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Do occupational safety and health professionals improve the occupational safety and health performance of an organisation?

Borys, D.1

Abstract
A review of the literature was undertaken to assess the evidence that the occupational safety and health professional improves the occupational safety and health performance of an organisation. Also assessed were the knowledge, skills and attributes of the occupational safety and health professional that might be linked with their effectiveness and that may vary depending on industry and organisational size.

Of the 58 articles retrieved during the literature search only two (2) studies were classified at level one on a hierarchy of evidence developed for the research. Both studies were conducted in the construction industry and both studies demonstrated the value of employing a suitably qualified in-house occupational safety and health professional, measured by reductions in fatality and injury rates. Two themes that emerged from the literature and which warrant further research are the importance of the line of report and the personal attributes of the occupational safety and health professional. It is suggested that knowledge without power and the ability to influence senior decision makers may negatively impact the occupational safety and health professional’s ability to add value.

While there is evidence that the occupational safety and health professional has an important role to play in reducing fatality and injury rates, missing from the evidence is the role they play in reducing the rates of disease and ill-health. There is also a lack of evidence for the value proposition for the occupational safety and health professional in high risk industries other than construction.

Introduction
There has been a long-standing interest in the value of the occupational safety and health professional (OSHP) (see for example Adams, 2000; Greer, 2001 & Lawrence, 2008). Economic factors are placing OSHPs today under increasing pressure to demonstrate their relevance and value. Professional bodies, in particular the American Society of Safety Engineers (ASSE), have responded to this challenge through a structured campaign to demonstrate the value proposition for the OSHP (Lawrence, 2008). Reflecting this trend, a recent article by Seabrook (2014) continues the call for OSHPs to demonstrate safety’s business value in delivering sustainable and profitable organisations. In a similar vein, Curtis (2014) questions if OSHPs are able to explain to top managers how safety practices contribute to the “bottom-line.”

A review the literature was undertaken in an effort to identify the current evidence, and the strength of that evidence, in support of the value proposition for the OSHP. The literature review addressed the following research questions:

1. What is the evidence that the OSHP improves the OSH performance of an organisation?
2. What knowledge, skills and attributes of the OSHP might be linked with the effectiveness of the OSHP?
3. Does the impact of the OSHP vary depending on industry and organisation size?

Methodology
An exhaustive search of the peer-reviewed and grey literature was undertaken using 36 combinations (search strings) of search terms within 12 databases, using EBSCOhost as the major host database.
The databases provided access to a broad range of journals in discipline areas related to safety including organisational studies, management studies, psychology and sociology, as well as all safety science journals including Safety Science, The Journal of Safety Research, Accident Analysis and Prevention and Professional Safety. A search of dedicated safety science databases including NIOSHTIC and HSELINE did not find articles beyond those found using EBSCOhost as the host database.

The database search was complemented with a more general search using Google. A total of 58 articles were retrieved, read, classified for relevance and categorised according to themes. The strength of the articles was classified according to a four-tier hierarchy of evidence designed specifically for this research and informed by other hierarchies of evidence (Institute for Work and Health, 2006):

1. Studies with strong evidence of direct value (n=2).
2. Studies with moderate evidence of direct value but where the evidence is moderated by other variables (n=16)
3. Studies with moderate evidence of inferred value but where the evidence is moderated by other variables (n=6)
4. Studies with weak evidence of direct value and expert opinion (n=34).

Results

Studies with strong evidence of direct value

Only two studies (Cameron, Hare & Duff, 2007 & Rebbitt, 2012) have investigated if there is a direct relationship between OSHPs and value, where value is measured by lower injury rates (Cameron et al. 2007) and lower fatality rates (Rebbitt, 2012). Both studies were conducted in the construction industry.

Cameron et al. (2007) combined quantity measures (how many OSHPs) with quality measures (OSHP experience and qualifications) to develop a questionnaire sent to 101 construction companies employing 660 OHSPs. Safety performance was measured using the reportable accident frequency rate (AFR) and accident costs (Cameron et al., 2007).

This study found statistically significant lower AFRs were associated with organisations that employed an in-house OSHP, having an AFR 60% lower than those using only external consultants. Furthermore, construction companies that gave their OSHP management authority had an AFR that was 60% lower than those where the OSHP gave advice only. Authority is associated with line of report to senior management (Cameron et al. 2007). The OSH practitioner(s) with full authority held a senior management position in the organisation which the authors suggest increases the influence and places the OHSP in a stronger position to voice concerns and have their recommendations implemented. The study also found a relationship between the functions (role and tasks) of the OSHP and OSH performance. For example, AFRs were 60% lower in construction companies where the OSHP vetted sub-contractors, compared to those construction companies where the OSHP did not vet subcontractors.

Based on their findings, Cameron et al. recommend that construction companies with at least a £4 million turnover should invest in an experienced and qualified OSHP. For companies with a turnover of £35 million or more, the investment in OSHPs should represent at least 0.1 to 0.2 percent of turnover. They caution, however, that continuing to increase the number of OSHPs indefinitely will not lead to lower accident rates, with the savings better spent on other strategies to improve OSH.

Rebbitt (2012) investigated the value proposition for the OSHP by comparing the number of OSHPs with fatality rates in the US, UK and Canadian construction industry. He confined the measure of OSH performance to fatality rates due to the lack of reliability inherent in measures of injury frequency rates.

Using linear regression analysis Rebbitt found a strong correlation between the density of safety professionals and a lower the fatality rate. Conversely, Rebbitt found no such correlation with the number of safety practitioners. Rebbitt concludes that these findings “demonstrate emphatically that safety professionals do have a solid value proposition and that they have been, and are, effective in preventing fatalities”. (p. 61)

Studies with moderate evidence of direct value in which evidence of value is moderated by other variables

Within studies that investigate a range of factors associated with lower accident rates (see for example Jaselskis, Anderson and Russell, 1996) it is more difficult to understand the relationship between the OSHP and direct value. The exception is an intervention study conducted across industry sectors in the Netherlands (Hale, Guldenmund, van Loenhout, & Oh, 2010). Leaving aside the issues associated with varying methodological quality, this group of studies provides moderate evidence of direct value.
Studies of matched pairs of companies with higher and lower accident rates

The seminal work in this area was undertaken by the National Institute for Occupational Safety and Health (NIOSH) in the United States, comprising a series of three studies that commenced in 1974 (Cohen, 1977). The aim of the studies was to determine the factors in successful safety programs. They drew on six studies dating back to 1964 that identified nine general factors associated with safety performance, one of which was “management commitment” that included the sub-category “safety officer holds high staff rank.” Of the six earlier studies, four identified safety staff as one factor associated with good safety performance.

Of the six earlier studies, work by Shafai-Sahrai (as cited in Cohen, 1977) was used as the basis for the NIOSH study. Using a matched pair’s study design, the questionnaire-based study identified eight factors associated with low accident rates, with safety training for workers, including lectures by the safety specialist, identified as one of the eight factors (Cleveland, Cohen, Smith & Cohen, 1979). The second phase of the NIOSH study, a site visit to seven of the 42 matched pairs of companies, aimed to verify the results of the first study (Cleveland, Cohen, Smith & Cohen, 1979).

In the third phase of the study the matched pairs design was abandoned and five plants with the lowest lost time injury rates in the United States were sent a questionnaire and were followed up with a plant visit (Cleveland, Cohen, Smith & Cohen, 1979). The studies provide mixed evidence for a direct relationship between the OSHA injury rate and value. From the first phase of this study there is moderate evidence for a relationship between the role and tasks performed by an OSHA. Less convincing, due to the weaker methodological quality of the third phase of the study, is the claim that the rank and stature of the OSHA is associated with lower accident rates. Intuitively, the higher up the organisation the OSHA reports, the more ability they have to influence the decision making of senior managers, which ostensibly translates into lower accident rates. However, it is a difficult argument to sustain based on the evidence available in this study.

Studies of a sample of companies within an industry sector or across industry sectors and accident rates

The construction industry, particularly in the United States, has shown greatest interest in identifying the safety strategies and factors associated with excellent safety performance. Of the 11 studies included in a literature review by Jaselskis, Anderson and Russell (1996), three identified that improvements in safety performance could in part be attributed to the employment of a full-time safety director, safety officer or safety professional. Of the three studies, one emphasised that it was important for the safety professional to report to the president or vice-president of the company (Hinze and Harrison as cited in Jaselskis et al., 1996). This early finding from the construction industry is consistent with the findings of the NIOSH study.

