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Review

Accuracy, Comprehensibility, and Use of Material Safety Data Sheets: A Review

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Objectives *Material safety data sheets (MSDSs) are used in workplaces to communicate to workers the hazards of chemical products. This article describes a review of the peer-reviewed scientific literature regarding the accuracy, comprehensibility and use of MSDSs in the workplace.*

Methods *Articles were retrieved via a systematic search of indexes and databases, followed by hand searching and citation index searching. Two reviewers independently read and coded the articles using an iterative matrix.*

Results *Of the 280 unique articles retrieved, 24 fit the review criteria. Eligible articles included a range of methodologies: laboratory analyses, site audits, surveys and qualitative inquiry. Articles were grouped into three main topic categories: accuracy and completeness, awareness and use, and comprehensibility. Accuracy and completeness were found to be relatively poor, with the majority of studies presenting evidence that the MSDSs under review did not contain information on all the chemicals present, including those known to be serious sensitizers or carcinogens. Poor presentation and complex language were consistently associated with low comprehensibility among workers. Awareness and use of MSDSs was suboptimal in workplaces where these factors were studied.*

Conclusions *Despite the fact that these studies varied in methodology and spanned a period of more than 15 years, a number of common themes emerged regarding inaccuracies, incompleteness, incomprehensibility and overall low use of MSDSs. The results of the literature review suggest that there are serious problems with the use of MSDSs as hazard communication tools. The article concludes with recommendations for governments, regulatory bodies, and occupational health and safety personnel to seriously reassess the ways in which MSDSs are written, monitored, regulated, and used.* Am. J. Ind. Med. 51:861–876, 2008. © *2008 Wiley-Liss, Inc.*

KEY WORDS: material safety data sheet; occupational health; workplace; review/ literature review; communication

INTRODUCTION

Material safety data sheets (MSDSs) are a key component of hazard communication in workplaces across North America, Europe, and increasingly other parts of the world. Indeed, regulatory requirements for MSDSs, material safety training and hazard labeling have been in place in North America for just over 20 years, as part of hazard communication programs that ensure workers have access to information about the chemicals they are exposed to in their

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workplace. MSDSs identify information about products including hazardous ingredients (including specific toxicological properties), precautionary measures for handling, and relevant first aid and emergency information. Chemical suppliers produce and distribute MSDSs to employers, who are then required to provide that information, in concert with training, to workers. Many policy makers and occupational health and safety professionals see MSDSs as an essential part of occupational health and safety programs [Smith, 1992; Bradshaw, 1995; Monroe and Orr, 2006].

However, since these regulations have been enacted, a growing body of discontent (often expressed in opinion pieces in medical or health and safety periodicals) has emerged over the effectiveness of MSDSs as a tool for workplace health and safety communication. Some of this discontent focuses on the lack of a clear relationship between simply providing information and expecting that this information will then have some impact on the intended audience. Indeed, provision of information alone has been found in fields such as health promotion and health communication to be a necessary, but not sufficient, means of preventing or changing deleterious health effects [Maibach and Parrot, 1995; Fagotto and Fung, 2002]. Other criticisms of MSDSs have pointed to the overly technical, poorly organized, and incomplete nature of the sheets [Sattler et al., 1997; Kahan et al., 1999; Packham, 2002].

The purpose of hazard communication legislation in Canada, the US and elsewhere is to ensure that MSDSs deliver up-to-date and clear information to workers, employers, and health professionals. The US Hazard Communication Standard (HCS) and Canadian Workplace Hazardous Materials Information System (WHMIS) both specify what an MSDS must include to be compliant. However, both provide flexibility in compliance, rather than regulating standardized wording and format.

EU regulations, in contrast, contain a list of standardized ''risk phrases'' (e.g., ''causes burns'') and ''safety phrases'' (e.g., ''keep out of reach of children'') to be used on MSDSs. Despite not being required by HCS or WHMIS, these phrases are increasingly used in North American MSDSs as markets integrate and products move across borders [Interactive Learning Paradigms Incorporated, 2006]. The Globally Harmonized System on the Classification and Labelling of Chemicals (GHS), an initiative that aims to standardize MSDSs globally, is developing standardized ''hazard statements,'' and it is likely that these will be adopted in North American regulatory systems [OSHA, 2004].

There has been considerable debate within the occupational health community about what format MSDSs should take [Monroe and Orr, 2006]. The European Union (EU), International Labour Organization (ILO), International Standards Organization (ISO), and American National Standards Institute (ANSI) all require or recommend that MSDSs use a format with 16 subject headings, in a specified order (hazard identification, first aid measures, fire-fighting measures and so on). This is recognized as the ''international standard,'' and will form the basis for international harmonization efforts under the GHS. Canadian MSDSs have traditionally had nine section headings, while American sheets most often have eight, but both countries are likely to adopt the new 16-part format in the coming years as part of the harmonization process. While these formats have been developed in consultation with industry, labor groups and the wider public [OSHA, 2004], it is unclear to what extent these guidelines and requirements are based upon a consensus in the scientific literature on MSDSs and their use in worksites.

Quality control and enforcement mechanisms for MSDSs are varied. The US Occupational Safety and Health Administration (OSHA) has developed compliance guidelines for employers [OSHA, 2000], and a guide for inspectors reviewing MSDS completeness [OSHA, 1998]. Similar guidelines are available in Canada [Health Canada, 2007]. These are not binding regulations, but provide employers and inspectors with guidance in assessing whether or not an MSDS meets legal requirements. There is no quality control mechanism through which all MSDSs must pass in either the US or Canada. However, in Canada, companies that apply for exemption from full disclosure on MSDSs on the basis that it would reveal trade secrets are required to submit these MSDSs for assessment of accuracy and completeness by the Hazardous Materials Information Review Commission. Within this subset of 296 MSDSs that companies knowingly submitted for review in 2005–2006, only 12 complied fully with regulatory requirements and the remaining 284 had an average of 8.7 information violations per MSDS [Hazardous Materials Information Review Commission, 2006].

