43%
	21–40	232	23%	43	32%	48	40%
	>40	441	45%	32	24%	21	17%
Research group size	1–10	772	74%	105	79%	73	61%
	11–20	211	20%	19	14%	21	17%
	>20	59	6%	9	7%	26	22%

$p = 0.038$; Figure 1B). Thirty-five percent of all respondents received additional lab safety training from their PI or laboratory supervisor. Training by a co-worker predominated for younger researchers and the lab environment difference for co-worker training shown in Figure 1B was no longer significant when adjusted for age. Research labs can vary greatly in the type of hazards they house, and experiments with hazards are highly individualized. Therefore, introducing a new student or research staff to laboratory safety by an experienced fellow student or staff is common practice in many institutions. Other laboratory safety training practices including training provided by an outside company or when training on new, complex instrumentation is required was reported by 7% or fewer of all researchers (Figure 1B).

Respondents' perception of their lab safety training was overall very similar between the three institutions. The majority of all respondents agreed that they were sufficiently trained to be compliant with lab safety regulations, and also trained well enough to effectively minimize the risk of injury to themselves and others in their lab (Figure 1C). However, only 67% of researchers stated that they were trained in the safe use of the specific hazards they included in their experiments (Figure 1C). When asked whether safety training in their organization focused on fulfilling compliance requirements rather than on improving laboratory safety, significantly fewer researchers from industry facilities agreed as compared to researchers from academic and government labs ($p < 0.001$ for both; Figure 1C). This suggests that industry researchers more readily accept training as a benefit to their safety, or they are more compliant with safety regulations regardless of its perceived usefulness in improving safety. Less than half of all respondents stated that their supervisor or PI regularly monitors whether laboratory duties are performed in a safe fashion using proper safety equipment (Figure 1C), suggesting that a number of PIs or supervisors place little value on an active involvement in lab safety.

Risk Assessment and Perception

Before analyzing participant's risk perception, it was important to establish whether or not respondents were exposed to hazardous materials or equipment. All participants worked in labs where hazards were used at least some of the time, and 76% of the respondents stated that two or more hazards were used frequently or very frequently. Of all hazards listed, highly toxic or mutagenic substances such as toxins and carcinogens were reported as most frequently used by 48% of researchers across the three types of institutions (Supplementary Fig. 1).

