EYE INJURIES IN THE WORKPLACE OCCURRING WHILE WEARING RECOMMENDED AND APPROVED EYE PROTECTION.

BY

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Executive summary

The study

Twenty two cases of eye injuries that occurred while workers were wearing approved and recommended eye protection were examined in detail. Originally, it had been intended to examine a larger number of cases, but very early in the study it was found that the problem under examination was obvious. It was decided to abandon the collection of repetitive data and to examine the cases and the tasks which generated them in more detail. Further confirmatory work could be done on a more diverse environment, however it is unlikely that these would provided substantially different findings.

Information was collected on the nature and pattern of injury, the task being undertaken, and the type and fit of eyewear used. A purpose built measurement device was used to measure the shape of the faces of the injured workers and gaps around the eyewear were measured using digital photography.

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The hazard

The particular hazard for the automotive industry is that workers are exposed to flying metal particles for long periods of time during every shift. This high rate of exposure results in a high rate of injury. In these circumstances, devices that are highly effective in protecting against eye injuries are required. The industry has utilised protective measures such as screens to reduce the hazard, but the need for personal protective equipment remains.

Eye protection must be worn for long periods in hot manufacturing environments. The protection must therefore be lightweight, well ventilated and comfortable. This has influenced workers to choose wide-vision spectacles. The gaps around this type of eyewear can be large. This study has identified eye injuries occurring where the gap was as small as 5 mm and as large as 20 mm.

The problem

AS1336 recommendations for medium impact operations and spot welding are inadequate. Under the influence of the Standard, workers and employers are choosing eye protection with the greatest comfort under the false impression that it provides adequate protection. However, the Standard does not adequately define fit, and the use of wide-vision spectacles, without ensuring adequate fit, should be discontinued.

Employers could pay more attention to fit and so reduce the risk of injury. Their attempts to do so are limited by the range of wide-vision spectacles available. Employers are currently faced with the need to require wide-vision goggles to be worn to increase eye protection, knowing that this would create compliance problems and possibly impede workers' vision, resulting in other risks and lowering of work performance.

In respect to design, there is a lack of precision in terms of lens curvature, a lack of adjustment and little flexibility to permit many workers to choose wide-vision spectacles that will fit well enough to protect them from injury during metal-working tasks.

In preliminary discussion with Australian Standards Committee for Standards 1336 & 1337, some members indicated to the principal investigator that they believed that the apparent failure of eye protection is mainly due to workers falsely claiming to be wearing protection at the time of injury. This belief flies in the face of the literature presented in this paper, and of the findings of this study which, while small, demonstrate that a problem exists with the design and fit of protective eyewear. It presents evidence of cases of eye protection failure and attempts to explain the mechanisms. It is uncertain whether the Committee has read the literature and dismissed it, or whether it has received inadequate information from its advisers.

The solution

The critical design issue is to develop a range of protective eyewear that provides adequate ventilation and comfort while maintaining close fit. Other types of eye protection recommended in AS1366 could provide greater protection. These, however, are far less convenient and carry with them problems of restricted vision, fogging and lack of comfort.

Design improvements could include:

- a wider range of sizes and increased adjustability;
- provision of a lightweight strap or flexible ear pieces to increase stability and prevent slippage of spectacles;
- use of flexible materials which can conform to the face while permitting adequate ventilation;
- the use of mouldable plastics to permit individual fitting similar to the process used for mouthguards.

The strategy

The strategy for dealing with this issue has a number of components. There is a need, as discussed above, to deal with design flaws and limitations in the Standards. In the short term, while the development of more suitable eyewear is investigated, an interim solution for workers and employers should be adopted.

Research and development of eyewear

Workers have shown a clear preference for the wide-vision spectacle design. They were almost universally used by both injury cases and other workers on the floor. Discussions with supervisors and workers indicated that wide-vision spectacles were chosen because they were light, comfortable, and did not fog or produce sweating problems in hot weather. It is, therefore, sensible to determine if this design can be improved to provide adequate levels of protection. The current use of a European male head-form is inadequate given the age, racial and gender mix of the workforce. To provide a proper fit, a better understanding of the variability of facial shapes among workers is required. One avenue of investigation could involve computer modelling of face shapes which may provide a much better basis for eyewear design. Work on facial modelling is being done by injury researchers to inform the United States ANSI Standards Committee on Eye Protection.

Once the design parameters are better understood, there is a need to explore the use of modern flexible materials to achieve better fit. Possibilities include the use of light aramid cloths to bridge gaps and mouldable plastics to increase the precision of individual fit.

Standards

There is a need for more empirical evidence to be used in the preparation of safety standards. Standards AS1336 and AS1337 do not adequately define the design and choice of protective eyewear for buffing and grinding, or spot welding operations. In light of the evidence presented here, and elsewhere, the Standards should be reviewed and amended.

Workplace practices

Many eye injuries could be prevented by implementing a close fit policy for all workers using wide-vision spectacles when grinding, buffing or spot welding metal. Where it is not possible to achieve a fit with gaps of less than 1 mm, alternative eye protection should be used. The figure of 1 mm has been chosen as being sufficient to allow some ventilation, but to trap or exclude solid particles. Further research is needed to determine the exact size of the gap that can be accepted.

Recommendations

Standards

AS 1336 should be amended to require:

- wide-vision goggles to be used for metal buffing and grinding operations where wide-vision spectacles can not be fitted with a gap of less than 1 mm;
- all spectacle-type eyewear to be fitted so that a gap of no more than 1 mm exists between the face and the eyewear at any point where particulate material can enter;
- eyewear that meets medium impact requirements, as amended to reduce gaps, be used for spot or resistance welding operations.

AS 1337 should be amended to include greater details of the head-form, including maximum cheek depth and brow to cheek measurements in both the vertical and horizontal plane. In addition, the 95th percentile sizes for Australian males and females separately, should be clearly marked on the head-form diagram. Other measurements may also be required to provide an adequate model for designing eyewear that will fit a range of workers. The head-form measurements and confidence intervals should be based on both male and female populations of 15 years and above to cater for the needs of young workers. This would assist designers to consider the curvature of lenses needed to achieve proper fit for the full range of workers and trainees.

Design of protective eyewear

Protective eyewear designers should undertake research and development in order to develop better fitting wide-vision spectacles. There is a need for a wider range of sizes, lens curvatures and the use of flexible materials to better fit facial contours of the full range of workers, while maintaining ventilation and comfort.

Workplace practices

While, theoretically, it would be preferable to design operations to eliminate the need for protective eyewear, this is impractical. The mobility requirements of the tasks make the use of additional screens difficult, if not impossible. A move to robotic welding operations would avoid human exposure, but this carries with it high set-up costs and the social costs of reduced employment. In the absence of other solutions, workplaces should ensure that protective eyewear used for metal work of any kind should fit so that the gap between the face and the eyewear at any point where particulate material can enter is no greater then 1 mm. Workers should be given instruction in the correct choice of eyewear and its adjustment to achieve an adequate fit.

For production line operations, employers may need to examine the feasibility of air supplied visors for workers undertaking repetitive spot welding, and grinding and buffing operations. This would provide incentives for workers to use this type of device by improving ventilation and providing positive pressure to reduce the entry of small particles.

Background

The nature and extent of the problem

It is estimated that, every day, 1000 eye injuries occur in American workplaces resulting in $300 million dollars per year in lost production time, medical expenses and worker's compensation. 70% of these injuries are caused by flying particles smaller than a pinhead and one fifth are caused by exposure to chemicals.[1] While many of these injuries are a result of workers not wearing appropriate eye protection, a significant number of eye injuries are sustained by workers who are wearing appropriately approved eyewear. Of those workers who received eye injuries whilst wearing appropriate eye protection, more than 50% felt that another type of eye protection could have better prevented or reduced the injury suffered.