Beyond issues of format and regulation, uncertainty still exists regarding the role of MSDSs as hazard communication tools. The primary goal of this article is to examine the evidence about whether MSDSs are fulfilling their mandate to provide workers with the information they need to understand and manage the risks they incur as a result of using chemicals in the workplace. This article therefore focuses on articles that cover the accuracy, completeness, comprehensibility, awareness, and use of MSDSs in a variety of workplaces worldwide. This article presents the results of a methodical and thorough search and review of the peer-reviewed scientific literature conducted on MSDSs published until July 2007.

METHODS

Search Strategy

The process for identifying peer-reviewed research articles conducted on MSDSs involved five stages, resulting in a total of 340 articles: (1) searching indexes/databases; (2) searching of tables of contents from relevant journals by

hand; (3) searching the references from all relevant journal articles by hand, (4) contacting authors who were involved in relevant preliminary studies (i.e., theses or conference abstracts); and (5) searching cited references.

For the first stage, the search included indexes and databases pertinent to occupational health, namely PubMed (1949–July 2007), CINAHL (1982–July 2007), EMBASE (1980–July 2007), and CCOHS OHS References (1974–July 2007). The search also included ISI Web of Science (1965–July 2007), Academic Search Premier (1975–July 2007), PsycINFO (1887–July 2007) and Proquest Theses & Dissertations (1980–July 2007) because of the interdisciplinary nature of MSDS research, particularly in the area of document comprehensibility. The search terms ''material safety data sheet(s)'' were used instead of subject headings because relevant subject headings (controlled vocabulary that is used to organize databases) were not available. This search, once duplicates had been removed, yielded 280 articles.

In the second stage, we hand searched the tables of contents of three journals where most reviewed articles were published from 2003–2007. These journals were the *Journal of Safety Research*, *Journal of Occupational and Environmental Hygiene*, and *American Journal of Industrial Medicine*. No additional relevant articles were identified during this stage.

The third stage was a hand search to identify and retrieve relevant references from the bibliographies of the articles already included in the review. This stage identified 20 additional articles of interest.

In the fourth stage, authors of eight preliminary studies (i.e., theses or conference abstracts) were contacted to find out if any peer-reviewed articles had resulted from their work on MSDSs. Of these, three were contacted successfully [Chung et al., 1999; Reilly et al., 2006; Smuts, 2004]; however, none of their preliminary work had resulted in peer-reviewed publications. Five other study authors could not be reached [Leibowitz, 1989; Lu and Moure-Eraso, 1993; Bailey, 1995; Wright, 1997; Conklin, 2003], and subsequent searches using their names on both PubMed and ISI Web of Science did not reveal any relevant publications.

The fifth stage involved a cited reference search on ISI Web of Science with all the citation databases selected (SCI-EXPANDED, SSCI, and A&HCI) and the default timespan selected (all years). This search resulted in 40 additional articles that cited previously identified articles in their reference list.

Inclusion and Exclusion Criteria

The initial search process was extremely broad since this topic area is multidisciplinary. Thus, a high proportion of articles were excluded from final review. The review was limited to empirical studies that were published in peer-reviewed scholarly journals; therefore, conference papers, commentaries, editorials, vignettes, case reports, theses and dissertations, and letters to the editor were excluded. Two authors (A.M.N. and C.H., who have expertise in epidemiology and health risk communication) read through the 340 abstracts to remove articles that did not address the research question. Many articles mentioned MSDSs, but did not address the research question; after these removals, 109 articles remained. Of the remaining articles, 66 articles were removed because they were not peer-reviewed, empirical studies, leaving 43 for a full article review.

Two authors (A.M.N. and C.H.) independently read the full text for the 43 relevant articles. At this point, a second set of exclusion criteria was applied: articles were excluded if they did not relate to the research questions of accuracy, completeness, comprehensibility, awareness, and use of MSDSs. Thus, articles concerning the legal use of MSDSs in workers' compensation appeal cases (1 article), studies on the topic of safety warning labels (18 articles), and studies evaluating the presence of MSDSs on the Internet (1 article) were excluded. In addition, it became apparent upon reading the full articles that they were not empirical, peer-reviewed studies. After this exclusion process, 24 articles met the final inclusion criteria.

Online Collaboration

The primary authors of this study, a team of two researchers, were not always located in the same physical space. The use of online tools such as RefWorks (a web-based bibliographic management software), a wiki, and a web-based word processor and spreadsheet were very practical for facilitating collaboration across distances. The information specialist collected and organized references using RefWorks, and documented search strategies and the review on a wiki. The two researchers abstracted data from the reviewed studies into a matrix hosted on an online spreadsheet, and all authors collaboratively wrote the literature review article using an online word processor.

Data Extraction

The following information was extracted from each study included in the final set: location, human populations (if applicable), aim(s), methodology, and important results. In addition, the articles were grouped into three main categories according to MSDS characteristics and use: accuracy and completeness, comprehensibility, and awareness and use. Because of the relative paucity of peer-reviewed literature on the topic of interest, the authors tended towards inclusiveness despite disparities in methodological quality. Methodological issues (e.g., sample size, replicable

methods, acceptable response rate in human subject research, etc.) were noted when relevant. Disagreements about study inclusion, data extraction, and categorization of articles were resolved by consensus.

RESULTS

Of the 43 full articles that were reviewed, 24 articles (published between 1992 and 2007) met the final inclusion criteria. The articles were divided into three categories according to MSDS characteristics and use. Six of the articles fell into more than one category. See Table I for a summary of results.

Accuracy and Completeness of MSDSs

Twelve articles assessed accuracy and completeness. There were two primary methodologies used to assess the accuracy and completeness of the MSDSs: textual analysis (n = 6) and chemical analysis (n = 7, one article used both methods). See Table II for a summary of methodologies and results.