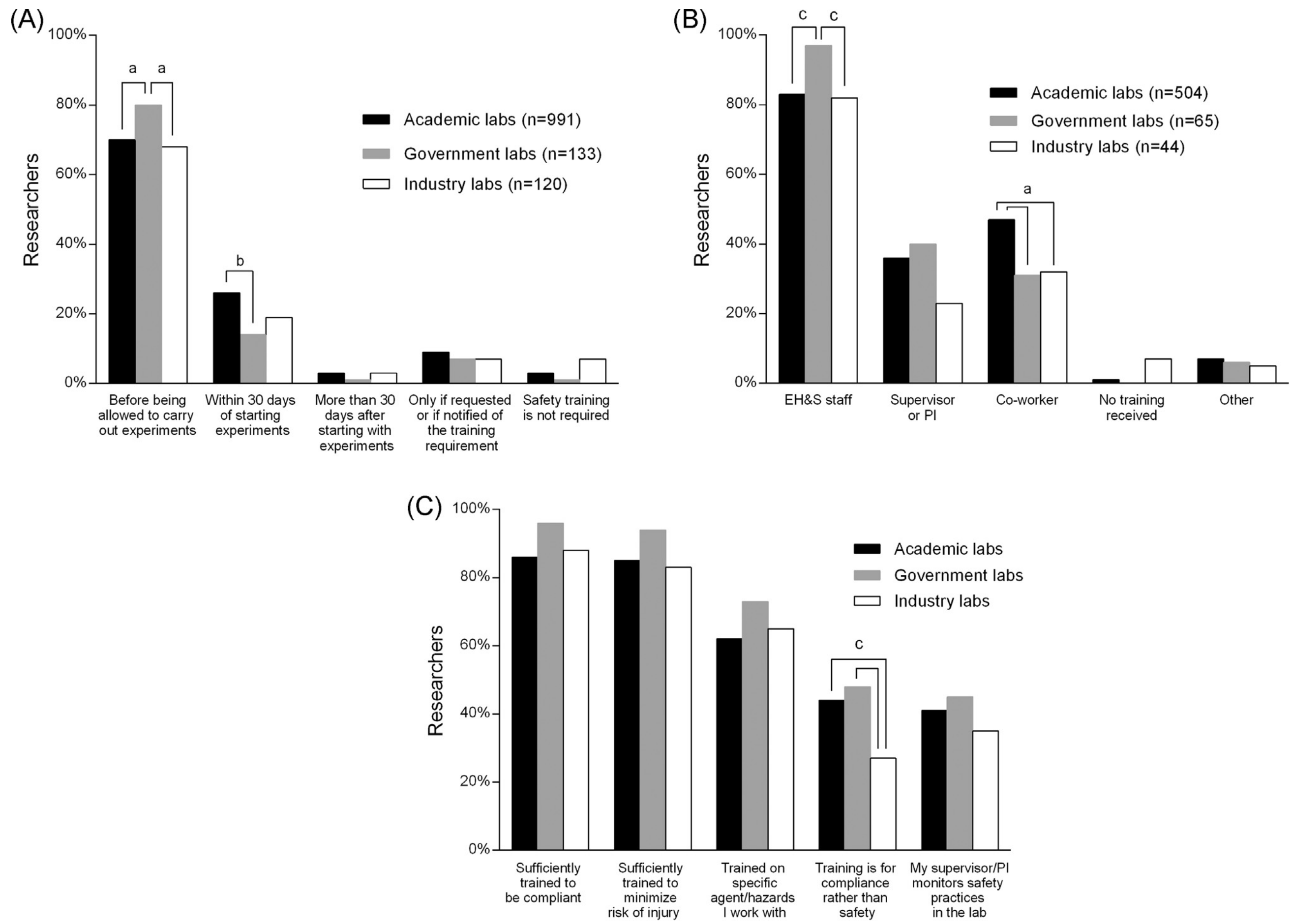

Figure 1. Laboratory safety training practices and perceptions in academic, government and industry laboratories. (A) Respondents' answers to the question "When do lab personnel receive new safety training?" Number of respondents is shown in parentheses. (B) Respondents' answers to the question "Who has provided you with lab safety training in your current lab?" "Other" refers to additional, not specified training practices. Number of respondents is shown in parentheses. (C) Respondents' perception of laboratory safety training; (Total number of respondents from academic labs are from left to right: 988, 987, 975, 987, and 500; total number of respondents from government labs are from left to right: 133, 132, 133, 133, and 64; total number of respondents from industry labs are from left to right: 120, 120, 119, 120, and 43). All groups were compared to each other. "a" indicates significant age bias of the data; when adjusted for age, group differences between lab environments were no longer significant. "b" indicates significant age bias of the data; however, the significant difference between groups remains even when adjusted for age ($p < 0.01$); "c" indicates significant group differences of responses that are not age biased ($p < 0.01$).

When performing experiments with hazardous substances or instrumentation, a risk assessment should be conducted to inform of potential dangers and offer procedures for risk mitigation. Researchers' risk perception toward working with hazards is generally based on two factors that could influence risk taking behavior, i.e., an objective, formal risk assessment to quantitate risk exposure, and a subjective awareness of potential dangers posed by the hazard.[25,26] The more formalized the risk of a hazard is assessed the less subjective is the process and, thus, less prone to underestimation of potential dangers that could lead to accidents. About 52% and 43% of the researchers in government and industry laboratories, respectively, stated that they used their organization's approved forms for risk assessment (Figure 2). Informal risk assessment was performed by 36% government and 43% industry researchers. In contrast, only 18% of researchers in academic labs assessed their risk with a university approved form ($\chi^2 = 93.34$, $df = 2$, $p < 0.001$) (Figure 2). Instead, 57% of them gauged their risk informally and 12% reported not to perform any type of risk assessment at all ($\chi^2 = 25.07$, $df = 2$, $p < 0.001$ and $\chi^2 = 12.19$, $df = 2$, $p = 0.002$, respectively). Few researchers used their own format for risk assessment. Risk assessment tools offered by outside companies were not commonly used, possibly because they were not offered at most institutions.