The Western Australian Department of Occupational Health, Safety and Welfare reported that in 1991-92, eye injuries occurred at the rate of 2.7 injuries per million hours worked, constituted 8.2% of all compensable injuries and resulted in an average of 4.9 working days lost per injury. The risk of eye injury was highest in the construction industry (8.3 injuries per million hours worked) and the manufacturing industry (7.5 injuries per million hours worked). Power tools, especially abrasive, planing and cutting devices, accounted for 29.2% of reported cases [2].

In 1994, OSHA in the US updated its eye protection rules. A significant issue in the review was the recognition that injuries were still occurring when properly selected and approved protective equipment was worn.[3] The American National Standard on Eye Protection (ANSI Z 87.1 1989) became due for its five year cyclic review in 1995. This is currently underway.

Australian workers' compensation data provide a limited picture of eye injury patterns because many eye injuries require relatively brief treatment, do not result in significant lost time, and do not reach the threshold for reporting in workers compensation statistics.

The Australian Institute of Health and Welfare's National Injury Surveillance Unit (NISU) studied eye injuries presenting to emergency departments of hospitals. This system is based on approximately 50 participating hospitals across Australia. The collection is not representative of a known population, so it was not possible to calculate injury rates. The analysis found a pattern of injury similar to the US. NISU detected 35,228 eye injuries reported in its sentinel injury surveillance system (ISIS) between 1986 and 1994. More than a third (13,595 cases) occurred while the person was on the job, or where the place was an area of production or commerce. Of these, 21% (2861 cases) indicated that eye protection had been worn at time of injury. Eye injuries were often associated with particular types of tools and tasks, namely grinders—where the operation was metal cutting or grinding—and welders. Some high severity incidents, requiring admission to hospital, involved hammering of metal, nail gun projectiles and chemical spillage into the eye.

The analysis showed that:

- Eye protection appeared to be effective in reducing the overall severity of injury with the risk of admission, or the need for follow up treatment, being greatest amongst those not wearing eye protection. There were, however, a number of cases detected where it appeared that relatively severe injuries occurred while protection was being worn.
- Eye protection was more likely to be worn in higher risk environments but that it was likely that, when eye protection was not worn, the injury was more severe due to the higher energy nature of the task involved.
- Portable grinders appeared to be more often associated with injury while wearing eye protection than did other tools. Bench grinders also exhibited similar patterns but not to the same extent.

It was not possible to determine from mass surveillance data the type of eye protection that was being worn at the time of injury or, if it was worn, that the correct eye protection for the task had been chosen. However, the descriptions of events suggested that, not infrequently, injuries occurred while appropriate eye protection was being worn.

Literature on work related eye injuries from the United States indicates that the problem is greatest for the automotive industry.[4] This is mainly due to the types of exposures and tasks in this industry and suggests that failure to wear eye protection, or its incorrect selection, is the most frequent problem.

Fong also argues that Australian Standard 1336 does not specify the correct type of eye protection for hammering operations.[5] Larger studies in the US point to failure occurring due to particles by-passing the eyewear, rather than impact failure. [6] This has also been noted in a South Australian study.[7] These issues are poorly researched, as the focus of most research is on wearing rates. It is important to ensure that eye protection is effective if greater commitment to wearing the correct protection is to be achieved.

Discussion with Occupational Health and Safety Staff at Mitsubishi Motors Australia (MMAL) and the Adelaide Refinery confirmed that eye injuries are occurring frequently even when approved eye protection is worn. MMAL indicated that up to 50 eye injuries were treated in a week. Adelaide Refinery indicated that eye injuries came in clusters, occurring during construction and maintenance operations when the Plant was shut down. Both companies agreed to participate in a detailed prospective study to determine the causes, and to search for design solutions.

The Australian Standards

Australian Standards provide guidance for the selection of best practice. While few safety standards are made mandatory by governments, they form the basis for assessing acceptable practice in occupational settings. Two Australian Standards are relevant to this study: AS 1336:1982 (updated January 1997) *Recommended Practices for Eye Protection in the Industrial Environments* and AS 1337:1992 *Eye Protectors for Industrial Applications.* The former details strategies for reducing eye injuries and the choice of personal eye protection for various tasks. The latter deals with standards for the construction, testing and marking of personal eye protection. The major parts of the standards relevant to this study are outlined below

Definitions

Definitions Selected from AS 1337

"**1.4.4** **Eye protector**—a device which includes a lens or lenses worn in front of the eyes and intended to provide protection for the eyes.

1.4.5 **Eyeshield**— a device which includes a transparent visor supported in front of the face to shield the eyes.

1.4.6 **Faceshield**—a device which includes a transparent visor supported in front of the face to shield the eyes, face, forehead and front of the neck.

1.4.8 **Goggles**—an eye protector fitting the contour of the face and held in position by an adjustable headband. Goggles are designated by the following types:

(a) *Eyecup goggles*—an eye protector consisting of two lenses mounted in cups supported by a flexible nose bridge and headband. *(b)* *Wide-vision goggles*—an eye protector in which the lens or lenses extend over the full width of the face, affording a large field of vision. Includes coverall goggles designed to fit over prescription spectacles.

1.4.10 **Hood**—a device that completely covers the head, neck and a portion of the shoulders, and which includes eye protection.

1.4.16 **Safety clip-ons**—a pair of protective lenses or a one-piece lens designed to clip on over the front of spectacles.

1.4.17 **Safety spectacles**—an eye protector with protective lenses mounted in spectacle-type frames, or moulded in one piece with or without side shields, and held in position, e.g. by side arms.

1.4.18 **Side shield**—a device commonly attached to spectacles that provides side protection to the eye.

1.4.24 **Visor**—a lens covering all or a large part of the face.

1.4.25 **Welding handshield**—a shield held in the hand which is intended to protect the eyes, face, forehead and front of the neck during welding operations.

1.4.26 **Welding helmet**—an eye protector which is worn by the operator to shield the eyes, face, forehead and front of the neck during welding operations.

1.4.27 **Wide-vision spectacles**—safety-spectacles incorporating a lens or lenses and permanently attached sideshields that follows the contours of the front and side of the ocular area.

1.4.28 **Wire-mesh screen**—a device which consists of woven metal gauze supported in front of the face and incorporates a transparent lens in front of the eyes."

AS 1337 section 1.4 Pages 4,5

General approach

AS1336:1982 provides the following general introduction.

"SECTION 4. USE OF PERSONAL EYE PROTECTORS

4.1 GENERAL. Where it is not possible to eliminate or control eye hazards, personal eye protectors should be supplied to operators and visitors in areas where eye hazards occur and should be worn at all times (see also Clause 1.4). Safety spectacles provide adequate protection from most flying particles coming from work areas in front of the operator. The attachment of suitable side shields provides additional protection against flying particles and stray radiation from welding operations.

The wearing of safety spectacles during exposure to flying particles should be regarded as the minimum acceptable method of protection and an essential step in any satisfactory eye protection program. Their general use needs to be supplemented by the ready availability of other types of eye protectors designed for specific applications and to provide protection against the hazards listed in Table 4.1.

Safety spectacles are not designed or intended to provide protection against particles having a medium or high impact energy. Where greater protection is required it should be in the form of a wide-vision goggle, faceshield or hood. (See Tables 4.1 and 4.2.)" *AS 1336:1982 Page 8*

This has been changed in the most recent Standard AS 1336:1997.