Jaselskis et al. (1996) sent a questionnaire to 48 construction companies in the US and compared results with Occupational Safety and Health Administration (OSHA) incident rates and the experience modification rating (EMR) for the companies involved, the latter a measure based on workers’ compensation claims experience. They found a statistically significant lower EMR was associated with greater involvement by the safety coordinator. The study also found that companies with more detailed safety programs had lower EMR. It is unclear as to why OSHA in companies with a higher EMR conducted fewer inspections and had less detailed safety programs. This finding, therefore, is open to interpretation, with either the qualifications of the OSHA or other organisational factors including cost or possibly management commitment to safety being factors.

A similar questionnaire based study by Findley et al. (2004) of 305 construction companies in the US also found that companies with a lower EMR employed a full time safety manager. As a result, these companies were more likely to implement the elements associated with an effective safety management program. On the basis of this finding, the author recommends that companies wishing to improve safety and their “bottom line” should employ a full time safety manager who reports to a senior manager.

Hinze & Wilson (2000) also used the EMR, together with recordable injury rates, to survey the safety practices of 40 well-performing companies in the US to determine the improvements these companies had made as a result of the “zero accidents” and “zero injuries” initiative. They identified five high impact techniques for improving performance and if these are considered to be the good safety practices that lead to lower injury rates, then it is likely that it is the OSHA who initiates and implements these practices. Without the OSHA performing these tasks it could be argued that lower injury rates would not have been achieved.

Abudayyeh, Fredericks, Butt and Shaar (2006) studied the correlation between management commitment to safety and the frequency of injuries and illnesses among a random sample of the top five hundred construction companies in the US. They found that companies that employed a safety manager on site, an indicator of management commitment, had a statistically significant lower injury and incident rates. In addition, they found...
that companies that authorise the safety manager to spend over $1,000 on safety improvements had fewer injuries and illnesses.

In contrast Hallowell (2010) found that employing a safety manager is less cost-effective than investments in management commitment to safety and sub-contractor selection. This finding departs from the previous studies in that management commitment is separated from employing a safety manager. In a subsequent study, however, Hallowell & Calhoun (2011) found that the employment of a site safety manager, together with use of worker engagement, existence of site-specific safety plans and management commitment, to be the most effective element of a safety program.

Esmaeili & Hallowell (2012) explored the diffusion of injury prevention strategies in the construction industry, finding that employing a site safety manager was one of three innovations less frequently implemented. They found that the three most frequently adopted safety innovations were project-specific training and safety meetings, frequent worksite inspections, and health and safety orientation training. The three least frequently adopted safety innovations were the employment of a site safety manager, contractor selection and management, and substance abuse programs. They conclude that “the construction industry has now reached saturation with respect to traditional injury prevention strategies and new safety innovations are needed” (p. 955). These findings and conclusions could be interpreted in two ways. First, that the appointment of OHSPs made long ago is of value now and is reflected in the three most frequently adopted safety innovations. Second, that OSHPs have not shown their value in the past and there was no need to appoint one now.

In a study of a single university construction site in the US, McDonald, Lipscomb, Bondy and Glazner (2009) were able to identify a range of factors associated with an injury rate which was half that for the rest of the construction industry. One factor was the employment and visibility of a full-time OSHP.

Pre-dating the previously discussed Cameron, Hare & Duff (2007) study was a Canadian study conducted by Hinze & Raboud (1988) that examined the relationship between company policies and practices designed to influence safety in the workplace and safety performance measured in terms of injury frequency rates. This study found that injury rates were lower in companies that employed a full-time safety officer.

A study of the management practices that contribute to a safe work environment in 62 hospitals found that the OSHP had no impact on injury rates (Vredenburgh, 2002). This study also found that “what differentiated the hospitals with low injury rates was that they also employed proactive measures to prevent accidents” (p. 259). Based on this finding, and despite finding that the OSHP had no impact on injury rates, Vredenburgh proposes that one implication of this study is that the OSHP should hold a “management-level classification” (p. 259). Although the reasoning behind this proposition is not clarified in the study, it is presumably because the OSHP is the best person to implement proactive measures to prevent accidents.

An intervention evaluation in the Netherlands investigated 17 projects across 29 companies drawn from different sectors (Hale, Guldenmund, van Loenhout, & Oh, 2010, see also Guldenmund & Hale, 2012, Guldenmund, Hale, van Loenhout, & Oh, 2008, Hale, Jacobs & Oor, 2010). This study found that the OSHP was central to the successful implementation of a range of safety initiatives. Hale et al. (2010) found that a distinguishing factor in successful interventions was “the amount of energy and creativity injected by top managers and, above all, by the coordinator (safety professional)” (p. 1026). They found that the OSHP or the top manager was the “active motor to make the change” (p. 1033). When interventions were not being driven by these motors, particularly the OSHP, companies were five times more likely to be unsuccessful in implementing OSH initiatives.

Studies with moderate evidence of inferred value in which evidence of value is moderated by other variables

The impact of the OSHP on safety climate

Zohar (1980) conducted what is generally accepted as the first study of an organisational climate for safety. Drawing on earlier studies, including the study conducted for NIOSH by Cleveland, Cohen, Smith, and Cohen (1978), Zohar developed a 40 item questionnaire comprising seven dimensions, one of which was the perceived organisational status of the safety officer, sent to 20 organisations in Israel. Zohar found that safety climate was correlated with the effectiveness of the safety program in the organisations that he studied. Of the two climate dimensions that influence safety climate, one was managers’ perceived attitude towards safety “exhibited in workers’ eyes by the organisational status of both the safety officer and safety committee” (p. 101). Zohar goes on to conclude that the “status of the safety officer can be assessed by executive authority relegated to him [sic] (e.g., authority to remove workers from production hall or to stop production processes when safety regulations are not followed)” (p. 101). This characterisation of the status of the safety officer is one that places an emphasis on their role as an enforcer of regulation.
Wu, Liu, and Lu (2007) conducted a questionnaire-based safety climate study across 100 university and college laboratories in Taiwan. They explored five organisational factors that affect safety climate, including the presence of a safety manager. A statistically significant finding was that universities that employed a safety manager had better safety climate scores. In a later study, Wu, Lin and Shiau (2010) conducted a questionnaire-based study of the predictive factors of safety culture in 22 departments of five telecoms firms in Taiwan and found that those who employed a safety manager had a better safety climate.

In an earlier study of role behaviour Cameron and Duff (2007) developed seven measures of management performance and objective injury data equals or surpasses all other known safety risk indicators, including unguarded physical hazards at the workplace” (p. 1). Therefore it is possible to infer a relationship between the OSHP and value, albeit through safety climate where climate is a predictor of safe behaviour, and by extension, lower accident rates. Nevertheless, when the lens is widened to consider the broader literature on safety climate, evidence emerges that safety climate is a significant predictor of injury rates. For example, Zohar and Polachek (2013) state, in relation to safety climate, that “recent meta-analytic studies indicated that its effect size on safety performance and objective injury data equals or surpasses all other known safety risk indicators, including unguarded physical hazards at the workplace” (p. 1). Therefore it is possible to infer a relationship between the OSHP and value, albeit through safety climate where climate is a predictor of safe behaviour, and by extension, lower accident rates.

Studies with weak evidence of direct value and expert opinion
There have been a number of studies that have returned surprising and often difficult to interpret findings on the relationship between the OSHP and value. Indeed some of these studies, at first glance, have found a negative relationship between the OSHP and value. Some have considered the status of the OSHP (who they report to), their competence and qualifications (what they know), their role and tasks (what they do) and the industry sector (where they work). The evidence emerging from this grouping of studies is weak due to the quality of the study design or is suggestive only based on expert opinion. However, it does contribute to the understanding of what qualities and competences are expected or required of good OSHPs.

Studies with ambiguous evidence of direct value
Shannon, Mayr and Haines (1997) undertook a systematic review of the literature published between 1970 and 1994 to examine the relationship between injury rates and organisational and workplace factors. Of the 61 studies retrieved, only 10 met their inclusion criteria. Of the 10 studies they reviewed, one found an association between the OSHP being represented on joint safety and health committees and reduced injury rates. When considering all 10 studies, however, and after applying their consistency criteria, Shannon et al. conclude that the amount...
of training received by committee members was the only factor consistently associated with lower injury rates. Therefore there is no evidence of a relationship between the OSHP and lower injury rates even though they were represented on such committees.