Researchers' personal risk perception is an important factor influencing their risk taking behavior.[25] The survey was analyzed to compare how researchers perceive their own risk

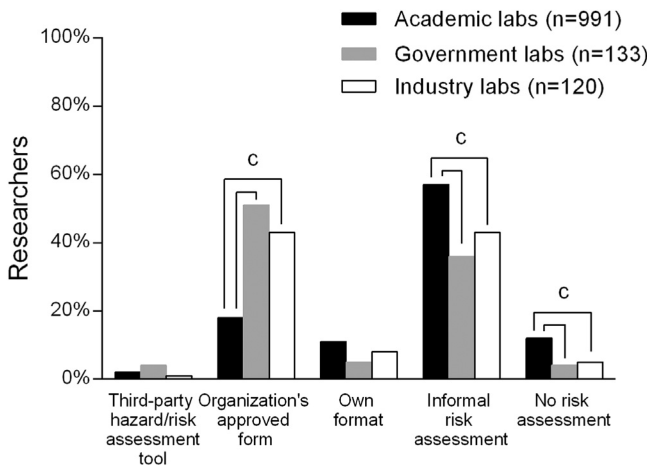

Figure 2. Types of risk assessments used by respondents from academic, government and industry laboratories before conducting an experiment. All groups were compared to each other. "c" indicates significant group differences of responses that are not age biased ($p < 0.01$).

when working in their lab with what respondents claimed was their organization's views of the risk level. Respondents generally thought their own risk in their labs to be significantly lower than the risk level they assumed their organization had determined, indicated by the negative mean difference in Likert scales (Table 2).

The majority of the respondents, regardless of their organization, perceived their personal risk of working in their laboratory to be either very low to low or moderate, and only 8% stated their risk to be high or very high (Figure 3). Of the respondents from academic labs, 16% (160 respondents) did not know how their organization viewed their risk level. In government labs and industry facilities, 6% (eight respondents) and 6% (seven respondents) of the researchers, respectively, had no knowledge of their institution's risk level. No correlation was found between researcher's personal risk perception and their age or years of job experience.

PPE Compliance Behavior is Strongly Influenced by Motivational Pressure

Compliance with personal protective equipment (PPE) regulations was used to assess the extent to which researchers adhere to safety policies. We initially examined the survey data as to ascertain whether or not respondents were required to wear PPE in their laboratories. Overall, 95%, 85% and 76% of all researchers confirmed that they were required to wear gloves, a lab coat and eye protection, respectively. Of these, most researchers always or usually wore gloves (Figure 4A). The high compliance is likely a reflection of the dual incentives for wearing gloves; researchers protect their own hands from hazards and, in addition, they safeguard their experiment from contamination by skin bacteria or skin oils. However after adjusting for age, researchers working in academic and government labs were less compliant with wearing required lab coats and eye protection as compared to industry researchers who donned required lab coats and eye protection more regularly ($\chi^2_{\text{lab coat}} = 14.49$, $df = 2$, $p < 0.001$ and $\chi^2_{\text{eye protection}} = 22.15$, $df = 2$, $p < 0.001$; Figure 4A). Adjusting for lab environment, compliance with wearing a lab coat and gloves was generally higher for the 40 and older respondent age group, although non-significant for eye protection ($\chi^2_{\text{lab coat}} = 24.24$, $df = 1$, $p < 0.001$; $\chi^2_{\text{eye protection}} = 3.60$, $df = 1$, $p = 0.058$).

Safety behavior was also strongly correlated with researcher's risk perception in their labs. Adjusting for age and lab environment, compliance with wearing PPE was lowest when researchers perceived to work in a low risk lab environment but increased with higher levels of assumed risk exposure in the lab ($\chi^2 = 29.07$, $df = 2$, $p < 0.001$; Figure 4B). Industry respondents embodied an exception when wearing a lab coat but not when donning required eye protection. Overall, the results suggest that perception of working in a high-risk environment represents a strong positive motivator to stay protected. A comparison between the three groups after adjusting for age and perceived risk level, revealed significant differences between the groups; industry researchers stood out by wearing a lab coat more frequently as compared to researchers from academic and government labs (OR = 3.04, $p < 0.001$; OR = 2.58, $p = 0.010$, respectively; Figure 4B). Furthermore, respondents from government and industry labs use eye protection significantly more often than academic researchers (OR = 1.86, $p = 0.010$; OR = 3.05, $p < 0.001$, respectively). Wearing gloves was independent of personal risk perceptions since compliance was overall high (data not shown).

To examine whether supervision correlates with safety behavior, we examined the question of whether or not

Table 2. Analysis of Individual's Risk Perception Versus Organization's Risk Level (Own Risk – Org Risk) by ANOVA with Responses Following a Five-Point Likert scale.