"SECTION 4 USE OF PERSONAL EYE PROTECTORS

4.1 GENERAL Where it is not possible to eliminate or control eye hazards, personal eye protectors shall be supplied to operators and visitors in areas where eye hazards may exist. These eye protectors should be worn at all times (see also Clauses 1.5 and 1.6). If eye protectors are supplied, they shall comply with the relevant requirements of AS/NZS 1337, and AS/NZS 1338 Parts 1 to 3, BS EN 207 and BS EN 208. Low impact safety spectacles provide adequate protection from low velocity flying particles coming from work areas in front of the operator. The attachment of suitable side shields provides additional protection against low velocity flying particles and stray radiation from welding operations.

Wearing low impact safety spectacles during exposure to low velocity flying particles should only be regarded as the minimum method of protection, and a minimum first step in any satisfactory eye protection program. For adequate protection against the different types of hazard present in industrial environments, their general use needs to be supplemented by the ready availability of other types of eye protectors designed for protection against the hazards specific to that workplace (see Table 4.1).

Agreement should be reached between persons involved in the eye protection program on the type of protection needed and the requirements for wearing eye protectors.

Low impact safety spectacles, including prescription eye protectors, are not designed or intended to provide protection against particles having a medium or high impact energy. Where greater protection is required, it should be in the form of goggles, wide-vision spectacles, wide-vision goggles, eyeshield, faceshield or hood. (See Tables 4.1 and 4.2.)

Where protection is required against excessive sunglare or glare from visible radiation, eye protectors fitted with tinted lenses should be used (see Table 4.1). Lenses for eye protectors worn by persons driving vehicles shall comply with the transmission requirements in Table 2.1 of AS/NZS 1337. If protection is required against hazards of ultraviolet or infrared radiation from other than solar sources, e.g. for welders' assistants or furnace operators, reference should be made to Table 4.2 and Section 5.

In all work situations, personal eye protection may not protect against dangers from the side and rear. Emphasis should be given to designing work areas for risk minimization.

In order to provide protection when a face shield or hood is lifted away from the face, eye protectors of at least low-impact resistance should be worn underneath the hood or faceshield." [8]

It should be noted that the changes made specifically approve the use of wide-vision spectacles for medium impact use. This study suggests that this change is problematic.

Use recommendations

The following extracts from Australian / New Zealand Standard 1336:1997 *Recommended Practices for Occupational Eye Protection* indicate the type of protection required for buffing, grinding and scaling operations. These operations resulted in 36% (8 cases) of the injuries examined. In addition to the information in the table below, spot welding, the other major cause of eye injury in this study (41%), is deemed to require outdoor, untinted, safety spectacles.[9]

EXAMPLES OF SPECIFIC HAZARDS AND CONTROL METHODS

Typical processes giving rise to hazards	**Hazard (of the process)**	**Typical methods of controlling hazards**	**Suitable types of eye protectors**
Manual chipping, riveting, spalling, hammering, handling wire and brick cutting	Flying fragments and objects with low velocity or low mass	Fixed or mobile screens	Low impact NOTE: Medium impact (marked I) and high impact (marked V) will give greater protection
Machine disc cutting of materials, scaling, grinding and machining metals, certain wood- working operations, stone dressing	Small flying particles with medium velocity or medium mass	Fixed or mobile screens exhaust systems, dust extractors, water	Medium impact (marked I) NOTE: High impact (marked V) will give greater protection

Extracted from TABLE 4.1 AS1336:1997 Pages 15-16

RECOMMENDED EYE PROTECTION

Identification of eye protector		**Type of eye protector**	**Eye protector marking—Lens identification* (see AS/NZS 1337)**	**Purpose and application of eye protection**
Medium impact	12	Wide-vision spectacles	I	Frontal and side protection to the eyes from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.
	13	Wide-vision goggles with direct ventilation	I	'All round' protection to the eyes from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.
	14	Wide-vision goggles with indirect ventilation	I	'All round' protection to the eyes from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.
	15	Eyeshields	I	Provide protection to the eyes, upper face, and forehead from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.
	16	Faceshields	I	Provide protection to the eyes, face, forehead and front of neck from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.

17	Hoods and helmets incorporating an eyeshield or faceshield	I	'All round' protection to the eyes, head and neck from medium energy flying particles. Tinted lenses will provide a degree of protection from glare.

* HT or CT applicable to toughened glass lenses only. Low impact plastics (*sic*) lenses are not marked.
Extracted from Table 4.2 AS 1336:1997 Pages 16-19.

Fitting personal eye protection

AS 1336:1997 Page 19

"4.3 ISSUE AND FITTING.* Arrangements should be made for the issuing of personal eye protectors to ensure—

(a) use of the correct type of eye protector; and
(b) that, wherever practicable, eye protectors are fitted to the wearer by a person who is competent to select the correct size and type.

Eye protectors may be issued in any of the following ways:

(i) For exclusive use by one employee.
(ii) For temporary use by an employee for a particular operation.
(iii) For temporary use by a visitor.

The choice between an issue for exclusive use by one employee and temporary issue to different employees will depend on the frequency and duration of exposure to hazards and the type of eye protector provided. In general, the issue for exclusive use by one employee is recommended.

4.4 FOGGING AND PERSPIRATION. When necessary, suitable anti-fogging compounds should be made available for use with eye protectors. Antifog type goggles are readily available. Sweat bands may be necessary for extreme conditions and should be easily replaceable.

* It should be noted that variations may exist in the dispensing of prescription spectacles throughout the States and Territories of Australia, and in New Zealand. The fitting of prescription spectacles is subject to regulation in each Country, State and Territory."

Standards Australia has recently completed a review of AS1336 resulting in AS1336:1997 and will commence review of AS1337 in the near future.

Developing the study

The evidence gathered suggested the need for a more in-depth understanding of eye injuries that occurred while workers were wearing approved eye protection. The response from industry provided an opportunity to study this issue in workplaces where good supervision and work practices made it likely that almost all eye injuries would occur while workers were wearing eye protection. There was little information to guide the size of the sample needed for a sound descriptive study. It was decided to develop a pilot study that would allow for good descriptions to be made of the circumstances leading to injury across a range of tasks and eyewear combinations. The main aims were to identify cases of eye injury where approved eye protection was being worn, and to determine why the injury had occurred. It was clear from the description of the eye injuries in the emergency department data, and the literature, that there was very little evidence of eye protection failing as a result of the penetration of large or high velocity particles through the lens or guard materials. The matter of material strength is an important focus of AS 1337. The major issue was that of small particles by-passing the protection. These particles were most often larger than would be required to be described as dust, but did not represent a high energy threat to the eye. As high energy injuries were rare, it was decided not to study them at this time.

This understanding resulted in the development of a number of objectives for the study.

Objectives

- To identify the frequency and nature of eye protection failure in the automotive industry.
- To thoroughly document circumstances leading to eye protection failure.
- To make recommendations about improvements in design, selection of protective eyewear for different tasks and in different settings, and fitting guidelines.
- If necessary, to recommend changes to Australian Standards on eye protection and guidelines for their use.

Research design

This is a descriptive study. Subjects were recruited by in house occupational health centres treating eye injuries where the worker indicated that appropriate eye protection for the task was being worn. Subjects were interviewed and photographed with the protection in place by a trained interviewer. The work environment was mapped and anthropometric measurements of the face taken.