Textual analysis

Six articles evaluated accuracy and completeness of MSDSs using some form of textual analysis [Winder and Turner, 1992; Paul and Kurtz, 1994; Kolp et al., 1995; Wright, 1998; Dalvie and Ehrlich, 1999; Frazier et al., 2001]. In most cases, expert reviewers (e.g., physicians, occupational physicians, industrial hygienists) assessed the contents of MSDSs against references from the literature, or against their own expert knowledge of the chemicals under consideration. The rigor and scope varied within the studies using textual analysis. The number of MSDSs reviewed in each article varied from 28 to almost 700. Some studies used a rating or coding system by which to compare each MSDS; one study compared each data sheet to a ''gold standard'' (i.e., compared each section of the sheet with sections in a complete and accurate sheet); while others simply performed a qualitative review of the data sheets.

Kolp et al. [1995] evaluated 150 randomly selected MSDSs prepared between 1986 (the date when the HCS was put into effect) and 1994 in Maryland, USA, for the accuracy and completeness of five areas of information. Each MSDS was reviewed by both an industrial hygienist and an occupational physician using a rating system informed by the scientific literature. The remainder of the textual analysis articles did not randomly select MSDSs for a general assessment, but looked at sheets for groups of products known to be hazardous, or examined MSDSs for chemicals known to cause specific health effects. A robust and rigorous example of this type of study is one that assessed the reproductive health hazard descriptions on 678 unique MSDSs gathered from worksites in Massachusetts, US [Paul and Kurtz, 1994]. The researchers analyzed the text of each MSDS against criteria set out in the HCS that dictate what information must be included on reproductive effects. They then ranked the quality of information as low, moderate, or high. Another study used a rigorous audit process to assess the quality of health information among a random sample of 61 American MSDSs for toluene diisocyanate (TDI), a workplace chemical that is well known to cause and exacerbate asthma [Frazier et al., 2001]. Two pairs of physicians conducted the audit.

The final three articles falling into the textual analysis category studied South African and Australian MSDSs. The first study suffered from a small sample size but used a rigorous method to audit ten MSDSs for isocyanates supplied in South Africa [Dalvie and Ehrlich, 1999]. The authors collected MSDSs from suppliers, and awarded points to each data sheet if it provided specific data in each section of the MSDS (e.g., health effects, exposure control measures, etc.). Each MSDS was then compared to a ''gold standard'' sheet, which contained full details under all the required headings. The second study compiled an inventory of 169 solvent thinners used in 46 spray-painter workshops in Australia [Winder and Ng, 1995]. Twenty different thinner products containing 83 disclosed chemical solvents were identified. This inventory was collected as part of a larger study, and the authors do not document in detail the methods used to evaluate MSDSs. The third study, also conducted in Australia [Wright, 1998] used an audit process comprised of a checklist and comparison against Australian safety guidelines to evaluate MSDSs found in 34 printing shops. This study also utilized chemical analysis to evaluate accuracy and completeness of selected MSDSs (see below).

Articles that used textual analysis found that health effects data was missing in 50–60% of MSDSs [Kolp et al., 1995; Dalvie and Ehrlich, 1999; Frazier et al., 2001]. Information on chronic health effects was more likely to be absent than information on acute effects [Paul and Kurtz, 1994; Kolp et al., 1995]. Many MSDSs also lacked information on personal protective equipment and occupational exposure limits. Specific recommendations from these articles include developing better guidelines for MSDS preparation to ensure that the intent of workplace right-to-know legislation is realized, and requiring suppliers to list the exact makeup of chemicals on MSDSs rather than listing concentrations as a range to protect proprietary formulations [Winder and Ng, 1995]. Some of the studies suggest that chemical suppliers may be violating occupational health and safety regulations or guidelines by providing incomplete or inaccurate MSDSs with their products. The possible impact of legislation [Paul and Kurtz, 1994] and scientific research

TABLE I. Summary of Results

References	Country	Study population (human)	Chemical, industry or condition	Accuracy and completeness	Comprehensibility	Awareness and use
Winder and Turner [1992]	Australia	46 workshops	Spray-paint			X
Kolp et al. [1993]	USA	100 unionized workers	Various industries		X	X
Kanerva et al. [1994]	Finland	N/A	Dental bonding. acrylates	X		
Paul and Kurtz, 1994	USA	N/A	Lead and ethylene glycol ethers	X		
Saari et al. [1994]	Canada	80 industrial plants	Various industries			X
Kolp et al. [1995]	USA	N/A	N/A	X		
Winder and Ng [1995]	Australia	N/A	Solvent thinners	X		
Janicak [1996]	USA	283 organizations	Various industries			X
Henriks-Eckerman and Kanerva [1997]	Finland	N/A	Acrylic resins	X		
Kanerva et al. [1997]	Finland	N/A	Dental bonding. acrylates	X		
Pirkis et al. [1997]	Australia	135 pig farms	Antibiotics			X
Hu et al. [1998]	Taiwan	1,003 workers	Manufacturing industries			X
Wright [1998]	Australia	34 workplaces	Printing industry	X		X
Chung et al. [1999]	UK	N/A	Gas metal arc welding and stainless steel	X		
Dalvie and Ehrlich [1999]	South Africa	N/A	Isocyanates	X		
Phillips et al. [1999]	USA	160 unionized workers	Laboratory setting		X	X
Welsh et al. [2000]	Canada	N/A	Synthetic lubricant, detergent concentrate, epoxy reducer	X		
Frazier et al. [2001]	USA	N/A	Toluene diisocyanate	X		
Ruttenberg et al. [2001]	New Zealand	151 people	Boat-building			X
Seki et al. [2001]	Japan	422 workplaces	Various industries		X	X
Sadhra et al. [2002]	UK	84 workers	Electroplating		X	X
Niewohner et al. [2004]	UK	Dry cleaning and electrical businesses	Dry cleaning and soldering		X	X
Zhu et al. [2005]	Canada	N/A	2-Butoxyethanol	X		
Smith-Jackson and Wogalter [2007]	USA	90 people	N/A		X	

[Frazier et al., 2001] was assessed by some studies, which found a modest improvement in the completeness of MSDSs after the promulgation of legislation or the publication of scientific evidence concerning the substances (although many MSDSs were not updated after the publication of scientific evidence). Only one study [Paul and Kurtz, 1994] examined the accuracy of MSDSs in the context of company size. The study found that mid-sized worksites (100–499 employees) had the most informative MSDSs, followed by large and then small worksites.