Organization[a]	*n*	Mean	Std Dev	Std Err	Min	Max	*df*	*t*-Value	*p*-value
Academia	831	−0.26	0.73	0.03	−4.0	3.0	830	−10.25	<0.001
Government	124	−0.38	0.79	0.07	−4.0	1.0	123	−5.33	<0.001
Industry	113	−0.15	0.78	0.07	−2.0	4.0	112	−2.05	0.043

[a] Researchers responding with "I don't know" were not included in the analysis.

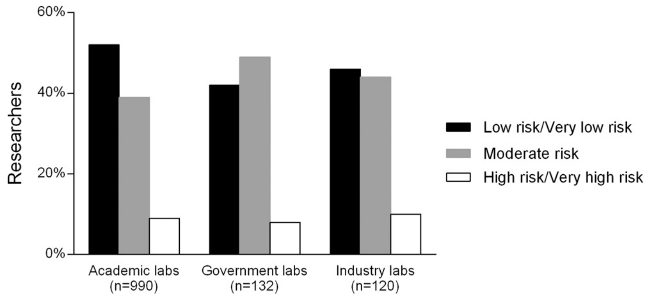

Figure 3. Respondents from academic, government and industry laboratories personal perception share similar personal risk perceptions about their lab environment (no significant differences).

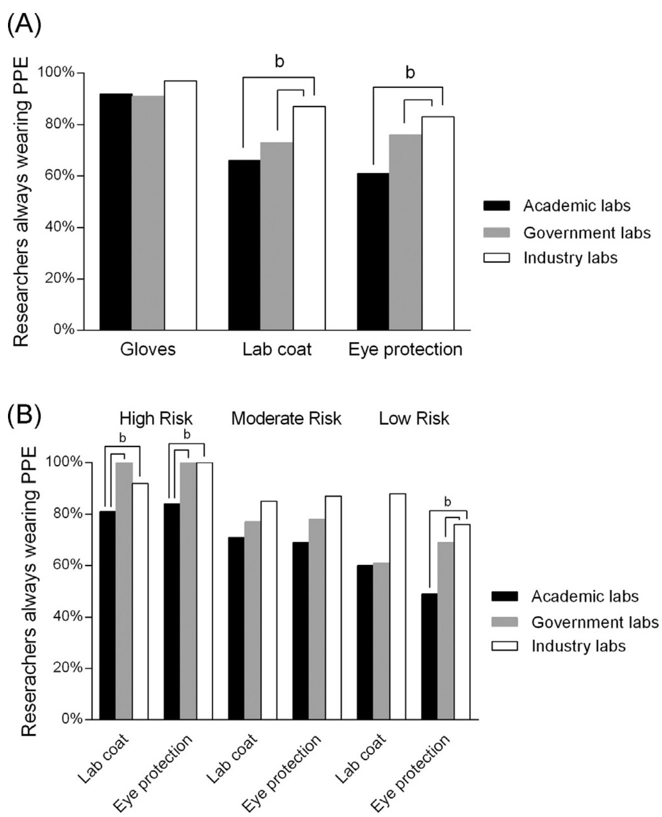

Figure 4. Respondents' compliance behavior with wearing personal protective equipment (PPE). (A) Respondents' responses to the question "How frequently do you use the Personal Protective Equipment that you previously indicated should be used for your current lab work?"; number of researchers from academic, government and industry labs wearing gloves is 946, 119, and 115, respectively, for wearing a lab coat the number is 839, 109, and 108, respectively, and for wearing eye protection the number is 727, 113, and 107, respectively. "b" indicates significant age bias of the data; however, the significant difference between groups remains even when adjusted for age ($p < 0.01$). (B) Respondents' compliance with PPE if they perceived their personal risk in the lab to be high (=high or very high), moderate or low (=low or very low); High risk: number of researchers from academic, government and industry labs wearing a lab coat is 74, 11, and 12, respectively, and for wearing goggles the number is 73, 9, and 11, respectively. Moderate risk: number of researchers from academic, government and industry labs wearing a lab coat is 353, 53, and 48, respectively, and for wearing goggles the number is 295, 14, and 99, respectively. Low Risk: number of researchers from academic, government and industry labs wearing a lab coat is 411, 44, and 48, respectively, and for wearing goggles the number is 350, 45, and 49, respectively. All groups were compared to each other.

researchers comply with PPE policies if the PI or lab supervisor does or does not monitor to make sure researchers work in a safe fashion using proper safety equipment. Gloves were excluded from this analysis since compliance was uniformly high (Figure 4A). Supervision had no impact on the safety behavior of researchers from industry and government labs (data not shown). However, researchers in academic labs donned their lab coat significantly more frequently when the PI or lab supervisor monitored their safety behavior (Figure 5). Without consistent lab safety supervision, significantly more researchers stated that they did not wear their lab coat even though it was required for their work (OR = 0.29, $p < 0.001$; Figure 5). Researchers who neither agreed nor disagreed that their safety behavior was supervised responded similarly to those whose PIs did not check safety, suggesting that persistent PI presence motivates compliance with wearing a lab coat.