It was originally intended to study 100 cases in order to cover a wide range of tasks and types of eyewear. However, it soon became evident that the eye injuries presenting at Mitsubishi were mainly related to two types of task, and that workers were choosing to wear a single design of eye protection. For this reason, it was decided to examine the work environment in more depth, and to document the range of eyewear that is available to workers.

Twenty-three cases of eye injury meeting the study definition referred from the health centres of Mitsubishi Motors, and a single case from Adelaide Refinery, were studied. Cases came in bursts, corresponding with the times when it was convenient to take measurements. This restricted cases to those occurring on day shift. For example, all cases from Thursday and Friday were collected when measurement was to occur early in the following week, but were limited to the number of cases that could be measured in the time slot available. These cases can be viewed as a typical sample of eye injuries occurring in the sites studied. One case from MMAL indicated that he had not been wearing eye protection at the time and was excluded from the study. No workers refused to be involved in the study.

Methods

Cases were identified over a four week period during February and March 1997. Timeslots were booked for interviewing and measuring injured workers. These generally permitted approximately 8 workers to be included. Recruitment of cases commenced during day shifts only for three to four working days before the scheduled interview time and ceased when the quota was filled. Injured workers were briefed about the study and asked if they would be willing to consent to being interviewed about the circumstances that led to the injury. Workers in the study handed in the eye protection they had been wearing at the time of injury and were issued with new eye protection.

Each subject was subsequently interviewed about the task being undertaken, how the injury occurred, and about the fit and adjustability of the eye protection used. The eye protection was examined for faults or damage, and any adjustments made by the worker were noted.

Photographs of subjects wearing the eye protection were then taken using a digital camera. The scale was determined by a scaling sticker placed on or near the subject's face. Photographs were taken from the top, bottom and side of the subject to determine whether there was an observable gap between the eyewear and the face. The digitised images were then analysed using software designed for measuring distances and areas in x-rays[10] This allowed the maximum width, maximum breadth and total area of each gap to be determined. The software is self-calibrating and was tested for accuracy against a number of known shapes covering horizontal, vertical and angular measurements.

Facial anthropometry was measured using a device tailor made for the task.[11] The device was fastened to the head of the subject by an adjustable strap. Adjustable arms, fitted with their own scale, were used to take the measurements. The hollow of the bridge of the nose was used as the reference point for all measurements. From this point, the width, depth and height of the brows, eye corners and cheeks were measured. Width and depth measures were taken on each side, and the distances averaged to offset any small differences caused by the alignment of the measuring device. It was not possible to produce reliable measurements of facial asymmetry using a mechanical device. The measuring points were taken as the most prominent point of the brow and the cheekbones, and the outside corners of the eyes. Data collection instruments, and the worker information sheet, are documented in Appendix 1

One of the critical issues of the study was whether workers were actually wearing the eye protection they claimed at the time of injury. To determine the level of compliance by workers, the researchers unobtrusively observed the workers as they were engaged in the various manufacturing processes. Observations showed that, in the body build section, with the exception of those supervisors not directly involved with on-line processes, the use of protective eyewear was universal. In the paint shop, however, the use of protective eyewear was very much task dependent. As few injuries presented from this area during the study period, it may be assumed that the individual's assessment of potential risk was reasonably valid. While the use of the eyewear claimed at the time of injury could not be confirmed by witness evidence, the observations made by the researchers suggest that there was no reason to believe that false claims were made.

Information drawn from subjects identified a small number of task types that were associated with the majority of injuries. Each of these tasks was then examined in detail. Photographs were taken of a number of operators undertaking each task. Observations were made of the volume and pattern of particle production, and of the relative position of the task to the eyes of the worker.

Results

Patterns of injury

The study set out to assess the frequency of eye injuries related to eye protection failure. Failure was defined as an injury occurring when the worker was wearing approved eye protection for the task being undertaken. All cases included in the study were of this class. Of the 23 cases referred to the study, only one was not wearing appropriate eyewear. As a complete census of eye injuries was not undertaken, absolute frequency cannot be measured. However, during the times of case identification and referral, a large enough number of cases presented to permit the filling of measurement quota (8 cases) within one or, at the most, two shifts. It can, therefore, be concluded that eye protection failure was a common occurrence and consistent with the number of cases of 50 per week reported by the Health Centre Supervisor. All cases were using eyewear that was approved and recommended in the Australian Standard.

While none of the injuries presenting during the study resulted in serious eye injuries or permanent damage to sight, there was a clear risk that serious injuries *could* occur. The study covered only a small number of injuries in a relatively short space of time. The rarer, more severe, injuries were therefore unlikely to be represented. However, the pattern of events leading to injury demonstrated the potential for serious injury. Cases with splatter burns made by moving hot particles, as well as the lodgement of larger foreign bodies which adhered to the eye, were seen. Both these types of injuries, among others, have the potential to damage sight or to result in long-term complications. Details of the injuries and the treatment response appear in Table 1.

particle could reach the eye from almost any direction, not just directly from the front or side of the eye, was evident. Often the particle sizes are very small, and might be best viewed as a metal dust problem.

Other

While resistance welding, and buffing and grinding operations, were the main cause of the majority of the eye injuries investigated in this study, other tasks have featured as well. Tasks such as paint chipping, chemical handling and hammering of metal parts also resulted in minor eye injuries. Overhead paint scraping and flying particles from a nearby angle grinding process resulted in particle entry through the top of the eye protection. Mopping with a chemical cleaning solution whilst crouching in a tank resulted in caustic material being splashed into the worker's face. Further investigation of the lenses of the wide-vision spectacles being worn at the time showed that, although they had been effective in reducing the damage, obvious gaps at both top and bottom allowed the chemical to enter the worker's eyes.

Facial anthropometry

Three main reference points were measured to determine the variability of facial geometry. These represent the extremities of the field that eye protection needs to cover. They are located with reference to the bridge of the nose as shown in Figure 1

Figure 1 Definitions of facial anthropometry measurements

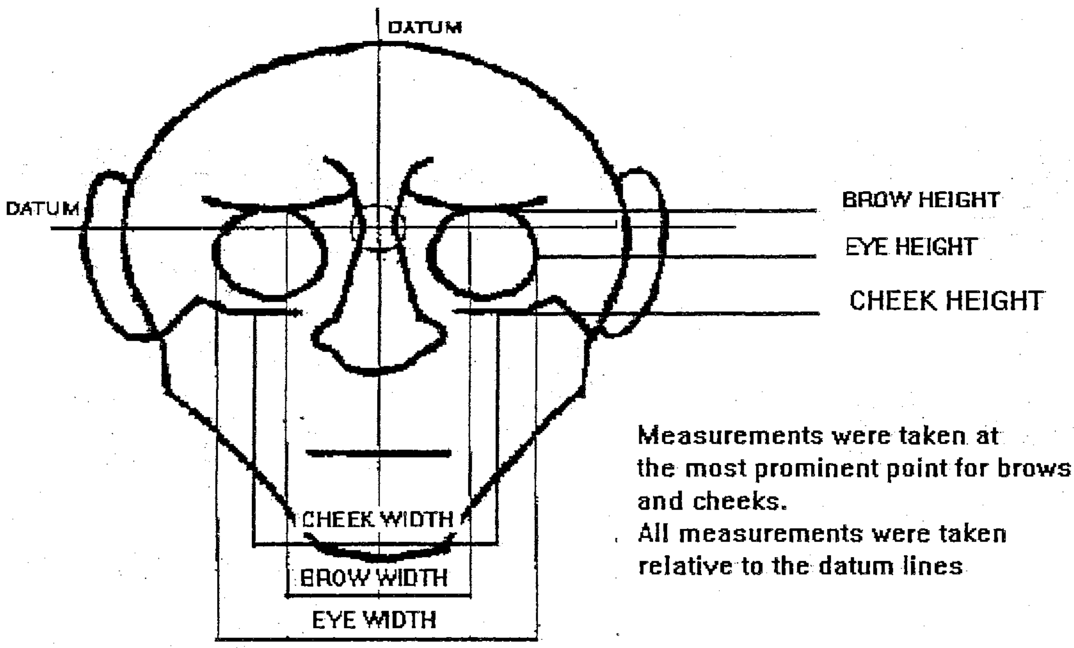


Table 2 Facial measurements of injured workers reference to the bridge of the nose.