Chemical analysis

Seven articles used chemical analysis to test the accuracy and completeness of the chemical information

TABLE II. MSDS Accuracy and Completeness (n = 12)

References	Country	Chemical type	Number	Methods	Main results
Kanerva et al. [1994]	Finland	Dentin bonding compounds (acrylates)	5 bonding agents	Chemical analysis using GC/MS compared to the information given on MSDSs	64% of chemicals uncovered during the analyses were undeclared on the MSDSs
Paul and Kurtz [1994]	USA	Lead and ethylene glycol ethers	687 MSDSs	Textual review of reproductive health effects information contained on MSDSs	Over 60% of the MSDSs made no mention of reproductive system effects. Of those that did, male reproductive effects were most common
Winder and Ng [1995]	Australia	Solvent thinners	20 MSDSs	Textual review of contents of MSDSs	10 of the thinners were mixtures containing unspecific solvents or proprietary ingredients. Only 8 disclosed all ingredients
Kolp et al. [1995]	USA	Various	150 MSDSs	Textual review of MSDSs for: chemical identification of hazardous ingredients; reported health effects; first aid procedures; recommended personal protective equipment (PPE); and exposure level regulations	89% provided identifiable chemical names, 37% had accurate health effects data (with chronic health information the most inaccurate), 76% provided adequate first-aid information, 47% had an accurate rating for PPE or a correct listing for applicable occupational exposure limits
Henriks-Eckerman and Kanerva [1997]	Finland	Acrylic resins	10 products	Chemical analysis using GC/MS compared to the information given on MSDSs	All products analyzed contained compounds that were not declared on the MSDS, most of which were contact sensitizers
Kanerva et al. [1997]	Finland	Dental acrylics and plastics	52 products	Chemical analysis using GC/MS compared to the information given on MSDSs	All substances contained undeclared chemicals, 37% of dental acrylics contained undeclared acrylics, and acrylic glues contained high concentrations of HEMA and isobornyl acrylate
Wright [1998]	Australia	Solvents in the printing industry	10 products	Chemical and textual analysis	30% of the MSDSs contained major errors in the ingredient information and undeclared chemicals
Chung et al. [1999]	UK	Welding material	5 types of steel and aluminum	Chemical analysis using ICP/MS	Fume compositions were found to differ from the manufacturers' MSDSs descriptions

TABLE II. (*Continued*)

References	Country	Chemical type	Number	Methods	Main results
Dalvie and Ehrlich [1999]	South Africa	Isocyanates	10 MSDSs	Textual analysis comparing MSDSs to a "gold standard" MSDS	MSDSs contained 50% (range 29–67%) of data from the gold standard. Health hazards (40%), exposure control data (46%), stability and reactivity (44%) and transportation information (24%) were most poorly represented
Welsh et al. [2000]	Canada	A lubricant, a detergent and an epoxy reducer and cleaner	One sample of each product	Chemical analysis using GC/MS infrared spectrophotometry, X-ray fluorescence and wet methods	MSDSs for these products did not accurately reflect the chemicals or the concentration found in the samples
Frazier et al. [2001]	USA	Toluene diisocyanate	61 MSDSs from 30 manufacturers, randomly selected	Textual analysis by physicians to review the quality of health information	Only 50% of manufacturers listed asthma as a potential health effect. One manufacturer provided no respiratory health information. Higher TDI concentrations were associated with better health effects information
Zhu et al. [2005]	Canada	2-Butoxyethanol	20 consumer products	Chemical analysis	75% of the products' MSDS accurately reflected contents. Of the 25% that did not, there were some significant variations in product composition

shown on the MSDS label [Kanerva et al., 1994, 1997; Henriks-Eckerman and Kanerva, 1997; Wright, 1998; Chung et al., 1999; Welsh et al., 2000; Zhu et al., 2005]. These studies used various methodologies (primarily gas chromatography mass spectrometry but also infrared spectrophotometry and X-ray fluorescence) to assess composition and concentration of substances and to compare the results of their own analyses to those listed on the MSDS. These studies were conducted on products such as acrylics, metals, and solvents.

Most of the articles [Kanerva et al., 1994, 1997; Henriks-Eckerman and Kanerva, 1997; Wright, 1998; Welsh et al., 2000] found that between 30% and 100% of the products analyzed contained undeclared chemicals. In addition, chemicals were found at higher levels than what was listed on the MSDS [Kanerva et al., 1994; Chung et al., 1999; Welsh et al., 2000; Zhu et al., 2005]. One article [Welsh et al., 2000] notes that presenting chemical substances as ranges is problematic, since there are often significant differences in toxicity between the low and high end of the stated range. The articles found that workers may be exposed to allergens, irritants, carcinogens or other health hazards without being aware of them. The studies employing chemical analysis were of mixed methodological quality: some provided detailed and comprehensive analytic methodologies, while others did not describe quality assurance or quality control processes.