Mearns, Whitaker and Flin (2003), in a study conducted in the off-shore oil and gas industry, interpret the results of the Shannon et al. study differently. They suggest that representation of OSHPs on joint safety and health committees was “consistently associated with lower injury rates” (p. 7). Mearns et al. developed a Safety Management Questionnaire (SMQ) as an audit tool comprising six elements; element one, safety and health policy, sought to explore the “number and status of dedicated safety and health staff” (p. 648). In year one of the study, they found that the presence of an off-shore OSHP was significantly correlated with “unfavourable” (p. 665) performance. A similar result was found in year two of the study. Mearns et al. comment that unfavourable scores predicted an increased propensity to report accidents. However, it could be argued that the presence of the OSHP had a positive impact on reporting rates, which is a good thing for learning and improvement (Hale et al., 2010).

A further study by Mearns, Whitaker and Flin (2001) draws on a 1997 internal company report for British Petroleum, Conoco and the Royal/Dutch Shell Group conducted by Sykes, Paxman and Thoem (as cited in Mearns, Flin & Whitaker, 2001). This study identified that one aspect of best practice was that the corporate safety and health advisor made policy recommendations and chaired a committee “comprising senior business managers” (p. 773). This finding suggests an indirect relationship between the OSHP and value as a result of their role (high status) and their function (chairing a high level committee). This study is limited, however, because the extent to which best practices equate with lower accident rates remains unclear.

**The status of the OSHP and speculated value (who they report to)**

The status of the OSHP has emerged repeatedly (see for example Zohar, 1980) as a factor that may be associated with their ability to add value. For example, Hopkins (2007) argues that “the best companies have safety staff at several different points of the hierarchy, with safety officers reporting directly to the most senior manager at that level, not via a human resources manager or some other intermediary” (p. 217). A recent salary and attitude survey of 3,939 OSHPs conducted by IOSH (2012) found that 55% of OSHPs do report directly to the board. Disturbingly, however, the IOSH survey found also that respondents were unable to articulate the value of their proposed safety interventions, a finding that has the potential to undermine their perceived value by managers.

Although Hopkins argues for a high status for the OSHP and a line of reporting to managers at different points in the organisational hierarchy, Minnick (2013) proposes a different view of the line of report for the OSHP. Drawing on a survey of 442 ASSE members in the US, Minnick argues there are two viewpoints on reporting structures for OSHPs; first, through a “line of power,” for example to a Chief Executive Officer; and second, through a “functional unit,” for example an environmental, health and safety department. It was found that role stress was less when the OSHP reported to a functional unit. Minnick also found that OSHPs were experiencing role overload “due to the expansion of the safety role into other roles, such as environmental safety and security, while expecting the same level of safety performance” (p. 152). This latter finding suggests that expanding the OSHP role, without an equivalent increase in the numbers of OSHPs, may inadvertently undermine the ability of the OSHP to add value. This raises an interesting paradox. Expanding the role of the OSHP to include, for example environmental management, is generally viewed as a necessary step towards demonstrating the value of the OSHP to business. Doing so, however, may have the reverse effect given Minnick’s findings. Minnick’s former finding, that role stress was less when OSHPs reported to a functional unit, could, in part, be explained by the inability of the OSHP to articulate the business case for safety when reporting directly to the Board or senior management. It also has to be recognised that stress, up to a point, may be good as it can reflect being in a position of influence close to the reins of power, rather than having a comfortable, but less influential position in a separate safety, health and environment unit.

**OSHP competencies and speculated value (what they know)**

Notwithstanding who OSHPs report to, a survey (Peter Wager & Associates, 2010) of Australian Chief Executive Officers (CEOs) found that CEOs perceived that OSHPs lacked the ability to understand business strategy, were unable to constructively influence business objectives and were “too negative or bureaucratic in managing the balance between business and OHS imperatives” (p. 110). Without these skills, it is easy to imagine that OSHPs would feel stressed, and feel safer reporting to a functional unit as Minnick (2013) found. Role stress may be compounded by the OSHPs’ inability to measure safety in a manner that is meaningful to senior managers, the end result being that OSHPs could find themselves caught in a vicious rather than virtuous cycle. The inability of the OSHP to engage senior managers is also highlighted in a US report that explored the return on investment
of the environmental health and safety function (BLR, 2006). This study found that the function is under-valued by senior executives due to “communication barriers between EHS professionals and executive management, and a lack of standard metrics for evaluating all aspects of EHS performance.” The report goes on to suggest that OSHPs must “measure the performance of their programs using the tools of business managers and the format and language of the organisation’s financial analysts” (p. 28).

In a bid to close the gap between OSHPs (and what they know) and managers (what they expect OSHPs to know), Leemann (2005) proposed a framework that would allow OSHPs to demonstrate their value-added contribution to an organisation. Leemann breaks the OSHPs role into five categories: i) ensure compliance; ii) no incidents; iii) communications; iv) influence; and v) cost-effective. Each role is broken down into functions. Roles and functions are cross-referenced to their underpinning competencies. Leemann offers three competency clusters for the OSHP: i) cognitive competence, ii) interpersonal competence and iii) intrapersonal competence. An interesting inclusion in this framework is the interpersonal skills of the OSHP. Pryor (2014) conducted a grounded theory study exploring the strategic influence of the OSHP in which seven (7) dyads of senior OSHPs and their managers across a range of industry sectors in Australia were interviewed. She found that trust was central to the OSHPs being able to influence the strategic decision making of their senior manager. Although Leemann’s framework and Pryor’s findings fall short of demonstrating the value of the OSHP in direct terms, a picture starts to emerge that an OSHP who enjoys high status (power) would benefit from complementing their role and functions with a set of personal attributes (influence).

**OSHP role and tasks and speculated value (what they do)**

The OSH community has taken it upon itself to promote the need for OSHPs to be able to argue the business case for safety and health (see for example Byrne, 2013; Hill, 2006; Veltri, 1992; Veltri et al., 2007; Veltri et al., 2013 & Williamson et al. nd) through the use of cost-benefit analysis (see for example Behm, Veltri & Kleinsorge, 2004 & Deshkar, 2010). Indeed, the need to evaluate the business value of the safety function was recognised over 20 years ago by Veltri (1992), who proposed a conceptual model to do this. Veltri argued that OSHPs must demonstrate the strategic value of what they do and instead of focusing solely on regulatory compliance, OSHPs must also contribute to productivity and business performance.

In an early effort to describe the safety functions of OSHP, DeJoy (1993) surveyed 1,190 safety professionals in the US spanning 10 industry sectors. DeJoy identified five primary functions: 1) serving as safety consultant/ advisor; 2) coordinating compliance/control activities; 3) assessing the effectiveness of controls; 4) analysing hazards and losses, and 5) conducting specialised studies and reviews. He went on to identify that OSHPs require good communications skills to carry out their functions.

Studying 400 Certified Safety Professionals and 100 safety educators’ perceptions of the most important competencies for OSHPs in the US, Blair (2004) found both groups rated “communicating effectively” as the most important competence, followed by “accepting responsibility” and “translating solutions into practical terms.” Blair concludes that safety educators should teach business and communication skills as part of their safety programs.

In a similar study conducted in Taiwan, Chang, Chen and Wu (2012) set out to develop a competency model for OSHPs. Unlike Blair (2004), they found different perceptions of what constitute important OSHP competencies among safety professionals and safety educators; although both groups did agree that applying business management principles was important, it was the least valued competency by both groups.

The role and tasks of the OSHP have attracted significant attention for some time (see for example Borys, Else, Pryor & Sawyer, 2006; Brun & Loiselle, 2002; Hale & Ytrehus, 2004) with the role variously described as one of a “politically reflective navigator” (Broberg & Hermund, 2004; Olsen, 2012), “change agent” (see for example Brown & Larson, 1998; Brun & Loiselle, 2002; Hasle & Jensen, 2006; Hill, 2006; Limborg, 1995 & Swuste & Arnoldy, 2003) or “compliance agent” (Hopkins, 2007). The notion that the OSHP should act as a “change agent” is often cited in the literature based on expert opinion. There is no evidence that acting as a change agent does or does not add value.