Reference Point	Height		Width		Depth	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Brow	-14.2.	1.1	34.8	4.5	-5.7	4.5
Eye	4.0	2.3	55.9	2.0	30.4	3.9
Cheek	25.4	6.3	45.5	5.0	23.1	3.3

Note – sign indicates that the measurement of height is above and depth in front of the datum point.

Table 2 shows the mean and standard deviation of these measurements. The most notable feature of the measures is the very high variability of brow depth, and moderately high variability of cheek height, brow width and cheek width. These measurements indicate that the relative position of the face at the top and bottom of the eyewear is very variable, as is the width at which the most prominent point occurs. It is this variability that makes it difficult to fit protective eyewear to the full range of workers. The curve of a lens that will contact both the brow and the cheek is much greater than that now used in the eyewear seen in this study. In addition we noted that the variations in brow and cheek depths across the plane of the face were marked. The measures taken in this study cannot quantify this observation.

Eyewear use and fit

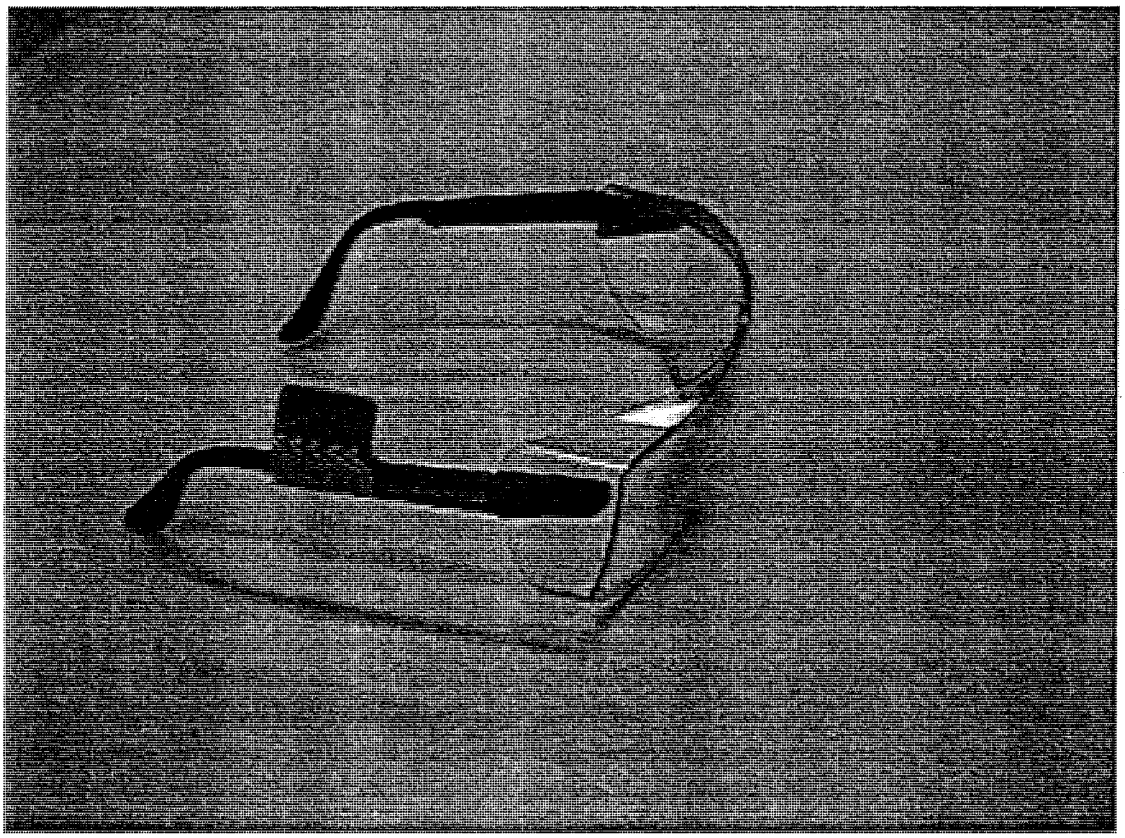
Choice of eyewear for the task

Resistance welding

41% (n=9) of the injuries occurred during resistance welding. AS 1336:1997 specifies the use of safety spectacles or eye-shields for this task. This is viewed as a low impact risk and workers chose to use wide-vision spectacles with or without tinting. There was no evidence of any damage to the eyewear that could have contributed to the injury. Some scratching, mainly due to storage methods, was observed.

Although workers have access to a wide range of eye protection, 89% (n=19) of subjects performing spot welding tasks chose the Bollé wide-vision spectacles. (This is similar to the total proportion of all workers carrying out these tasks.) They saw them as light and functional, as well as providing sufficient ventilation for continuous use. It was also apparent that the style of the Bollé was perceived to be fashionable, which was also a factor in the worker's choice of preferred eye protection. All of the workers interviewed who had been performing spot welding tasks for any significant length of time indicated that they had, on average, experienced at least one previous eye injury, with one reporting five injuries in less than two years. During the period of the study, one subject was treated on consecutive days for similar injuries to each eye. Despite this, they had not sought other eye protection such as wide-vision goggles. The need to wear protection continuously, for a full shift, with problems of sweating, eye ventilation and fogging in the hot conditions, and the lack of aesthetics of goggles, were mentioned as reasons for not considering them.

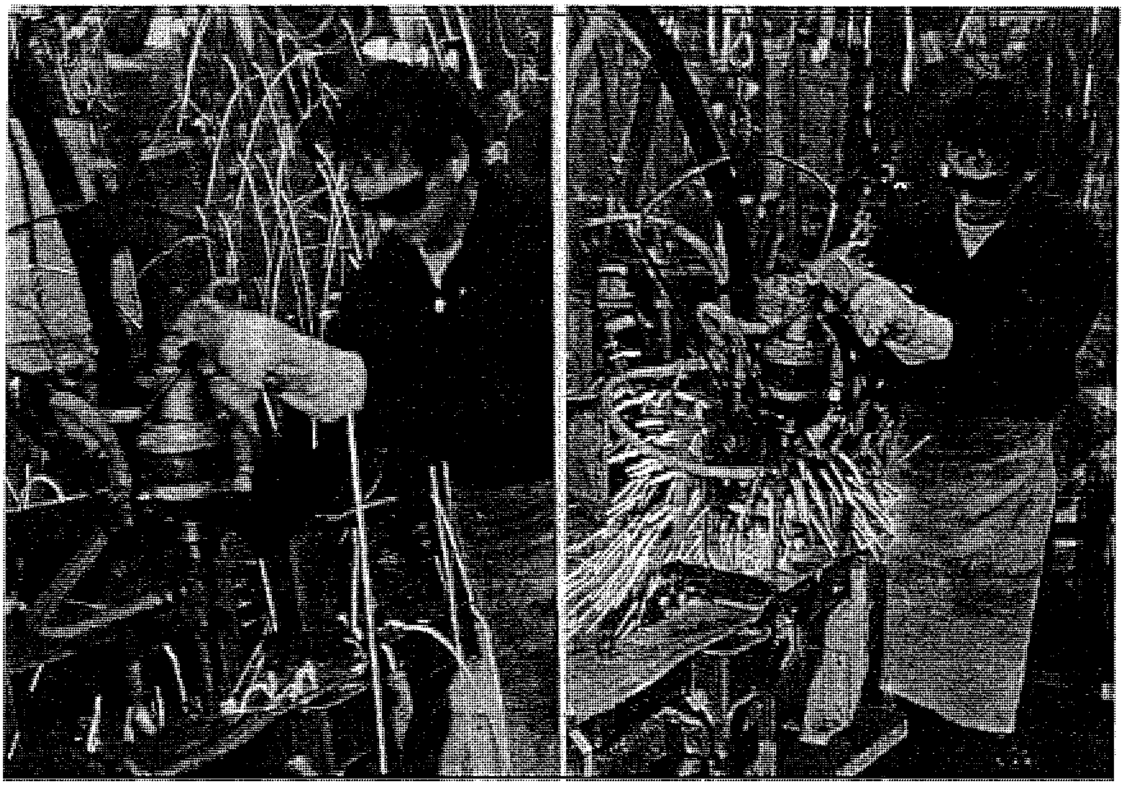
Plate 1 The type of Bollé wide-vision spectacles used by the majority of workers on the MMAL body build line