Comprehensibility of MSDSs

Four of the articles found in this literature search [Kolp et al., 1993; Phillips et al., 1999; Seki et al., 2001; Smith-Jackson and Wogalter, 2007] focused on the issue of comprehensibility of MSDSs, and two [Sadhra et al., 2002; Niewohner et al., 2004] included questions about comprehensibility in interviews with workers on the topic of chemical risks and MSDS format, respectively. Researchers

TABLE III. Comprehensibility (n = 6)

References	Country	Number of participants	Industry	Methods	Main results
Kolp et al. [1993]	USA	91 workers	Manufacturing industries	"Open-book" type test with four groups, 3 used MSDSs, 1 used ICSC	30% of the MSDS information was not comprehensible by the study population
Phillips et al. [1999]	USA	160 workers	Large laboratory	"Open book type test" with four groups, 2 MSDS, the ICSC and a control group	30–35% of the information was not comprehensible by the study population. Format did not affect comprehensibility
Seki et al. [2001]	Japan	422 workplaces	Manufacturing and non-manufacturing industries	Postal questionnaire with comprehensibility scale for words common on MSDSs	Some terms were well understood, however technical terms were understood by fewer than 50% of respondents
Sadhra et al. [2002]	UK	84 workers	Chromium plating industries	Postal questionnaires	32% of platers stated that MSDSs were too complex for them to understand
Niewohner et al. [2004]	UK	Not stated	Dry cleaning and electrical/electronic businesses	Postal questionnaires, semi-structured interviews and focus groups	MSDS design and language were found to be key inhibitors of comprehension
Smith-Jackson and Wogalter [2007]	USA	90 people: 30 firefighters, 30 students and 30 community members	Various	Interviews, participants were asked to organize MSDS information in a manner that made most sense to them	Health information was found to be of greatest priority and should be placed more prominently on MSDSs

used different methods to explore issues of comprehensibility, including test/retest approaches, one-on-one interviews and self-administered questionnaires. See Table III for a summary of methodologies and results.

Two US studies used open-book test formats to explore workers' understandings of specific MSDSs [Kolp et al., 1993; Phillips et al., 1999]. Both of these studies used unionized employees (from different trades) as the test groups and both tested more than one safety data sheet format. Both studies used the International Chemical Safety Card (ICSC) format—a card that summarizes essential health and safety information on chemicals for their use at the ''shop floor'' level by workers and employers—as a comparison to the OSHA MSDS format. The results of both studies found that workers had difficulties understanding the MSDSs (30% in Kolp et al. [1993], and 30–35% in Phillips et al. [1999]). Kolp et al. [1993] suggest that comprehension was higher for straightforward sections such as first aid directions, but lower for more technical sections describing, for example, what body systems were affected by hazardous substances. There was also confusion regarding chronic versus acute health effects (particularly related to cancer), and both articles noted that it was difficult for respondents to determine whether a chemical was a carcinogen. Both articles concluded that the format of the MSDSs led to confusion, although the ICSC format scored higher than the OSHA format.

Format issues were also explored by three studies using a mental models approach that consisted of one-on-one interviews [Morgan, 2001]: one in detail [Smith-Jackson and Wogalter, 2007], one as a component of a larger survey [Sadhra et al., 2002], and one peripherally [Niewohner et al., 2004]. The first study used a range of community- and workplace-based subjects and asked them to put the various sections of an MSDS (e.g., composition, hazards identification, handling and storage, etc.) in an order that made the most sense to them [Smith-Jackson and Wogalter, 2007]. Subjects were given between 8 and 12 sections to represent a range of MSDS formats. It was recommended that the health effects data be given the greatest priority and be placed in a more prominent position; physical reactivity data was given less priority. The second study [Sadhra et al., 2002]

asked experts and workers whether MSDSs were too complex for workers to understand: 92% of experts thought that they were, while the majority of workers thought that MSDSs were written at a level appropriate for workers. The third study focused on developing an alternative format to current MSDS type communications. This study also determined that current formats impeded comprehensibility, in part because they provided too much information for people to process [Niewohner et al., 2004]. One study on comprehensibility was conducted across a range of large and small workplaces in Japan [Seki et al., 2001]. This research asked respondents whether eight words commonly used on MSDSs were understandable on a scale of 0–8. Some words were well understood (i.e., gas mask, carcinogenicity) while other more technical terms, such as CAS number, sensitization and mutagenicity, were understood by fewer than half of the respondents. Respondents in other studies also suggested that the technical nature of terms made MSDSs more difficult to understand [Kolp et al., 1993; Niewohner et al., 2004]. Few studies examined workplace- or worker-specific factors that affected MSDS comprehension. Workplace size may play a role: one study noted that workers from larger, unionized workplaces showed somewhat better results than those from smaller companies [Seki et al., 2001]. In addition, a study that recruited participants from one large, unionized workplace [Phillips et al., 1999] had more positive comprehension results than did a study that drew from a spectrum of different sized, unionized workplaces [Kolp et al., 1993].

The results comparing education and training to MSDS comprehension were mixed. One study [Phillips et al., 1999] suggested that training was important, but education was not. Another [Kolp et al., 1993] found a relationship between education and comprehension but not between training and comprehension. It is possible that the differences in these results again reflect the type of workplaces that the respondents were drawn from.

Awareness and Use of MSDSs

Twelve articles assessed worker awareness and use of MSDSs. Five of these [Kolp et al., 1993; Phillips et al., 1999; Seki et al., 2001; Sadhra et al., 2002; Niewohner et al., 2004] also examined comprehensibility and one [Wright, 1998] also examined accuracy and completeness. Four of these studies were from New Zealand and Australia [Winder and Turner, 1992; Pirkis et al., 1997; Wright, 1998; Ruttenberg et al., 2001], three from the US [Kolp et al., 1993; Janicak, 1996; Phillips et al., 1999], two from the UK [Sadhra et al., 2002; Niewohner et al., 2004], and one each from Japan [Seki et al., 2001], Taiwan [Hu et al., 1998], and Canada [Saari et al., 1994]. MSDS use was studied predominantly in industrial workplaces, although one study in Australia looked at MSDS use in farming. See Table IV for a summary of methodologies and results.