In a UK study, Conchie & Burns (2009) studied how employee trust in an information source shaped workers’ safe behaviour. They collected data from 131 workers on a single construction site and found that the safety manager, together with the Health and Safety Executive, were the most trusted sources of information influencing worker behaviour.

Nytrö, Saksvik, and Torvatn, (1998) explored the implementation of internal control regulations in Norway in an effort to determine the organisational factors that predict the successful implementation of systematic management of health, safety and environment programs. They found that the availability of a suitably qualified
OSHP working within the organisations they studied was the strongest predictor of success in managing a systematic approach. They caution, however, that improvements in activity, that is, increased implementation of the internal control regulations, does not guarantee effectiveness as measured by reductions in the rate of fatalities, injuries and disease. Nevertheless, this finding does suggest that it is the OSHP, rather than any other job function, which will have the knowledge and skills to implement systematic approaches. A similar study conducted by Chaves et al. (2009) interviewed “key contacts” in 78 companies in Bahia to evaluate the implementation of OSH programs. They found that company-related, employee-related and occupational safety and health specialist-related factors were associated with the successful implementation of these programs.

A recent study by Veltri et al. (2013), argues that the key is to ensure that safety is fully integrated into business operations. According to Veltri et al. (2013) this shifts the responsibility for safety and operations to operations managers. This study is unique in that it broke down the barriers between safety researchers and operations management researchers. Equal numbers of researchers from both disciplines used 10 case studies from nine organisations across different industry sectors in Ontario, Canada. The researchers explored the relationship between safety and operational practices and outcomes, comparing the results with data on injury rates. They found that the “top performing facilities on operational outcomes were also the top performers on safety outcomes and these facilities all had supportive cultures and used joint management systems” (p. 127). On the basis of these findings, it is reasonable to argue that the value of the individual OSHP and the safety function may be measured by the degree to which OSHPs are successful in integrating safety and health into the day-to-day operations of the business.

**Industry sector (where they work)**

Contrary to the view that a determining factor related to the impact of the OSHP may be the type of industry and its associated level of risk (IOSH Culture study), DeJoy (1993) previously found that safety functions did not differ across industries (including mining, construction and electronics), operations or size. Furthermore, in their single industry sector study of safety climate in university and college laboratories in Taiwan, Wu, Liu and Lu (2007), found no difference in safety climate scores based on organisational size and location, and employing an OSHP resulted in all locations achieving better safety climate scores. If safety climate is taken as a proxy measure for safety performance, then the presence and functions of the OSHP seems to make a difference irrespective of organisational size and location.

**Discussion**

This literature review has four key findings. First, there is a distinction between the value of the individual OSHP, and the value (positive or negative) of safety. It is possible to argue that these are complementary rather than competing perspectives; OSHPs value may be measured by the extent to which they are able to convince organisations in the first instance of the business value of safety.

Second, only two studies provide strong evidence in support of the value proposition of the OSHP. These studies are important because within them the value of the OSHP is not moderated by other variables or factors investigated. Both were conducted in the construction industry, a sector that dominates the literature. It is unclear why there has been interest in the construction industry but not in other high-risk industries, for example mining, or the (chemical) process industry.

Third, all the studies reviewed measure the value of the OSHP in terms of either a reduction in fatality or injury rates. There are no similar studies that explore the rates of disease and ill-health.

Fourth, the methodological quality of all the studies undermines the strength of the evidence. Cohen’s (1997) research using matched pairs of companies represents the highest methodological quality. Unfortunately the value of the OSHP was investigated among many other variables. Furthermore, this study is over 40 years old. The second highest methodological quality is found in the intervention evaluation conducted by Hale et al. (2010) who employed a before and after design, but like the Cohen study, investigated the value of the OSHP among other variables – resulting in this study being classified as providing only moderate evidence.

The findings of the literature review regarding the relationship between OSHPs and business value is presented as a value pyramid in Figure 1. At the base of the pyramid is the safety and health Body of Knowledge (BOK) that is the bedrock knowledge upon which OSHPs build their professional practice and formulate their advice to organisations on how to achieve safe operations. The middle section of the pyramid represents the OSHP who is the linchpin between the safety and health BOK and business value. This section of the value pyramid is broken into five (5) interrelated sub-sections. Taken together, these characteristics or qualities of OSHPs allow them to fulfil their full potential and add value to the organisations within which they work. The top section of
the pyramid represents the business value of the OSHP in terms of safe operations and reductions in fatalities, injuries, disease and ill-health and is built on the sections beneath.

![Diagram of the value pyramid]

**FIGURE 1**
Re-Conceptualising the relationship between the occupational safety and health professional and business value

Notwithstanding the findings, it is apparent that there are significant gaps in the evidence base. For example, no strong evidence was found in support of personal attributes or line of report or experience.

**Conclusion**
OSHPs are facing increasing pressure to justify their value to their organisations, driven in part by a struggling global economy which is placing pressure on organisations to cut costs wherever they can. The purpose of this literature review was to determine the strength of the evidence in support of the value proposition for the OSHP. While many studies have investigated a range of safety management factors associated with better safety performance, including the role of OSHP, only two studies bring into sharp relief the value of the OSHP in reducing workplace fatalities and injuries. This finding is at once disappointing and encouraging – disappointing due to the dearth of studies on such an important topic, encouraging because there is evidence for the value proposition of the OSHP.

The profession and researchers should work together to strengthen the evidence base and enable the OSHP to more easily demonstrate their value in both good and tough economic conditions.

Further research using robust methodologies and focusing on the value of the OSHP is required. It is important to investigate how the elements in the value pyramid are related to one another.

Research is also needed to investigate the extent to which formal university programs are delivering the requisite knowledge, skills and attitudes of the OSHP that will allow them to successfully add value. At the very least, research should include disease and ill-health as well as fatalities and injuries as measures of value.

**Acknowledgements**
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Dermal Exposures to Organophosphorus Pesticides for Ambulance Workers - Permeation Through Disposable Gloves: Findings for Omethoate

Ismaniza Ismail1, Dino Pisaniello1, Sharyn Gaskin1 and John W. Edwards3

Abstract
Ambulance personnel may be exposed to organophosphorus pesticides during patient handling in scenarios involving accidental or intentional poisonings. While disposable gloves are routinely worn, there appears to be a significant knowledge gap with respect to the potential for dermal exposure, and mediating this, the level of protection afforded by disposable gloves. Research was conducted to investigate the influence of organophosphorus pesticide concentration, exposure duration and temperature on the amount of chemical permeating the gloves. Omethoate, an organophosphorus pesticide typically used in horticulture and home gardens, was investigated. American Society for Testing and Materials (ASTM) permeation cells were used to test gloves used by South Australian ambulance workers; neoprene gloves (0.07 mm thickness) and nitrile gloves (0.11 mm thickness), individually and in combination. Chemical analysis was via High Performance Liquid Chromatography (HPLC-UV (220 nm)).

It was found that gloves provided limited protection against the full strength formulated omethoate at an elevated temperature (45°C). Maximum flux was 1093 (±154.1) µg/cm²/min (nitrile) and 132 (±27.9) µg/cm²/min (neoprene) over a 4-hour exposure period, and 52 (±6.7) µg/cm²/min for combined gloves. It is recommended that the current SAAS practice of combining nitrile and neoprene gloves continue, but considerations should be given on more frequent changing of gloves, especially when working in warmer conditions.

CITE THIS ARTICLE AS

KEYWORDS
Organophosphorus pesticides; permeation; omethoate; dermal exposure; ambulance gloves; temperature

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Introduction
Accidental chemical exposures and poisonings may have significant public health impacts, as well as placing logistic demands on response agencies (Edwards et al. 2003). In South Australia, it is estimated that there are 4 to 5 poisoning cases every month attended by ambulance workers, with an unknown proportion of organophosphorus pesticides (OP) cases (Casey, 2014, pers. comm.). The health risks associated with handling OPs are well identified and include inhibition of cholinesterase enzymes (Bey, Sullivan & Walter 2001; Eskenazi, Bradman & Castorina 1999; Holmgaard & Nielsen 2009). Skin contact with the OPs when ambulance workers attend to victims of OP accidents and poisoning cases may expose them to potential health risks (Figure 1). Therefore a policy to protect South Australia Ambulance Service (SAAS) ambulance workers with particular gloves for skin protection has been developed.
FIGURE 1
Simulation of exposure potential when SAAS ambulance worker with double gloves attend to handling OP accidents and poisoning cases

The Australian Defence and US Paramedical/Fire Services recommended double gloving method of neoprene gloves to prevent skin contact with chemicals whilst handling casualties (Stevenson, 2013, pers. comm.). In practice, however, due to cost factors, the South Australia Ambulance Service (SAAS) opted for nitrile gloves worn over neoprene gloves for this purpose (Figure 2).