Safety Perceptions and Attitudes

Lab safety perceptions were similar between respondents from all three institutions, and 90% or more of the researchers agreed that their lab was a safe place to work (Table 3). Furthermore, the majority of all respondents stated that safety in their laboratory took precedence over all other lab priorities or was very important. However, respondents from government labs significantly differed in their safety attitudes; a higher percentage of government researchers stated that safety rules negatively impacted their productivity (30% for government researchers versus overall 15% for academic and industry researchers) and also interfered with their scientific discovery process (37% for government researchers versus overall 23% for academic and industry researchers) (Table 3).

Impact of Injuries on Safety Attitude and PPE Compliance Behavior

To examine whether or not experience of laboratory injuries was correlated with researchers' attitude toward laboratory safety and PPE compliance behavior, we first examined the survey data for the number of injuries

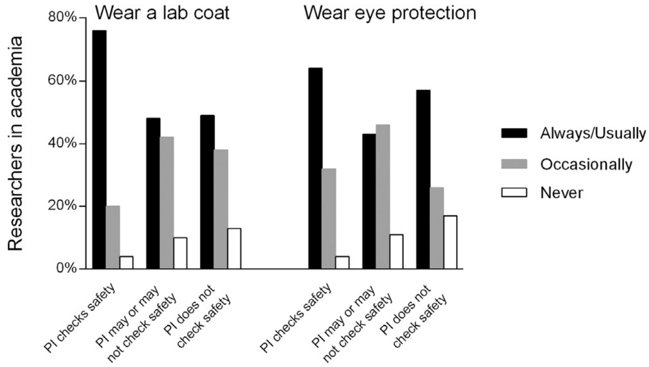

Figure 5. Effect of PI or lab supervisor on compliance by academic researchers with wearing a lab coat and eye protection; lab coat: $n = 173$ (PI checks safety), $n = 95$ (PI may or may not check safety), and $n = 148$ (PI does not check safety); eye protection: $n = 159$ (PI checks safety), $n = 76$ (PI may or may not check safety), and $n = 118$ (PI does not check safety). All groups within each category were compared to each other.

respondents had witnessed or personally experienced in their labs. Injuries were distinguished as major or minor injuries to someone in the lab, or as injury to oneself while working in the lab. A major injury was defined as requiring medical attention by a health care professional, while a minor injury could be dealt with by providing first aid by the injured or another lab member. Researchers from the three institutions witnessed or personally experienced similar numbers of injuries (Table 4). There was no correlation with the respondents' age and the number of injuries experienced. However, respondents with more years of lab experience sustained more personal injuries ($\chi^2 = 36.4$, $df = 10$, $p < 0.01$).

The survey did not provide any information when researchers had witnessed or sustained injuries during their careers. Therefore, we focused on students and postdoctoral fellows from academic institutions ($n = 445$) with the assumption that this sub-population had experienced accidents during their very recent careers. To examine whether the experience of injuries were related to the attitude of students and postdoctoral fellows toward laboratory safety, the number of injuries was correlated with the question of whether or not injuries could have been prevented if safety protocols would have been followed. However, no significant association was identified between the severity and the number of injuries experienced and students' safety attitudes, suggesting that the experience of one or more injury events is not sufficient to affect how trainees view safety measures. Furthermore, no correlation was found between injury experience and PPE compliance safety behavior.

However, there was a significant correlation between PI or laboratory supervisor's safety supervision and the number of injuries that were witnessed or personally experienced by the academic trainee sub-population (Figure 6). When the PI or lab supervisor monitored lab safety behavior, trainees recorded fewer injuries. Conversely, respondents with increased number of injuries also stated that the PI or lab supervisor did not supervise lab safety. The estimated odds of witnessing no major accidents, minor accidents, and injuries to self for researchers in labs where the PI audits lab safety are 3.23, 2.7, and 1.87 times higher, respectively, than the odds for researchers in labs where lab safety is not supervised. This finding suggests

Table 3. Lab Safety Perceptions and Attitudes. p-Values were Calculated by Pearson's Chi-Square.