MSDS awareness and use varied by country, reflecting different regulations governing MSDS use around the world. The Japanese study found that 60% of workplaces did not have MSDSs, although the study was conducted just prior to regulations enforcing the use of MSDSs in Japan [Seki et al., 2001]. The Taiwanese study found very low levels of awareness, with only one-third of surveyed employers even being aware of MSDSs. Taiwan introduced MSDSs in 1992, and their use was not well enforced [Hu et al., 1998]. In Australia, MSDS regulations were established in 1991 and regulated under National Occupational Health & Safety Regulations and Codes of Practice (given legal effect under State legislation by 1995 and since repealed) (International Occupational Safety and Health Information Centre 2007). A study of spray-paint workshops found that none of the workshops had MSDSs [Winder and Turner, 1992], while a study of Australian pig feed handlers exposed to antibiotics found very low levels of awareness of MSDSs [Pirkis et al., 1997]. A study of Australian printing shops indicated that 47% of workplaces did not keep MSDSs where workers could easily access them [Wright, 1998]. Little evidence of MSDS use was found in a 2001 audit of the New Zealand boat building industry even though MSDS regulation has been in effect since 1992 in that country [Ruttenberg et al., 2001]. Research done on the UK electroplating industry revealed differences between worker and expert perceptions of MSDS awareness and use: 23% of experts believed that workers were required to read OHS information, while 77% of workers reported that they were required to read this information. In addition, the study reported that 40% of workers used MSDSs often, while 19% had never used one [Sadhra et al., 2002]. The US research does indicate greater awareness and use patterns. Two studies from that country found that between 60% and 70% of employees in unionized workplaces knew about/used MSDSs [Kolp et al., 1993; Phillips et al., 1999]. MSDSs have been mandatory in the US since 1986.

The factors associated with less than optimal awareness and use of MSDSs were varied and included issues such as awareness of regulations, training and workplace size, and type of industry. One study examined 59 American organizations that had been cited for Health Communication Standard violations and determined that corporate understanding of the regulations had an important influence on violations [Janicak, 1996]. Of the cited organizations, 40% indicated that they did not know they were in violation of the MSDS regulations; another 46% thought that they were in compliance. This study suggests that there is a gap between what employers believe they must do to comply and what regulatory bodies such as OSHA expect.

Worker education and training, required by the same regulatory frameworks that stipulate the use of MSDSs, may

TABLE IV. MSDS Awareness and Use (n = 12)

References	Country	Chemical type	Number of participants	Methods	Main results
Winder and Turner [1992]	Australia	Solvents in automotive paints	64 workers in 46 spray-paint workshops	Interviews	MSDSs were not found in any of the workshops visited. Some workers recalled MSDS from schooling, but many others did not know what an MSDS was
Kolp et al. [1993]	USA	Various	About 100 unionized workers in manufacturing industries	Open-book test	Over 80% of participants indicated that they had seen an MSDS before. 45% recalled having seen an MSDS as part of any OHS training activity
Saari et al. [1994]	Canada	Various	80 manufacturing (transportation equipment and machines) plants	As part of a larger study, a checklist was developed to assess the quality of MSDSs. Scores were developed to review quality of MSDSs by 5 criteria	Companies were stratified by the type of OHS training they received: S1 (trained in-house trainers), S2 (external trainers), S3 (combined in-house/ external), S4 (some employees externally trained), S5 (none of the above, other training). S1, S3, S5 were above average in terms of having MSDS, having them be accessible and organized, and having the most appropriate MSDSs. MSDS use was better in companies that devoted resources to OHS and in those who used newer technologies
Janicak [1996]	US	Various	283 organizations that were cited for hazard communication standard (HCS) violations	Survey to respondents that included a 4-question section on compliance to MSDSs	Of the HCS violations, 32% pertained to the MSDS section. Of the reasons for these failures 46.7% felt they were in compliance with HCS regulations, 13.3% were aware of regulations but did not think that they applied, and 40% did not know about the requirement
Hu et al. [1998]	Taiwan	Various (manufacturing industry)	1,003 employers	Employer interview	Only 33% of employers knew what MSDSs were
Wright [1998]	Australia	Solvents in the printing industry	34 worksites in the printing industry	Employer survey	Copies of MSDSs were not easily accessible by workers in almost half of the workplaces (47%)
Pirkis et al. [1997]	Australia	Antibiotics in pig feed	135 representatives from piggeries	Phone interviews	Only 18% of respondents were aware of MSDSs, and only half of those had ever seen one

TABLE IV. (*Continued*)

References	Country	Chemical type	Number of participants	Methods	Main results
Phillips et al. [1999]	USA	Various	160 union workers employed in laboratory	Inventory questionnaire and quantitative testing	33% of those tested reported that they did not usually use MSDSs, even though they recognized that their work was hazardous. 70% indicated they had requested and received MSDS information with 90% getting a hard copy. 60% reported rarely to almost never using MSDSs
Ruttenberg et al. [2001]	New Zealand	Hazards associated with boat building (primarily solvents and epoxy resins)	151 people from 120 boat building firms	Nurse and inspector-administered audit, including questionnaire survey and observational data	Observation found little use of MSDSs as a source of knowledge about toxicity of chemicals used by workers
Seki et al. [2001]	Japan	Various	422 workplaces using hazardous chemicals	Postal questionnaires	59.4% of workplace MSDSs were not posted or kept. This study also addressed accuracy and completeness
Sadhra et al. [2002]	UK	Chromic acid and other chemicals used in chrome plating	21 interviews and 84 questionnaires	Interviews and questionnaires with workers and experts	19% of workers had never used an MSDS, while 40% said they used them often. 77% of workers said that their company makes sure they read written safety information (including MSDSs)
Niewohner et al. [2004]	UK	Perchloroethylene and rosin-based solder flux	52 dry cleaning and 31 electronics businesses (only 17% and 12% responded)	Semi-structured interviews and discussion groups	85% of drycleaners and 41% of solderers reported that MSDSs are available at their work site

play an important role in awareness and use. Two studies of unionized workplaces, both of which noted higher awareness levels, found that workers had learned about MSDSs during training sessions [Kolp et al., 1993; Phillips et al., 1999]. One study conducted in Quebec industrial plants also examined the impacts of different types of training on MSDS use [Saari et al., 1994]. This research indicated that ''train the trainer'' programs were more successful than worker-directed training for improving MSDS use. This study also noted that the most successful uses of MSDSs were found in larger companies with more established occupational health and safety traditions.