FIGURE 2
Double gloving method (nitrile on top of neoprene gloves) as practised by SAAS first responders

There does not appear to be a detailed appraisal of the effectiveness of the gloves in resisting permeation, and the decision to use the double gloving method was most likely based on glove selection guides, which are based on glove tests conducted by manufacturers at room temperature only. Moreover, barrier protection may vary depending on the types of OPs and the concentrations on the glove surface. This is especially so if the formulated products come with co-solvents and additives that behave differently (Ehntholt, D.J, Bodek & Valentine 1989; Klingner & Boeniger 2002; Que-Hee 1989; Schwope & Goydan 1992).

This study was conducted to examine the resistance of nitrile and neoprene gloves (individually and in combination) to permeation against a typical OP in various conditions. It was assumed that; ambulance workers could be dealing with undiluted products; exposure time may vary (realistic maximum duration is 4 hours (Casey, 2014, pers. comm.); and exposure could occur at various temperature (normal ambient temperature or hot summer days).

Methodology
Experimental design
Nitrile and neoprene gloves used by SAAS workers were tested individually and in combination, on formulated omethoate. Omethoate is one of the OPs commonly used in Australia in both commercial and home garden situations, and it is classified as Chemicals of Security Concern in Australia by the Council of Australian Government (COAG) (Commonwealth of Australia 2013; Immig 2010). In order to mimic a real-life scenario, the gloves were tested with two concentrations of OP solution; full strength (814g/L) and application strength (0.6g/L). Temperatures selected for the tests were 23 (±2)°C for exposure in normal room temperature and 45°C to resemble the worst case scenario; extreme hot conditions that may be experienced in South Australia. For each concentration and temperature conditions, experiments were repeated four times to ensure reproducibility and reliability of the data.
Glove performance (permeation resistance) tests were conducted using American Society for Testing and Materials (ASTM) permeation test cells and disposable gloves as used by SAAS. The first type of glove was Sterling® Nitrile (powder-free exam gloves) (KC300, Ref 13941, Lot SM204230CLXX) produced by Kimberly-Clark. The second type was Micro-touch Affinity® Neoprene (non-sterile examination gloves) (C/No 0362, Ref 3772, Lot 12082134EQ) manufactured by Ansell.

In this study, glove swatches were cut out of the palm area of the gloves and the thickness was measured at several points. For this purpose, a digital thickness gauge (547-301, 0.01mm-10mm, Mitutoyo) was used. Thickness of nitrile gloves and neoprene gloves were 0.07 and 0.11 mm respectively.

A simple two-compartment cell (ASTM permeation test cell) was used to determine OP permeation, by sandwiching the glove swatches between the donor chamber and the receptor chamber of the cell. Cells exhibited a diffusion-available surface area of 5.31 cm$^2$ and a receptor compartment volume of 16.4 ml. Based on suitability and chemical solubility, pure MilliQ water was used as receptor fluid. Receptor fluid was continuously stirred with a modified stirrer connected to two 1.5V batteries at 350 rpm. Samples (200 µL) were taken from the receptor chamber at appropriate intervals during the experimental period and replaced with fresh receptor fluid. The experiments were either set-up in ambient conditions (23 (±2)°C ) or in an oven for 45°C.

**Chemicals**

Formulated omethoate with the brand name Folimat® from Ospray Pty Ltd (Queensland, Australia) containing 814 g/L omethoate and 400 g/L propylene glycol methyl ether acetate (PGMEA) as co-solvent was tested. This concentrated omethoate is hereto referred as ‘full strength’. Application strength omethoate (0.6 g/L) was prepared by diluting the full strength omethoate with pure MilliQ water. Analytical grade compounds (Fluka-36181 for omethoate, and 82300 for PGMEA) from Sigma-Aldrich was used for preparing standard solutions. Stock solution (25 mg/ml) was prepared in pure MilliQ water and stored in the fridge at 4°C.

**Apparatus**

All samples were analysed by High Performance Liquid Chromatography (HPLC) with the operating conditions adapted from Sartorelli et al. (1998). Omethoate concentration was determined by a GBC LC 1120 HPLC Pump connected to a PE Nelson 900 Series Interface and Shimadzu SPD-20A Prominence UV/Vis detector. A volume of 20 µl sample was directly injected into the Alltech Alltima (C18, 5 micron, length 150 mm, I.D 4.6 mm) separation column. The retention time for omethoate was 5.4 minutes. The software program used for peak integration was Perkin Elmer TotalChrom Navigator. The mobile phase was aqueous methanol 30:70 v/v (flowrate 0.5 ml/min) with the UV detector set to a wavelength of 220 nm.

**Calibration curve**

A calibration graph for determination of omethoate was obtained by diluting the stock solution with pure MilliQ water to 10 working standards. Their concentrations ranged from 0.01 – 100 µg/ml. To obtain a linear calibration curve, peak areas were plotted as a function of the concentration and the curve was used to determine the concentrations in the experimental samples. Good linear fits were obtained daily for accuracy, with correlation coefficient ranging from 0.9959 to 0.9999. The Limit of Detection (LOD) (3:1 signal to noise ratio) was found to be 0.01 µg/ml.

**Descriptors of permeation**

The following variables were used as descriptors for the ability of omethoate to permeate through the gloves into the receptor fluid: maximum flux, breakthrough time and cumulative permeation. Flux (µg/cm$^2$/min) refers to the speed or permeation rate of omethoate (µg) crossing a defined glove area (cm$^2$) in a set time (min). Breakthrough time (minutes) is based on the AS/NZS 2161 standard which defines that breakthrough only occurs when the flux reaches 1 µg/cm$^2$/min. Cumulative permeation (µg) is the amount of omethoate recovered in the receptor chamber after the 4-hour test duration. Calculation of these descriptors was based upon measurement of omethoate in the receptor chamber during the experimental period.

**Data processing**

As a dilution factor is introduced every time a 100 µL sample is removed from the receptor chamber and replaced by 100 µL fresh receptor fluid, all data on total permeation were corrected for these dilutions to avoid underestimating total permeation.
Results

Comparison of omethoate permeation through gloves under variable conditions.

Table 1 summarises the results of the glove performance (permeation resistance) tests under various temperature and application concentrations with the descriptors by glove permeation by omethoate.

TABLE 1:
Summary of glove test outcomes for omethoate under various temperatures and concentrations

<table>
<thead>
<tr>
<th>Type of gloves</th>
<th>Results</th>
<th>45°C / 814 g/L</th>
<th>23 (±2)°C / 814 g/L</th>
<th>45°C / 0.6 g/L</th>
<th>23 (±2)°C / 0.6 g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrile</td>
<td>Breakthrough time (BT)</td>
<td>20 min</td>
<td>15 min</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average flux (µg/cm²/min) at BT</td>
<td>3.5 (±0.5)</td>
<td>1.3 (±0.3)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average concentration (µg/ml) at BT</td>
<td>6.8 (±0.7)</td>
<td>3.4 (±0.4)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average maximum flux (µg/cm²/min)</td>
<td>1093 (±154.1)</td>
<td>21 (±3.6)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average cumulative permeation after 4hrs (mg)</td>
<td>865 (±98.4)</td>
<td>23 (±3.5)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td>Neoprene</td>
<td>Breakthrough time (BT)</td>
<td>20 min</td>
<td>120 min</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average flux (µg/cm²/min) at BT</td>
<td>1.6 (±0.2)</td>
<td>2.5 (±0.5)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average concentration (µg/ml) at BT</td>
<td>2.8 (±0.3)</td>
<td>54 (±10.9)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average maximum flux (µg/cm²/min)</td>
<td>132(±27.9)</td>
<td>5.4 (±0.5)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average cumulative permeation after 4hrs (mg)</td>
<td>115 (±16.3)</td>
<td>5 (±0.5)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td>Combination (nitrile on neoprene)</td>
<td>Breakthrough time (BT)</td>
<td>50 min</td>
<td>not achieved</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average flux (µg/cm²/min) at BT</td>
<td>1.1 (±0.2)</td>
<td>not achieved</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average concentration (µg/ml) at BT</td>
<td>5.6 (±0.7)</td>
<td>0.8 (±0.1)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average maximum flux (µg/cm²/min)</td>
<td>52 (±6.7)</td>
<td>0.5 (±0.04)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
<tr>
<td></td>
<td>Average cumulative permeation after 4hrs (mg)</td>
<td>38 (±4.3)</td>
<td>0.5 (±0.04)</td>
<td>not achieved</td>
<td>not achieved</td>
</tr>
</tbody>
</table>

No breakthrough was achieved for application strength omethoate tested at both ambient and high temperatures for all gloves. However, for full strength formulated omethoate, the protection afforded by the gloves varied.