Survey question	Answer option	Academic labs		Government labs		Industry labs		*p*-value
		#		#		#		
Feel safe in laboratory	Strongly agree/agree	889	90%	125	95%	115	95%	0.226
	Neither agree nor disagree	35	3%	7	5%	4	3%	
	Strongly disagree/disagree	67	7%	0	0%	2	2%	
Characterization of safety in laboratory	Takes precedent over all other lab duties/very important	691	67%	103	78%	92	77%	0.463
	Equally important as experiment	197	20%	24	18%	19	16%	
	Less important than experiment/low priority	103	10%	6	4%	9	8%	
Safety rules negatively impact productivity	Strongly agree/agree	160	16%	39	30%	17	14%	0.004
	Neither agree nor disagree	194	20%	24	18%	22	19%	
	Strongly disagree/disagree	636	64%	69	52%	80	67%	
Safety rules interfere with scientific discovery process	Strongly agree/agree	252	26%	49	37%	24	20%	0.017
	Neither agree nor disagree	213	21%	22	16%	22	18%	
	Strongly disagree/disagree	519	53%	62	47%	74	62%	

Table 4. Respondent's Experience with Injuries (No Significant Differences).

Item		Academic labs		Government labs		Industry labs	
		#		#		#	
# major injuries[a] witnessed in the lab	0	708	71%	91	68%	78	65%
	1–2	239	24%	34	26%	35	29%
	3–5	39	4%	6	5%	3	3%
	6+	5	1%	2	1%	4	3%
# minor injuries[b] witnessed in the lab	0	283	29%	37	28%	27	22%
	1–2	367	37%	44	33%	47	39%
	3–5	218	22%	36	27%	32	27%
	6+	123	12%	16	12%	14	12%
Injury to self	0	547	55%	64	48%	68	57%
	1	251	25%	34	26%	28	23%
	>1	193	20%	35	26%	24	20%

[a] Major injuries are defined as requiring medical attention by a health care professional.
[b] Minor injuries are defined as first aid provided by the injured, a colleague or the respondent.

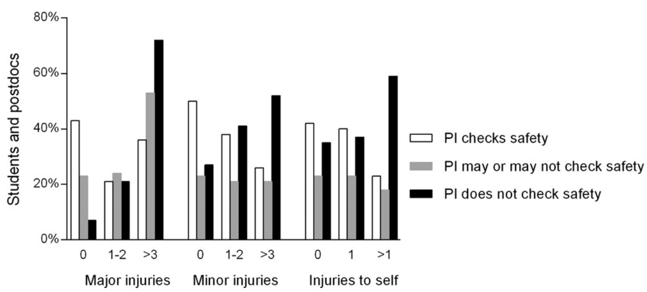

Figure 6. Impact of PI or lab supervisor, overseeing lab safety practices, on the number of injuries. The number of injuries witnessed or personally experienced by students and postdoctoral fellows in academic labs ($n = 406$) was correlated with the question "My supervisor, lab manager or PI regularly checks to make sure I am performing my laboratory duties in a safe fashion using proper safety equipment". Major injuries: $\chi^2 = 18.96$, $df = 4$, $p = 0.008$; minor injuries: $\chi^2 = 21.36$, $df = 4$, $p = 0.003$; injuries to self: $\chi^2 = 16.26$, $df = 4$, $p = 0.003$.

that lab safety supervision by a PI or lab supervisor significantly impacts safety in a way that prevents injuries.

DISCUSSION

This is the first study, to our knowledge, comparing safety climate parameters of researchers from academic, government, and industry labs. We observed several similarities between the three groups; for example, greater than 85% of respondents, regardless of their institutions were trained within 30 days of beginning their research experiments and EH&S staff provided the predominant means of formal training (Figure 1A and B). Furthermore, most respondents perceived their training to be sufficient to allow safe operations in their lab environment without risking injury to themselves or others (Figure 1C). Yet, almost a quarter of all respondents stated that they had not been trained in the use of specific hazards required for their experiments pointing to a significant deficiency in all three institutions. Although respondents had previously stated that their lab had a supervisor, in more than half of the cases the PI or lab supervisor did not reinforce lab safety practices regularly. Thus, while safe and best laboratory practices are likely addressed in formal training sessions, lab leadership often does not follow through with demonstrating active support for safety.