Awareness and use of MSDSs may also be affected by industry or company type. One study found that MSDS awareness and use was much better in drycleaners than in electronic shops [Niewohner et al., 2004]. Quebec-based research determined that MSDS programs were better in companies where new technologies were being used [Saari et al., 1994]. Such a difference may be due to greater degrees of MSDS promotion in certain sectors or the role that suppliers play in providing MSDSs. One study hypothesized that new technologies may come with paperwork that needs to be organized, and this paperwork would include MSDS information [Saari et al., 1994]. Unfortunately, these articles did not explore the differences in MSDS use across industrial sectors in detail.

The results of this section need to be tempered by the fact that many of the studies that examined MSDS awareness and use using postal surveys suffered from poor response rates. For example, one study had only a 21% response rate [Janicak, 1996] and the postal survey that was part of one mental models study collected responses from 17% of

the drycleaners and 12% of the electrical shops [Niewohner et al., 2004]. Such response rates limit the potential generalizability of the study results.

DISCUSSION

The evidence presented in this review points to a number of serious problems in the content and use of MSDSs in workplaces worldwide. Despite the fact that these studies varied in methodology and spanned a period of more than 15 years, a number of common themes emerged regarding inaccuracies, incompleteness, incomprehensibility and overall low use. None of the studies was uniformly positive in its assessment of MSDSs.

It is clear from the peer-reviewed literature that both workers and health care providers value MSDSs for the information that they provide on health effects data, in particular, and that having such information available is important. When asked, workers indicated that they would prefer health effects data to be presented at the very top of an MSDS sheet as opposed to having it listed after information about the chemical composition and company information [Smith-Jackson and Wogalter, 1999]. However, the literature suggests that simply giving more prominence to health effects data on MSDSs may not be enough, since a number of studies found the data provided to be suboptimal. As this review indicates, many MSDSs do not have complete, accurate, or well organized information about health effects [Paul and Kurtz, 1994; Kolp et al., 1995; Dalvie and Ehrlich, 1999; Frazier et al., 2001], a situation that poses clear problems both for workers who deal with potentially hazardous substances in their workplaces, and for health care providers who are charged with responding to workplace-related health problems. In addition, a number of studies found that health effects information is often written in a complex, jardon-laden style that is difficult for workers to understand [Kolp et al., 1993; Phillips et al., 1999; Seki et al., 2001; Niewohner et al., 2004].

By employing methods of chemical analysis to verify the composition and concentration of materials against information on the MSDS, a number of articles in this review show that data sheets often present inaccurate and/or incomplete information about potential health hazards [Kanerva et al., 1994, 1997; Henriks-Eckerman and Kanerva, 1997; Welsh et al., 2000]. Because many products contain undeclared chemicals, or chemicals at a higher level than is declared on the MSDS, even workers who can access, read, and understand the sheet may be inadvertently exposed to health hazards.

During the collection of data for this review, a large volume of gray literature, case reports, and editorial positions was uncovered. Much of this non-peer-reviewed work echoes many of the themes highlighted by the reviewed empirical studies. In particular, this literature asserts concern about placement and content of health effects information. A number of authors [Tompkins, 1992; Sattler et al., 1997] also suggest that much of the information used on the data sheets is too technical, too complicated and too poorly organized to be useful to workers. Other articles have found fault with the complexity of language used in the average MSDS, noting that the majority of workers have not had enough education to cope with these highly technical documents [Tompkins, 1992; Kahan et al., 1999]. Health care professionals have also critiqued the utility of MSDSs as diagnostic tools, complaining that they are incomplete [Lerman and Kipen, 1990; Beach, 2002; Bernstein, 2002; Packham, 2002], or that they often lack important data on chronic health effects [Bunn, 1985; Mitchell, 2001]. Although outside of the categories under review in this article, physicians have published many case reports detailing their difficulties in diagnosing patients suffering from work-related health problems due to incomplete or inadequate MSDSs [Kanerva et al., 1994; Nixon, 1997; Corazza et al., 2001; Koutis and Freeman, 2001; Cahill and Nixon, 2005]. A 1994 report by the Occupational Safety and Health Branch of Human Resources Development Canada found significant problems through a chemical analysis of selected MSDSs. This report provides a detailed and comprehensive set of recommendations on how MSDSs should be improved [Karpinski, 1994].

By comparing the results of studies conducted in different parts of the world, it appears that legislation requiring workplaces to make MSDSs available is effective. In the US, where MSDSs have been legislated since 1986, two studies found that the majority of workers used (or at least knew about) MSDSs [Kolp et al., 1993; Phillips et al., 1999]. In contrast, studies conducted in Japan [Seki et al., 2001], Australia [Winder and Turner, 1992; Winder and Ng, 1995; Pirkis et al., 1997; Wright, 1998], New Zealand [Ruttenberg et al., 2001], and Taiwan [Hu et al., 1998] found low to very low awareness and use of MSDSs among a variety of workers/employers. These countries did not legislate the use of MSDSs until the late 1990s. These findings suggest that the effects of legislation take some time to trickle down to the workplace. However, the research data on this topic is small, and it is difficult to pinpoint the specific programs or policies (e.g., training, enforcement, etc.) that improved awareness and use.

Some of the studies suggest that steps taken by governing bodies to improve the format of hazard communication materials may be having a positive effect. Two studies [Kolp et al., 1993; Phillips et al., 1999] found that workers deemed the ICSC format easier to understand than OSHA's standard 8-part MSDS. ICSCs have been designed explicitly for workers at the shop-floor level, and consist of a series of standard risk phrases. They focus on summarizing health and safety information collected, verified and peer reviewed by internationally recognized experts, and they take

into account advice from manufacturers and poison control centers. They are not meant to replace MSDSs, but to be distributed in concert with the more complex document. The intent of having two formats is to increase the modalities in which hazard communication is delivered: management can use the MSDS for training and administrative (including legal) purposes, while workers can consult ICSCs to get important information relevant to their immediate workplace needs (US Center for Disease Control, 2008). Currently, ICSCs are being produced by the International Programme on Chemical Safety (IPCS), a joint activity of the United Nations Environment Programme (UNEP), the International Labour Office (ILO), and the World Health Organization (WHO).