In general, higher temperature decreased the breakthrough time and permeation flux was higher. At ambient temperatures, nitrile recorded breakthrough after 15 minutes, neoprene 2 hrs and no breakthrough was observed for the combined gloves. Where breakthrough was achieved at higher temperatures, the average maximum flux was greatest with the thinner nitrile gloves (1,093 (±154.1) µg/cm²/min), followed by neoprene gloves and combined gloves (132 (±27.9) and 52 (±6.7) µg/cm²/min, respectively). Reduced flux rates of 21 (±3.6) µg/cm²/min for nitrile gloves and 5.4 (±0.5) µg/cm²/min for neoprene were evident at ambient temperatures. Similarly, flux for combined gloves was least at both temperatures. Cumulative permeation showed a similar pattern with values greatest for nitrile gloves (865 (±98.4 mg) and least for combined gloves (38 (±4.3) mg).

Although the breakthrough time for 23 (±2)°C/full strength formulated omethoate for nitrile gloves is shorter than the breakthrough time at higher temperature (45°C/full strength formulated omethoate), the permeated amount at the specified breakthrough time of the former (3.4 (±0.4) µg/ml) was only half of the latter (6.8 (±0.7) µg/ml). The flux for neoprene gloves were similar under both temperature conditions (1.6 (±0.2) µg/cm²/min for 45°C, 2.5 (±0.5) µg/cm²/min for 23 (±2)°C) (Table 1). When handling the full strength formulated omethoate, combined gloves may be suitable but only under ambient temperature conditions (Table 1 and Figure 3).
It is also shown that wearing individual gloves (either nitrile or neoprene gloves) at ambient temperature provided less protection because permeation was observed as early as 15 minutes for nitrile and 120 minutes for neoprene (with an average maximum flux of 21(±3.6) and 5.4 (±0.5) µg/cm²/min respectively).

Figure 4 shows that at the higher temperature, protection afforded by combined gloves began to decrease after 50 minutes. In other words, elevated temperature resulted in shorter breakthrough times and enhanced permeation of pesticides through the gloves. Similar to the permeation pattern observed for ambient temperature, the average cumulative permeation of omethoate at the end of the 4-hour tests was more for nitrile gloves, followed by neoprene gloves and combined gloves.

**FIGURE 4:**
Permeation of full strength formulated omethoate through the gloves at high temperature, 45°C over the 4-hour exposure period. Breakthrough occurred at 50 minutes.

*Independent behaviour of co-solvent*

Figure 5 displays the comparison of permeation of omethoate (the active ingredient) and PGMEA (the solvent used to mix the formulated product) using full strength formulated omethoate at high temperature.
Comparison of omethoate and PGMEA permeation through the gloves (individually and in combination) using full strength formulated omethoate at 45°C over the 4-hour exposure period.

Although the concentration of PGMEA is lower than omethoate in the formulated product, PGMEA permeated through the gloves into the receptor chamber much faster and in a greater amount for all conditions. Breakthrough times of PGMEA were 5 minutes (for nitrile gloves), and 10 minutes (for neoprene gloves). With combined gloves, the average cumulative permeation of PGMEA was six times more than omethoate at the end of the test (Figure 6).
Discussion

There appear to be no comparable glove permeation studies of omethoate. While the selection of most gloves is based on general glove selection guides that generally test gloves in restricted conditions at room temperature, this study shows that glove effectiveness may vary depending on the type (material) and combination of gloves, exposure duration and environmental conditions.

Elevated temperatures decreased breakthrough time and resulted in higher cumulative concentrations of omethoate at the end of the 4-hour test. The lower toxicity co-solvent, PGMEA permeated through the gloves much faster and in greater amounts and may accelerate the permeation of omethoate. A previous study concluded that the concentration of the solvent in the formulations strongly affected the breakthrough and the total mass of material permeating the glove materials (Ehntholt, D.J et al. 1990). This suggests that co-solvents need to be considered when selecting an appropriate type of glove for skin protection.

Nitrile and neoprene gloves (used individually or combined) provide good protection at higher temperature conditions only for up to 4 hours when handling application strength omethoate. Although the use of full strength formulated chemicals could be an unlikely scenario in poisoning/suicide cases, the speed, severity, and extent of dermal absorption are relative to the formulation of the OPs (Holmgaard & Nielsen 2009).

Average maximum flux for combined gloves was 65 times higher when the temperature increased from 23(±2)°C (0.8 (±0.1) µg/cm²/min) to 45°C (52 (±6.7) µg/cm²/min). With those rates, it was found that the average cumulative permeation of omethoate through the combined gloves after a 4-hour exposure were 0.5 (±0.04) mg and 38 (±4.3) mg respectively. For occupational risk assessment, the flux is often used to estimate the risk. Nevertheless, flux itself is insufficient to evaluate the toxicity profile of a pesticide after dermal exposure (Holmgaard & Nielsen 2009).

Once a pesticide permeates the gloves, the next stage will be skin absorption of the OPs which may result in local effects on the skin or systemic effects. This, however, will be influenced by many factors. Under normal conditions, the rate of diffusion through the skin will depend on hydrophilicity (‘water-liking’) or lipophilicity (‘fat-liking’) as well as solubility, molecular weight and size of the compounds (Holmgaard & Nielsen 2009).

Besides, it also depends on the thickness of the skin membrane that the pesticide has to pass through, skin pores, anatomical location and skin condition (Semple 2004). Temperature may also affect solubility and diffusion coefficients of compounds, shorten the breakthrough time and consequently contribute to dermal absorption (Vahdat & Bush 1993; Zellers & Sulewski 1993).

In the worst case scenario, the cumulative permeated omethoate (865 (±98.4) mg) could potentially be absorbed through the skin at different rates and result in sensitisation or inhibition of cholinesterase enzyme. Although this is unlikely because of the limited contact time with the full strength formulated omethoate when wearing only one layer of gloves, extra precautions should be taken and the duration of wearing gloves in contact with pesticides should be minimized especially when working on hot days.

Although the thicker neoprene gloves provided better protection than the thinner nitrile gloves, the permeation resistance of individual gloves may appear different when tested with other OPs. Physicochemical properties (e.g. solubility, octanol-water partition coefficient (Kow), molecular weight) of the pesticides and the properties of the gloves (e.g. polarity, quality) may all affect the permeation of OPs and the effectiveness of the different glove types. Composition, molecular size, and partitioning behaviour have been listed as further variables for consideration in permeation of this complex mixture (Lin & Que-Hee 1998).

Demonstrated breakthrough times do not necessarily represent safe limits for handling the pesticides. All findings and conclusions presented are based on the AS/NZS 2161 standard which defines that breakthrough occurs when the flux reaches 1 µg/cm²/min. However, observations have found that the pesticides have permeated the gloves earlier than this (based on Limit of Detection/Limit of Quantification 0.05). Although permeation under normal working conditions while wearing combined gloves is unlikely to be significant, extra precautions (e.g good personal hygiene practices) should be taken while handling high concentration pesticides in hot conditions.

There is a possibility of large discrepancies between products, even if they are produced by the same manufacturers, therefore it is reasonable to assume that each product may perform differently. It is worth noting that the tests conducted in the laboratory may not be directly applicable to the workplace environment because of the difference in conditions (Schneider et al. 1999). In this study, the gloves are tested out-of-box and only exposed to the test conditions, whereas gloves used by the ambulance workers in the real scenario might have decreased performance due to movement or flexing effects, as reported by Phalen and Wong (2012).
Conclusions & Recommendations

At ambient temperature, combined gloving seemed to provide adequate protection (breakthrough not reached) while handling full strength formulated omethoate for up to 4 hours. It is therefore recommended that the SAAS practice of wearing combined nitrile and neoprene gloves continue.