Respondents from all three institutions also shared similar perceptions of their personal risk when working in their laboratory. Specifically, researchers across all institutions believed their risk was lower than what they assumed their organizations had categorized (Figure 3 and Table 2). Risk perception in research laboratories should be guided by hazard analyses before experiments are conducted, especially, when experiments are performed for the first time. However, only 50% or fewer of all researchers used risk assessment forms provided by their organization (Figure 2). Especially in academic institutions, the vast majority of researchers used non-standardized forms for risk assessments. If no formal identification of hazards is conducted, a false sense of safety may prevail where the scientific outcome of an experiment becomes more important than the hazards involved. The National Research Council suggests incorporating hazard identification and standardized risk assessment as an integral part of every experiment.[18] Our study suggests that risk perception motivates safety behavior; PPE compliance behavior for researchers from academic and government labs was highly correlated with the risk they associated with their lab (Figure 4B). This behavior could be interpreted two ways: work in high risk environments may have more stringent compliance and training requirements that are more tightly monitored as is the case for high containment biosafety level 3 and 4 laboratories.[27,28] Alternatively, researchers may be more aware of their risk level when working with highly hazardous materials; the internal pressure to protect one's health and safety may be a contributing factor in PPE compliance. Lower risk perceptions correlated with decreased PPE compliance for researchers from academic, government, and, to some extent, industry labs. A study on the use of hearing protection devices (HPDs) by industry workers demonstrated that workers used hearing protection more consistently when their perceived risk of exposure to noise was high. On the other hand, the study found no significant correlation between HPD use and objectively quantified risk exposure suggesting that workers in this study tended to underestimate their risk level.[25] Therefore, individual's risk perceptions could be considered an important predictor of safety behavior with the caveat that personal risk perception may not be accurate.

Respondents from government labs most notably differed in their safety attitudes displaying a more negative view of safety rules as compared to academic and industry researchers (Table 3). Although agreeing that safety in their lab is very important, government researchers are far more critical of safety-related policies compared to academic and industry researchers regarding impact on productivity and the scientific discovery process.

Overall, respondents from industry researchers stood out by reporting a higher acceptance of safety training and PPE compliance with respect to wearing a lab coat consistently (Figures 1C and 4A and B). The greater compliance behavior could be due to differences in how training is conducted in industry versus academic and government lab facilities. Alternatively, a more centralized and hierarchical structure in industry research labs may result in a greater acceptance of what could be considered the norm.[29] Furthermore, workers in many industries actively participate in all aspects of work-related safety practices, and a better safety outcome was documented for industries that involved workers in this process.[18,30–32]

In contrast, responses from researchers in academic labs suggest a less well established safety culture compared to industry researchers, as judged by more frequently used informal risk assessment forms or the complete absence of any type of risk assessment prior to conducting an experiment (Figure 2), and diminished PPE compliance with respect to wearing a lab coat and eye protection (Figure 4A and B). Official risk assessments forms may also not be provided to researchers in many colleges and universities leaving the task of evaluating risks involving hazardous materials to the researchers, or making this safety process optional all together. Because scientists in academic institutions place such high emphasis on their research and also generally fail to empower students to voice safety concerns, the National Research Council suggests the use of a "formalized approach to include hazard analysis, risk assessment and safety as an integral part of the academic research process".[18] Researchers from government labs responded more similarly to academic researchers than to industry researchers with respect to lab coat compliance (Figure 4A and B). A decentralized organizational safety structure could explain the diminished PPE compliance behavior for researchers from academic[18] and, to some extent, government labs.