Resistance welding uses movable guns. The position of the work, relative to the eyes of the worker, changes according to the position of the material to be joined, and work can be as close as 30 cm from the worker's eyes, while the angle can vary from right to left, and above and below eye level. Several workers operate in close proximity during final assembly operation. This leads to a need for eye protection that gives all-round coverage

Plate 2 shows the patterns of sparks produced during the joining of one type of panel. The amount of sparking is inconsistent, and the direction of travel of sparks changes according to the shape of the panel and the angle of the gun. The picture on the right shows large sparks being directed down, posing low risk to the operator. The one on the left shows particles travelling upward. The gap at the bottom of this operator's eye protection was up to 9 mm, the overall bottom gap average was 12 mm. Sparks can also be seen falling from above the worker's head, which could occur, both as a result of this operation, or from sparks from nearby operations. The average top gap for workers was 11.5 mm.

Plate 2 Resistance welding operations



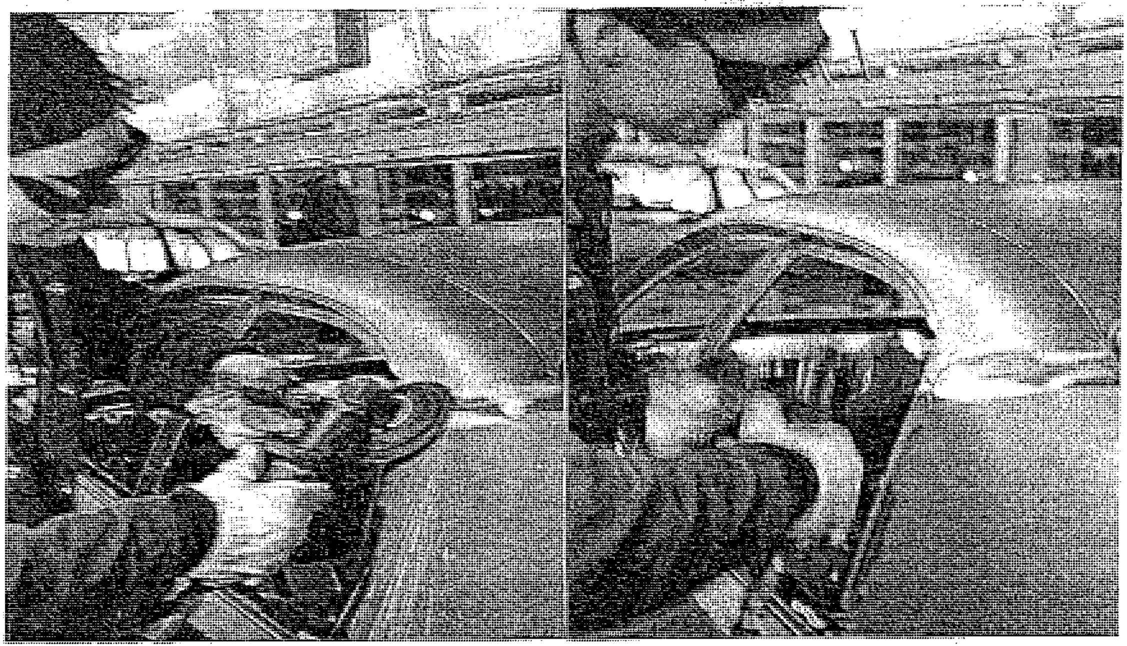
Buffing and grinding

Buffing and grinding operations were involved in 36% of cases. AS 1336:1997 views this as a medium impact task. It specifies the use of wide-vision spectacles, face-shields or hoods and helmets. All workers injured were using wide-vision spectacles. These were stamped with the lens code I signifying them as suitable for a medium impact task. The earlier version of AS 1336 specified the use of wide-vision goggles (secured by a strap around the head) as defined in AS 1337 page 4.

Once again, the predominant eyewear chosen was Bollé wide-vision spectacles. Only 14% (n=3) of injured workers used other brands. The injury pattern appears consistent with the wearing patterns on the floor. Observation of workers on the floor showed that nearly all were wearing Bollé wide-vision spectacles. There is little likelihood that Bollé wide-vision spectacles carry increased risk. It is most likely that the problem is generic across all brands, but the distribution of eyewear use in this study prevented this assessment from being made.

Plate 3 shows one of the grinding operations that resulted in several of the eye injuries seen. The exhaust of the air-powered grinder, and the wind generated by the spinning tool, cause particles to be ejected in clouds during certain parts of the operation. It can be seen that, during the main operation, sparks are directed away from the face of the operator. Material can, however, build up in the rain gutter area and, when the grinder is moved off the work, the accumulated particles can be blown into the workers face by the vortex of the tool or the exhausted air. It will also be noted that the operators face is close to the work. The task requires that a line of sight is maintained across the work so that imperfections can be seen and ground away. As a result, the eyes are not always facing the tool, and the bottom gap between cheeks and eyewear can be exposed to particles.

Plate 3 Grinding and buffing a door pillar



Gaps around eyewear

Each subject was asked to fit the eyewear used at the time of injury with standard adjustments. This included adjustment of tilt and sidearm length where possible. Any gaps were identified and measured using the photographic techniques described above. The most significant gaps were at the top (between the brow and the eyewear) and bottom (between the cheek and the eyewear). There was no evidence that available adjustments would substantially reduce the top or bottom gap without increasing the opposite gap.

Table 3 Distribution of gaps around protective eyewear

Gap position	Depth mm			Area sq mm		
	Min	Max	Mean	Min	Max	Mean
Top	5	20	11.5	500	1770	934
Bottom	8	20	12.0	510	1750	888
Top plus bottom				1170	2956	1775

Note: The width and depth are the maximum observed, measured perpendicular to the plane of the face at that point. Area is the total area of observable gap trace around the edge of the eye protector and the forehead line perpendicular to the line of the eye protector.