The European Commission is now distributing the ICSCs, and versions in languages other than English are being made available through national authorities all over the world. National authorities can customize the cards in order to provide explanations and information specific to the regulatory status of the chemical in that country. NIOSH has produced US-specific cards, which have been modified to include Occupational Safety and Health Administration Permissible Exposure Limits (OSHA PELs), National Institute for Occupational Safety and Health Recommended Exposure Limits (NIOSH RELs), Immediately Dangerous to Life and Health values (IDLHs), and Links to the Appendices in the NIOSH Pocket Guide to Chemical Hazards. The IPCS also stresses that even with the provision of ICSCs, worker training is still an integral component of hazard communication. As ICSCs are more widely distributed in workplaces worldwide, more research on their acceptability and comprehensibility by workers and employers would be welcome. At a 1995 OSHA meeting on the HCS, a number of small businesses stated that they wanted a shorter, easy-to-read MSDS, but they did not want to have to deal with an additional document besides the already-existing MSDS [National Advisory Committee on Occupational Safety and Health 1996]. Another limitation of the ICSCs is that they are only developed for pure substances, and not for the chemical mixtures that are common fixtures of workplaces worldwide.

The articles reviewed as part of this study provide mixed evidence for the effectiveness of training on awareness and comprehensibility of MSDSs by workers. Two of the 24 articles found that workers who had been provided with occupational health and safety training were more likely to be aware of MSDSs and their purpose [Kolp et al., 1993; Phillips et al., 1999], although only one [Phillips et al., 1999] found a positive association between training and ease of MSDS comprehension among workers. The study that compared the success of various types of worker training programs suggests that training programs may need to be tailored to the needs of different workplaces, based on factors such as workplace size, type of industry, education level of workers, etc. [Seki et al., 2001]. A number of studies note that larger workplaces tend to have more established occupational health and safety training programs, and thus their workers tend to have a better understanding of MSDSs [Saari et al., 1994; Phillips et al., 1999; Seki et al., 2001], and access to more accurate MSDSs [Paul and Kurtz, 1994]. The type of workplace (i.e., industry vs. farming) and the organization of workers (i.e., unionized vs. non-unionized) may also have an impact on workers' understanding, awareness, and use of MSDSs. The evidence suggests that less strictly regulated industries employing workers who are not formally organized may not provide enough high-quality training to equip their workers with a good understanding of the role and content of MSDSs [Pirkis et al., 1997; Niewohner et al., 2004]. However, most of the articles included in this review do not investigate training issues specifically, or provide any conclusive results. Although beyond the scope of this review, a number of studies have evaluated the effectiveness of different types of worker health and safety training [Mukherjee et al., 2000]. These studies provide general recommendations about which types of training initiatives are more likely to be successful.

Strengths and Limitations

This study has several strengths. First, two people (with expertise in epidemiology and health communication) reviewed the articles independently. A third person with expertise in analytical chemistry reviewed the studies that used analytic methods in their analysis. Second, a trained library information specialist undertook a very broad and comprehensive literature search. The search strategy included multiple databases, many of a multidisciplinary nature, to maximize the possibility of retrieving important studies. By selecting the search terms ''material safety data sheet(s)'' and not combining them with any subject headings, the search strategy uncovered a high number of articles (many of which did not meet the exclusion criteria).

Several limitations in this review should be considered. First, it is possible that despite the rigorous search strategy, some articles were missed due to being indexed in the databases without the exact phrase ''material safety data sheet'' in the searchable fields (e.g., when the abstract was not available for an article or when another term was used to refer to MSDS in the article). Subsequent stages of the literature search were designed to minimize the risk of overlooking important articles. Second, this study included only articles written in English. Although some articles presented study findings from non-English speaking countries, it is possible that studies from other countries were missed. Third, some studies lacked full descriptions of methods and outcomes, limiting the reviewers' ability to describe them fully, or to

generalize based on their results. Finally, the research questions, methodologies, and approaches used in these studies were variable, precluding a meta-analytic approach.

CONCLUSIONS

While MSDSs are still considered a mainstay of worker health and safety, this research suggests that there are significant problems with their accuracy and completeness. As such, they may be failing workers as a prevention tool. Beyond this, many workers are unable to understand MSDSs due to the complex language used to describe hazards and the way in which MSDSs are laid out. These issues, coupled with a lack of training and/or poorly enforced MSDS regulations, may contribute to low use and awareness of MSDSs by workers in various industries. These critiques of MSDSs are not new and have existed in the published literature since 1992. These critiques also appear to stand up across different industries, in different countries and for different chemical exposures.

Taken together, these factors indicate a need for governments and regulatory bodies to seriously reassess the ways in which MSDSs are written, monitored and regulated, and to consider the evidence base in new initiatives such as the Globally Harmonized System. In particular, the findings on comprehensibility suggest that initiatives to produce the simpler, shop-floor-oriented ICSCs that highlight health information may have significant value; the evidence on MSDS completeness and accuracy suggests a need for greater monitoring and compliance efforts; and the poor quality of writing found in MSDSs suggests a potential role for training and certification of MSDS writers. As international efforts to harmonize chemical hazard communication systems proceed through the Globally Harmonized System, it is to be hoped that the evidence concerning their effectiveness in practice is considered alongside other concerns. While there is clearly motivation among regulatory bodies to improve MSDSs [OSHA, 2004; National Office of the Workplace Hazardous Materials Information System 2007], there is a need to commit resources for research into which formats and standards work in practice.

Occupational health and safety professionals should be aware that current MSDSs often suffer from significant problems. We advocate more research on training's role in hazard communication systems, and we urge occupational health and safety professionals to investigate new initiatives such as the ICSC. These initiatives may provide an effective complement to MSDSs in helping workers understand important health and toxicity information. The goal of MSDSs will not be achieved unless those who work with chemicals have access to, and understand fully, the information they need to protect themselves on the job.

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