A decentralized safety structure was stated as one of the problems in improving the safety culture at a large academic institution.[14] Laboratory researchers and health & safety experts participating at a 2012 Laboratory Safety Workshop also voiced leadership issues, from the higher administrative levels to the principal investigator, as a cause of inconsistent safety culture and a lack of vision.[33] This is reflected by our survey analysis, which demonstrates a positive correlation between PPE compliance behavior by academic researchers and an active role the PI or lab supervisor assumes in monitoring lab safety (Figure 5). More importantly, monitoring lab safety was associated with reduced numbers of major and minor injuries witnessed, and injuries sustained by the student and postdoctoral fellow sub-population (Figure 6). Students and postdoctoral fellows can be considered especially vulnerable to accidents. Graduate students, especially in their beginning years, often do not realize that risks maybe associated with their experiments when they change or scale up procedures. Postdoctoral fellows typically enter a new lab to expand their scientific expertise; therefore, postdocs similarly to graduate students are generally inexperienced in the experimentation in their new research field. Analyzing workers' compensation data, Breslin and Smith found that job experience is a strong predictor of occupational injury and was independent of worker's age.[34] Sorock and co-workers found a significant increase of work-related accidents when workers performed tasks using an unusual work method, while being distracted or rushed.[35] As representing the forefront of experimental design and development of new techniques, students and postdocs are well described by Sorock's transient risk factors. The findings of our research support the significance of lab safety supervision for individual research labs. In this study, both PPE compliance behavior and injury reduction are independent attributes positively impacted by the PI or lab supervisor as no significant correlation between wearing PPE and injuries witnessed or sustained was observed for the trainee sub-population. Wearing required PPE is only one of the safety behavior parameters within a research laboratory and may not be by itself sufficient to account for reduced injuries. It was noted in a recent study that good supervisor relations with university students also appear to have a preventative effect on injuries.[36] Our analysis adds to the discussions on employee's perceptions of safety climate, which impact their behavior outcome.[18,37–41] By monitoring academic trainees' compliance behavior, the PI or lab supervisor signifies and models that safety is of concern in the research lab, and appears to motivate students and postdoctoral fellows to enact safety behaviors. In a study on responses to occupational hazards, Cree and Kelloway observed a strong correlation between employees' perceptions of managers' and supervisors' commitment to safety and employees willingness to participate in institutional safety programs.[42] Furthermore, a longitudinal study by Griffin and Neal on the relationship between safety climate, safety motivation and safety behavior demonstrated that individuals working in an environment with a positive safety climate reported an increase in their safety motivation, which can have a lasting effect[5]. It is unclear from our study whether or not PIs and lab supervisors used a positive reward system or leadership style to enforce safety motivation, which would be an important topic for a follow up questionnaire.[43,44] Furthermore, additional longitudinal studies are needed to determine the effect of safety practices with an established positive outcome on their sustainability.

Limitations

One of the limitations to this study is that there is the potential for self-reporting bias. Thus, our results may not be applicable or translatable to general safety practices in academic, government, and industry labs in the United States. Furthermore, the government and industry researcher populations were small as compared to the researcher population from academia, and therefore, may limit generalizations to these institutions. In addition to this, the cross-sectional nature of the study questions asked in the survey impedes the ability to determine when observed accidents may have occurred and thus precludes the determination of causation.

CONCLUSIONS

This study compared academic, government and industry researchers' opinions about various safety culture aspects of their work environments. The outcomes from this study suggest the following:

- Safety training in any research environment comprises an important aspect of laboratory safety by providing researchers with confidence to conduct experiments without endangering themselves, their co-workers, and their environments. However, complete coverage of training with hazardous compounds or procedures should be given high priority and implemented by both PIs and EH&S officers. All highly publicized accidents in academia of recent years were associated with highly hazardous reactions or equipment.[2] Therefore, thorough training with demonstrated self-efficacy should become a documented prerequisite for working with hazards.
- The mismatch between researchers' perception of their own risk and what they think their institution perceives is their risk in the laboratory could potentially result in accidents due to researchers underestimating their risk. It is imperative that during safety training, risk levels are clearly defined and possibly reiterated during lab inspections by EH&S officers.
- The safety culture in academic labs is less well established as compared to the safety culture in government and industry research labs. Industry labs, overall, display the best functioning safety culture. In our study, PPE compliance and risk assessment were used as indicators of safety culture and the statement is based on based on the finding that researchers' risk perception in all three work places was similar (Figure 3).
- In academia, active involvement of the PI or lab supervisor in safety oversight positively affects safety behavior, i.e., compliance with PPE, and reduces the number of accidents in the lab. In light of the findings of this analysis, we recommend to raise awareness of PIs' and lab supervisors' role in academic institutions with respect to their significant impact on researcher safety. EH&S officers should emphasize the importance of the PI's role in lab safety when interacting with them during training or in other personal conversations such as lab inspections. However, we also suggest a top-down educational approach of department chairs during faculty meetings, in which the active role of the PI in lab safety is emphasized. Sustained active safety engagement demonstrates commitment to lab safety and motivates researchers' safety behavior.

Future studies related to laboratory safety practices and safety culture should evaluate behavioral observations at individual institutions longitudinally in order to support the observations and their associations.

ACKNOWLEDGEMENT
This study was supported by funds from the University of California Center for Laboratory Safety (UCCLS). We thank Rhett Roback, the Advisory Board of the UC Center for Laboratory Safety, BioRaft, and Nature Publishing Group for survey development. Nature Publishing Group for conducted the survey and supplied us with the data. We thank Naomi Mimila for assistance with the data analysis.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jchas.2015.03.001.

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