However, at elevated temperature (45°C), gloves provided limited protection against full strength formulated omethoate, even when worn in combination. Given the outcomes of enhanced permeation at elevated temperature, in combination with AS/NZS 2161 standard, consideration should be given to more frequent changing of gloves when working in warmer conditions. In practice, it is unlikely that gloves are in contact with the full strength formulated omethoate for long periods of time e.g. 4 hours. To better clarify the influence of varying temperature conditions on glove permeation of omethoate, further work is recommended at other moderate temperatures e.g. 30-35°C. Tests should also be conducted on other types and brands of gloves that might be used by ambulance workers in other states and countries, to establish a better understanding of these variables. Exploring the effects of movement on the permeation resistance may also provide more accurate information under worker-use conditions.

In addition, for future studies, glove permeation of other OPs of different physicochemical properties should be conducted. Work is currently underway assessing the ability of omethoate to penetrate human skin in vitro in order to better understand the potential risks.

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Luminance In the Occupational Visual Field: An Evaluation of Office Workstations
B. Piccoli1, M. D’Orso2, G. Polselli1, I. Leka1 and D. Pisaniello3

Abstract
Inappropriate lighting is one of the most common causes of visual disturbances in office workers. Visual demand can also lead to musculoskeletal problems such as tension neck syndrome. On the other hand, appropriate location of light sources and a suitable level of illumination can enhance visual capacity. A rational approach to visual risk assessment of tasks and workstations involves measurements in the occupational visual field, and in particular luminance measurement. We report a large scale photometric evaluation in six companies in northern and central Italy. Operator tasks were predominantly administrative with some computer aided design activity.

Occupational visual field luminance ratios were found to be excessively high (>1:250 cd/m²) in 19% of workstations (n = 100), moderately high (1:100-1:250 cd/m²) in 20% and considered satisfactory (<1:100 cd/m²) in 61%. Illuminance in the working plane ranged from 100-2500 lux and correlated poorly with luminance. Parameters were highly dependent on light fitting position and window location.

The survey demonstrated shortcomings in lighting design and workstation layout, both from artificial and natural sources. It is recommended that photometric assessment incorporate both luminance (occupational visual field) and illuminance measurements.

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KEY WORDS:
Occupational asthenopia, visual risk assessment, office lighting, visual effort, luminance, illuminance.

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Introduction
Inappropriate lighting, both natural and artificial, is one of the most common causes of ocular and visual complaints in office workers. High contrasts between light and dark areas of the visual field, as well as stray light “washing out” screen images, can make visual processing difficult and lead to awkward postures.

Visual tasks have become more demanding in last 30 years due to the ubiquity of screen-based equipment. Although there is a greater awareness of office ergonomics, a review of the literature suggests that the prevalence and the profile of workers’ visual complaints has not changed substantially (see Table 1).

TABLE 1.
Prevalence of visual complaints in VDU operators*

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Population studied</th>
<th>Frequency of complaints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghiringhelli</td>
<td>1980</td>
<td>Swiss VDT operators</td>
<td>76%</td>
</tr>
<tr>
<td>Liubli et al.</td>
<td>1980</td>
<td>German VDT operators</td>
<td>65%</td>
</tr>
<tr>
<td>Starr et al.</td>
<td>1982</td>
<td>VDT in telephone operators</td>
<td>76%</td>
</tr>
<tr>
<td>Dain et al.</td>
<td>1985</td>
<td>VDT operators</td>
<td>25%</td>
</tr>
<tr>
<td>WHO</td>
<td>1987</td>
<td>VDT operators</td>
<td>45%</td>
</tr>
<tr>
<td>Wibom and Carlsson</td>
<td>1987</td>
<td>Scandinavian VDT operators</td>
<td>70%</td>
</tr>
<tr>
<td>Piccoli et al.</td>
<td>1989</td>
<td>Italian VDT operators</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Scullica and Rechichi</td>
<td>1989</td>
<td>Italian VDT operators</td>
<td>25%</td>
</tr>
<tr>
<td>Lindner</td>
<td>1994</td>
<td>VDT operators</td>
<td>58%</td>
</tr>
<tr>
<td>Thomson</td>
<td>1998</td>
<td>English CDT operators</td>
<td>50%</td>
</tr>
<tr>
<td>Fenga</td>
<td>2008</td>
<td>Italian VDT operators</td>
<td>74%</td>
</tr>
<tr>
<td>Megwas and Aguboshim</td>
<td>2009</td>
<td>Nigerian VDT operators</td>
<td>90%</td>
</tr>
<tr>
<td>Shrestha et al.</td>
<td>2011</td>
<td>Nepalese VDT operators</td>
<td>92%</td>
</tr>
<tr>
<td>Tebboune and Mebarki</td>
<td>2012</td>
<td>Algerian VDT operators</td>
<td>85%</td>
</tr>
<tr>
<td>Han</td>
<td>2013</td>
<td>VDT Chinese college students</td>
<td>95%</td>
</tr>
</tbody>
</table>

*The average in the period 1980-2013 is 65%, between 1980 and 1996 is 54% and between 1996 and 2013 is 81%.
In this paper, we review the complex factors that determine visual load and influence complaints, with a focus on office lighting. We report a large scale photometric evaluation in six companies and 100 workstations where operator tasks were predominantly administrative, with some computer aided design activity.

**Visual discomfort and its relationship with visual effort and lighting**

An office Visual Display Unit (VDU) operator typically focusses on images and objects at short distances, commonly below one metre, activating intense accommodation of the eye. This is often for extended periods (many hours a day, sometimes without any break) and in environments which restrict the variation of near and far vision (due to the presence of partitions, walls, etc.) overloading ocular motility/binocularity functions.

As a consequence, there is a requirement for sustained accommodation and convergence effort. This is accompanied by a continuous pupillary adjustment. From a physiological standpoint, it activates a complex physiologic mechanism known as “sinkinesia” or “fixation triad”, controlled by the Edinger-Westphal mesencephalon nuclei, the role of which is essential to allow the formation of sharp images, on both eyes (binocular vision). This is achieved by the simultaneous contribution of three kind of muscles (inside and outside the eye globe); the ciliary muscle, to place the image into focus; the extraocular muscles, to position the image on the retina, in particular, on the fovea (the central area of the retina of 5.5 mm in diameter, where there is maximum resolution), for optimal visual acuity (VA); and the iris sphincter muscle, to regulate the amount of light entering the eye.

In ideal conditions, the visual and neuromuscular system, controlling accommodation and convergence, allow for: high precision (optimal focus and fovealization of the image to discern small details); rapid response (for clear and comfortable vision, when observing screen, keyboard and any documents, with latency within a fraction of a second); and stamina (high efficiency for hours every day).

However, in many circumstances, these systems are overloaded. In addition, where there is near-continuous light stimulation of variable intensity and origin, pupillary reflexes (fast) and retinal adaptation (slow) mechanisms can be overloaded.

In practice, a VDU operator’s activity is constrained by (i) the assigned tasks (which may be inflexible), (ii) structural characteristics of the work station (not fully adjustable) and (iii) screen and document placement (often squeezed in a limited space). During intense work the operator attention is predominantly concerned with the screen, keyboard, documents, devices, etc. Accordingly, the ocular fixation (gaze) covers a limited area, termed the Occupational Visual Field (OVF), defined as the part of space inside which the operator must primarily look at, to carry out the assigned work tasks.

A VDU operator typically keeps an average head-screen observation distance of approximately 80 cm. (Piccoli 2007). The OVF can be depicted as a cone with the vertex at the bridge of the nose (nasion), with an angular width which oscillates between +/-25 and +/-35 degrees in relation to the fixation axis, aimed at the centre of the screen. This is illustrated in Figure 1, where the average screen viewing distance in this case is 64 cm, assessed objectively with ultrasound (Piccoli 2001).

![FIGURE 1](image)

**FIGURE 1**

The Occupational Visual Field for a VDU Operator (observing screen, document holder and keyboard).
The effect of inappropriate lighting

Owing to relatively slow retinal adaptation, heterogeneous light distributions within the OVF produces a greater disturbing effect than distributions in the peripheral field of view.

Bright objects in the visual field, other than the objects of interest, potentially interfere with the physiologic visual and perceptive mechanisms, as well as the cognitive processes of the operator. In an attempt to overcome this interference, the worker may adopt a poor posture in an otherwise well-designed work station (Grieco and Molteni, 1999).