Relationships between gaps and facial measurements

The shape of the worker's face makes a great deal of difference to the way that eyewear fits. The picture below is one example of the way in which the design of the eyewear and the shape of the worker's face cause problems.

of the face shapes encountered, and a more complex assessment is needed. The head-form used for the Australian Standard is that based on the European male. Given the diversity of ages of workers, the distribution of nationalities and the employment of female workers for operations requiring buffing, grinding and spot welding, it appears that the head-form does not provide sufficient information for designers. In addition, the measures used in AS1337 do not adequately define the shape of the face in a way that identifies to designers the range of shapes necessary to provide adequate protection.

AS 1336 calls for good fit, but does not define it. This is an important weakness in the Standard. In the absence of guidelines, inconsistent practice will continue, and the large gaps demonstrated in this study will continue to occur. The literature, including the present study, underlines the importance of a proper fit and the need for the development of appropriate guidelines for the fitting of protective eyewear. These need to take into account the task being undertaken and the nature and direction of travel of likely hazards. Gaps between the face and the eyewear, in the directions of likely assault, should be minimised. The exact specification of gap size needs to be the subject of further debate and analysis, as there is a trade off between protection and ventilation that must be made if rigid frames are permitted. Introduction of designs using softer face-fitting materials that breathe may be one way to eliminate gaps, whilst still providing ventilation.

Conclusions

The hazard

The particular hazard for the automotive industry is that workers are exposed to flying metal particles for long periods of time during every shift. This high rate of exposure results in a high rate of injury. In these circumstances, devices that are highly effective in protecting against eye injuries are required. The industry has utilised protective measures such as screens to reduce the hazard, but the need for personal protective equipment remains.

Eye protection must be worn for long periods in hot manufacturing environments. The protection must therefore be lightweight, well ventilated and comfortable. This has influenced workers to choose wide-vision spectacles. The gaps around this type of eyewear can be large. This study has identified eye injuries occurring where the gap was as small as 5 mm and as large as 20 mm.

The problem

AS1336 recommendations for medium impact operations and spot welding are inadequate. Under the influence of the Standard, workers and employers are choosing eye protection with the greatest comfort under the false impression that it provides adequate protection. However, the Standard does not adequately define fit, and the use of wide-vision spectacles, without ensuring adequate fit, should be discontinued.

Employers could pay more attention to fit and so reduce the risk of injury. Their attempts to do so are limited by the range of wide-vision spectacles available. Employers are currently faced with the need to require wide-vision goggles to be worn to increase eye protection, knowing that this would create compliance problems and possibly impede workers' vision, resulting in other risks and lowering of work performance.

In respect to design, there is a lack of precision in terms of lens curvature, a lack of adjustment and little flexibility to permit many workers to choose wide-vision spectacles that will fit well enough to protect them from injury during metal-working tasks.

In preliminary discussion with Australian Standards Committee for Standards 1336 & 1337, some members indicated to the principal investigator that they believed that the apparent failure of eye protection is mainly due to workers falsely claiming to be wearing protection at the time of injury. This belief flies in the face of the literature presented in this paper, and of the findings of this study which, while small, demonstrate that a problem exists with the design and fit of protective eyewear. It presents evidence of cases of eye protection failure and attempts to explain the mechanisms. It is uncertain whether the Committee has read the literature and dismissed it, or whether it has received inadequate information from its advisers.

The solution

The critical design issue is to develop a range of protective eyewear that provides adequate ventilation and comfort while maintaining close fit. Other types of eye protection recommended in AS1366 could provide greater protection. These, however, are far less convenient and carry with them problems of restricted vision, fogging and lack of comfort.

Design improvements could include:

- a wider range of sizes and increased adjustability;
- provision of a lightweight strap or flexible ear pieces to increase stability and prevent slippage of spectacles;
- use of flexible materials which can conform to the face while permitting adequate ventilation;
- the use of mouldable plastics to permit individual fitting similar to the process used for mouthguards.

The strategy

The strategy for dealing with this issue has a number of components. There is a need, as discussed above, to deal with design flaws and limitations in the Standards. In the short term, while the development of more suitable eyewear is investigated, an interim solution for workers and employers should be adopted.

Research and development of eyewear

Workers have shown a clear preference for the wide-vision spectacle design. They were almost universally used by both injury cases and other workers on the floor. Discussions with supervisors and workers indicated that wide-vision spectacles were chosen because they were light, comfortable, and did not fog or produce sweating problems in hot weather. It is, therefore, sensible to determine if this design can be improved to provide adequate levels of protection. The current use of a European male head-form is inadequate given the age, racial and gender mix of the workforce. To provide a proper fit, a better understanding of the variability of facial shapes among workers is required. One avenue of investigation could involve computer modelling of face shapes which may provide a much better basis for eyewear design. Work on facial modelling is being done by injury researchers to inform the United States ANSI Standards Committee on Eye Protection.

Once the design parameters are better understood, there is a need to explore the use of modern flexible materials to achieve better fit. Possibilities include the use of light aramid cloths to bridge gaps and mouldable plastics to increase the precision of individual fit.

Standards

There is a need for more empirical evidence to be used in the preparation of safety standards. Standards AS1336 and AS1337 do not adequately define the design and choice of protective eyewear for buffing and grinding, or spot welding operations. In light of the evidence presented here, and elsewhere, the Standards should be reviewed and amended.

Workplace practices

Many eye injuries could be prevented by implementing a close fit policy for all workers using wide-vision spectacles when grinding, buffing or spot welding metal. Where it is not possible to achieve a fit with gaps of less than 1 mm, alternative eye protection should be used. The figure of 1 mm has been chosen as being sufficient to allow some ventilation, but to trap or exclude solid particles. Further research is needed to determine the exact size of the gap that can be accepted.

Recommendations

Standards

AS 1336 should be amended to require:

- wide-vision goggles to be used for metal buffing and grinding operations where wide-vision spectacles can not be fitted with a gap of less than 1 mm;

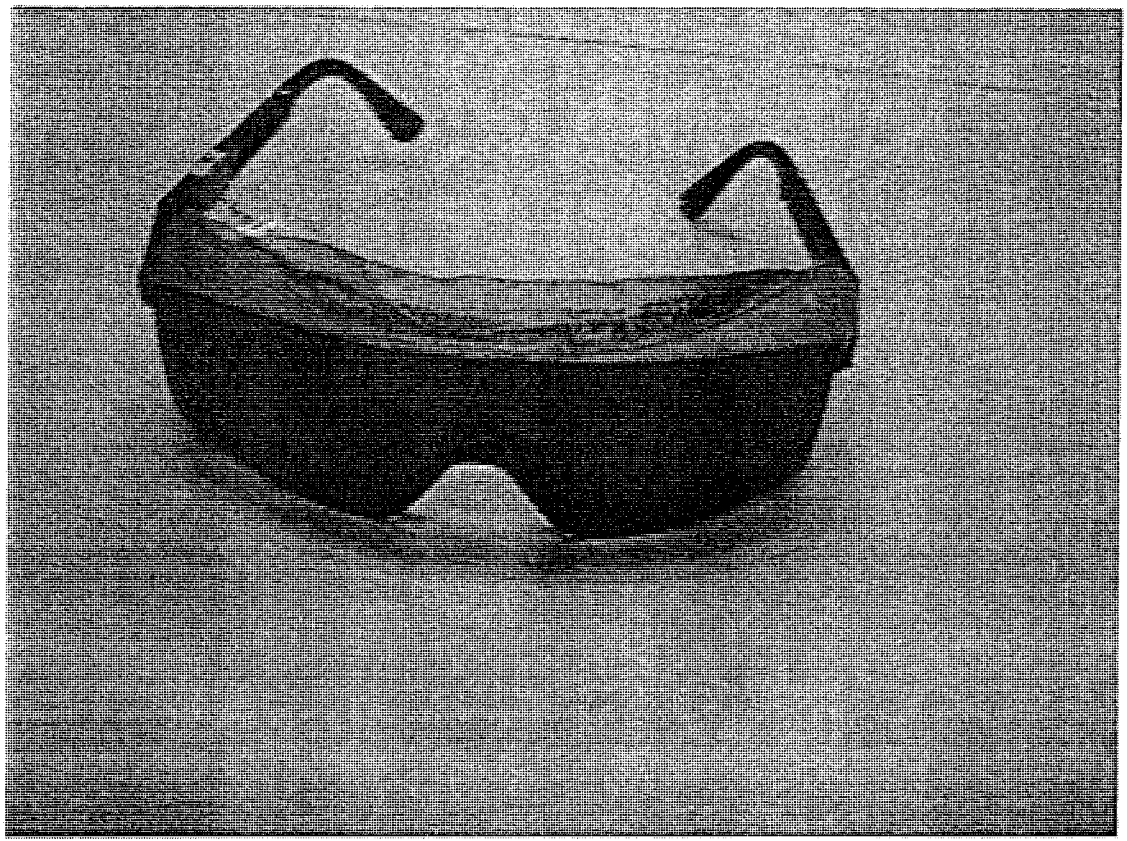
Plate 4 One worker in this study shows the degree of mismatch between his chosen protection and the shape of his face

In this project we examined some simple measurements, as discussed above, of shape of worker's faces. During measurement, it became obvious that a more complex approach was needed to explain the size and shape of gaps being observed. Correlations between the anthropometric measures, and the depth and area of the gaps, were calculated. There was only one observed significant correlation, which was between average eye depth and the bottom gap ($r=0.56$, $p < 0.05$).

There were large variations in face contours. Neither brow nor cheek reference points were sufficient to describe the variation of facial curves across the face at these points. Several of the younger workers had very thin faces with prominent bone structures resulting in eyewear resting on these features, leaving gaps at other points.

Several subjects mentioned that the eyewear did not provide a snug fit. Although the spectacle arms on Bollé wide-vision spectacles are adjustable, some workers complained that, even when adjusted to their shortest setting, they still slipped down on the nose. Further investigation found that none of the subjects in the study had adjusted them past the first extension hole. In addition to the adjustable arms, the Bollé 807 has a tilt adjustment designed to minimise either top or bottom gaps, depending on the perceived source of any potential particle irritant. If workers perceive the problem as coming from below, the tilt was set to minimise the bottom gap. If the problem was seen as particles falling from the top the tilt was set to minimise this gap. One worker had set the tilt to minimise the bottom gap and then used masking tape to create a closer fit at the top. The adjustments available were not able to eliminate gaps at both the top and bottom simultaneously.

Plate 5 Worker ingenuity failed to avert an injury even though the problem was recognised.



Protective eyewear available at Mitsubishi

While workers choose from a limited range of eyewear, a wider selection is available. Table 4 shows the range available at the time of the study. It was clear, from the interviews, that workers have developed a fashion for choosing one particular brand and style of eyewear.

Table 4 Types and dimensions of protective eyewear available at Mitsubishi

Type	Brand	Lens Codes	Width	Sidearm length Min Max	Tilt Adjustment
Faceshield	Gardwel Lic 448	A-I	260	NA	NA
	As above with chin guard	_	240	NA	NA
Supplied air visor	Pulsafe Clear-flow supplied air visor AF9133 Din23 BS 2092.2c LIC 3429	_		NA	NA
Wide-vision spectacle	Bollé Lic no 807 Clear	I	135	90-115	Y
	Bollé Lic no 807 Tinted Dark	_	135	90-115	Y
	Bollé Lic no 807 Tinted Yellow	I	135	90-115	Y
	Bollé Lic 807 (Heavy duty side wings	_	130	95-115	
	Yukon Crews Z87.1, Z94.3 AS1337 Lic 859 Alsafe 2020 Z87.1 AS 1337 Lic 448	_	155	80	N
Wide-vision goggle	Alsafe AS 1337 Lic 446	A-I	150	NA	NA
Safety Spectacle with side guards	Gardwel AS 1337 Lic 448	GS	135	105	N
	Unknown AS 1337 Lic 797 Graded tint	SU	140	105	N

- all spectacle-type eyewear to be fitted so that a gap of no more than 1 mm exists between the face and the eyewear at any point where particulate material can enter;
- eyewear that meets medium impact requirements, as amended to reduce gaps, be used for spot or resistance welding operations.

AS 1337 should be amended to include greater details of the head-form, including maximum cheek depth and brow to cheek measurements in both the vertical and horizontal plane. In addition, the 95th percentile sizes for Australian males and females separately, should be clearly marked on the head-form diagram. Other measurements may also be required to provide an adequate model for designing eyewear that will fit a range of workers. The head-form measurements and confidence intervals should be based on both male and female populations of 15 years and above to cater for the needs of young workers. This would assist designers to consider the curvature of lenses needed to achieve proper fit for the full range of workers and trainees.

Design of protective eyewear

Protective eyewear designers should undertake research and development in order to develop better fitting wide-vision spectacles. There is a need for a wider range of sizes, lens curvatures and the use of flexible materials to better fit facial contours of the full range of workers, while maintaining ventilation and comfort.

Workplace practices

While, theoretically, it would be preferable to design operations to eliminate the need for protective eyewear, this is impractical. The mobility requirements of the tasks make the use of additional screens difficult, if not impossible. A move to robotic welding operations would avoid human exposure, but this carries with it high set-up costs and the social costs of reduced employment. In the absence of other solutions, workplaces should ensure that protective eyewear used for metal work of any kind should fit so that the gap between the face and the eyewear at any point where particulate material can enter is no greater then 1 mm. Workers should be given instruction in the correct choice of eyewear and its adjustment to achieve an adequate fit.

For production line operations, employers may need to examine the feasibility of air supplied visors for workers undertaking repetitive spot welding, and grinding and buffing operations. This would provide incentives for workers to use this type of device by improving ventilation and providing positive pressure to reduce the entry of small particles.

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[1] US Department of Labour OSHA Fact Sheet 93-03 *Eye Protection in the workplace* 1993 :1

[2] Department of Occupational Health, Safety and Welfare "Eye injuries in industry" *Jobsafe Statistics No 5 93* West Perth 1993

[3] Gagnet G New rule mandates hazard assessment to specify protective equipment needs *Occupational Health and Safety* V63: No. 8 1994 page 52

[4] US Department of Labour OSHA Fact Sheet 93-03 *Eye Protection in the workplace* 1993 :1

[5] Fong LP, Taouk Y The role of eye protection in work related injuries *Aust NZ Journal of Ophthalmology* May 1995 101-106

[6] Dannenburg A et al Penetrating eye injuries in the workplace *Arch. Ophthalmol* Vol 110 June 1992 843-848.

[7] South Australian Health Commission *Injury Surveillance Monthly Bulletin* No 31 March 1991:1

[8] Standards Australia AS 1336:1997 *Recommended practices for occupational eye protection.* Page 13

[9] Standards Australia AS 1336:1997 *Recommended practices for occupational eye protection.* Appendix A2 Page 38.

[10] Measurement software was developed by Rosso Agostino Vialla Campania 42, 20133 Milan Italy

[11] The facial measurement device was designed and manufactured by Mr Chris Myers and Tim Eden of University of South Australia's School of Industrial Design.

[12] US Department of Energy *Environmental Safety and Health: Safety Note* (http://tis.eh.doe.gov/docs/sn/nsh9102.html) 1991

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