Therefore, it is possible to classify two groups of factors predominantly responsible for the typical ocular/visual discomfort and disorders of VDU operators; i) those caused by overloading of accommodation and convergence (related to near visual effort); ii) those caused by overloading of pupillary motility and retinal adaptation (related to the lighting conditions at the work station).

These can be exacerbated by a range of individual factors. Visual disturbances can be more prevalent among workers who need (or do not have) adequate optical correction, those suffering from ocular motility impairments and those affected by degenerative pathologies causing a marked reduction of visual acuity (maculopathy, cataract, pseudophakia, keratoconus, dry eye syndrome, etc.), pathologies commonly found in general and working population. (Resnikoff et al., 2008).

Environmental factors including chemicals (affecting indoor air quality) and microclimate (high air speed as well as low relative humidity), can act on the ocular surface (Wolkoff et al., 2005) and further exacerbate problems.

In summary, ocular and visual disturbances originate from different components of the visual system. Lighting is just one these, acting synergistically with other adverse factors. According to the International Commission on Occupational Health, Scientific Committee on Work and Vision (Piccoli et al., 2003), these symptoms constitute a syndrome termed “occupational asthenopia”. Here “work environment factors and tasks, combined with the ophthalmic characteristics of the subject, may potentially favour the appearance or recurrence of a series of ocular and/or visual signs and/or symptoms”. Thus, the term “occupational asthenopia” is more inclusive than more commonly used terms such as eye irritation, visual fatigue visual strain, veiling/disability glare. Indeed, the range of terminology, is potentially a cause of confusion, leading to limited interpretation and collection of relevant data.

Methods

The study was conducted in north and central Italy (mostly in Milan and Rome) between 2010- and 2013. The participating organisations were mainly in the finance sector and resource industries. Detailed information about work tasks was obtained from the workers. All measurements were carried out during normal working hrs, i.e. 09.00-17.00hrs.

Detailed measurements of luminance and illuminance were collected with a Hagner Universal Model S2 photometer using the method of Piccoli et al. (2004).

There were 4 phases for luminance assessment being; i) operator task analysis, including the identification of objects/images (occupational targets); ii) determine the OVF - the space that encloses the occupational fixation zones involved; iii) measure luminance and construct isoluminance maps (see Figure 3); and compare luminance ratios in the OVF.

Results

Parameters measured were highly dependent on light fitting position and window location.

The OVF luminance ratios were found to be excessively high (>1:250 cd/m²) in 19% of workstations, moderately high (1:100-1:250 cd/m²) in 20% of workstations and considered satisfactory (<1:100 cd/m²) in 61% of workstations. A summary of the values that exemplify these three conditions at workstations is reported in table 2 and in figures 3 – 8.
TABLE 2
List of 25 of the 100 workstations studied*

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Company</th>
<th>Luminance ratio</th>
<th>Portion of the OVF concerned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>Moderate</td>
<td>central-left (min# - max = 20/2,500 cd/m²)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>Moderate</td>
<td>central (min# - max = 40/4,500 cd/m²)</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>High</td>
<td>left (min# - max = 40/10,000 cd/m²)</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>High</td>
<td>central-right (min# - max = 30/12,000 cd/m²)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>Adequate</td>
<td>(min# - max = 25/300 cd/m²)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>High</td>
<td>right (min# - max = 20/5,100 cd/m²)</td>
</tr>
<tr>
<td>7</td>
<td>D</td>
<td>Moderate</td>
<td>left (min# - max = 20/3,200 cd/m²)</td>
</tr>
<tr>
<td>8</td>
<td>D</td>
<td>High</td>
<td>right (min# - max = 18/6,000 cd/m²)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>Moderate</td>
<td>left (min# - max = 22/2,300 cd/m²)</td>
</tr>
<tr>
<td>10</td>
<td>D</td>
<td>Adequate</td>
<td>(min# - max = 45/450 cd/m²)</td>
</tr>
<tr>
<td>11</td>
<td>D</td>
<td>Adequate</td>
<td>(min# - max = 42/300 cd/m²)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>Moderate</td>
<td>right (min# - max = 24/3,300 cd/m²)</td>
</tr>
<tr>
<td>13</td>
<td>D</td>
<td>High</td>
<td>left (min# - max = 15/4,000 cd/m²)</td>
</tr>
<tr>
<td>14</td>
<td>D</td>
<td>Moderate</td>
<td>Left (min# - max = 24/4,500 cd/m²)</td>
</tr>
<tr>
<td>15</td>
<td>D</td>
<td>High</td>
<td>Central-left (min# - max = 18/5,000 cd/m²)</td>
</tr>
<tr>
<td>16</td>
<td>D</td>
<td>Moderate</td>
<td>Central-right (min# - max = 40/4,000 cd/m²)</td>
</tr>
<tr>
<td>17</td>
<td>D</td>
<td>Moderate</td>
<td>Central-right (min# - max = 40/5,000 cd/m²)</td>
</tr>
<tr>
<td>18</td>
<td>D</td>
<td>Adequate</td>
<td>(min# - max = 22/1,500 cd/m²)</td>
</tr>
<tr>
<td>19</td>
<td>D</td>
<td>Adequate</td>
<td>(min# - max = 45/2,500 cd/m²)</td>
</tr>
<tr>
<td>20</td>
<td>D</td>
<td>Moderate</td>
<td>left (min# - max = 50/8,000 cd/m²)</td>
</tr>
<tr>
<td>21</td>
<td>D</td>
<td>Adequate</td>
<td>(min# - max = 80/4,000 cd/m²)</td>
</tr>
<tr>
<td>22</td>
<td>E</td>
<td>High</td>
<td>central-right (min# - max = 20/4,500 cd/m²)</td>
</tr>
<tr>
<td>23</td>
<td>E</td>
<td>High</td>
<td>central (min# - max = 20/6,500 cd/m²)</td>
</tr>
<tr>
<td>24</td>
<td>E</td>
<td>High</td>
<td>central (min# - max = 50/17,000 cd/m²)</td>
</tr>
<tr>
<td>25</td>
<td>F</td>
<td>Moderate</td>
<td>central (min# - max = 40/6,000 cd/m²)</td>
</tr>
</tbody>
</table>

*Luminance ratios were deemed excessively high (ratio > 1:250), moderately high (ratio 1:100 - 1:250) or “adequate” (< 1:100). # Inferred average of most significant values within the central portion of the OVF, including screen, keyboard and main devices.

Illuminance on the working plane ranged from 100-2500 lux and correlated poorly with luminance. In this regard, see figures 3 and 4 where, although illuminance on the working plane is adequate (630/420 lux), luminance levels from windows are very high (up to 10000/12000 cd/m²). Also in figure 7 it is evident that illuminance levels on the desk (100 to 150 lux) are barely influenced by the high luminance from the window at the left end of the room. Lastly, in figure 8, other than the very high luminance ratio are existing in the operator’s OVF (1:340), it is noteworthy that the lamp on the wall is possibly annoying the operator when window luminances are low i.e. in the evening or with venetian blind in use.

Discussion & Conclusion
The problem of visual disturbance in office work is very common. Luminance is the more appropriate indicator of visual disturbances, based on anatomy and physiology.

In order to measure the luminance and luminance ratios in the visual field, a rational method should be used (Piccoli et al., 2004).

Across 100 workstations, there was a poor relationship between luminance and illuminance. Indeed, illuminance ratios ranged from tens of lux (min.) to 2500 lux (max.) with a ratio of 40, a much lower ratio compared to that of
Moreover, we found that glare from natural light was not always well controlled even though blinds are available. This may be attributable to poor maintenance, disagreement among operators on blind use and, particularly in open spaces/big offices, low natural light at working stations distant from windows.

Interestingly, utilisation of task lighting was uncommon, but this could be effective, particularly for aged operators, in controlling illuminance on documents, keyboard, etc. without increasing the artificial lighting.

Consideration of workers’ lighting-related visual disturbancies and analysis of luminance leads to better design of lighting systems and workstation layout. Lighting risk assessment carried out by the measurement of luminance is a better diagnostic process than that by illuminance alone. Luminance measurements can be very precise and detailed in showing where lighting conditions are problematic within the operator’s OVF. Finally, luminances can be very useful in re-design of lighting systems at workstations.

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REFERENCES


