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SOME DESIGN RECOMMENDATIONS TO IMPROVE COMFORT IN HELMETS: A CASE STUDY FROM CHINA

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Unless the basic user needs are satisfied in safety helmets, it is difficult to get workers to wear them habitually and for long periods. Hotness, weight and fitting problems are major wearability issues that require improvements. The enormous need for an optimally designed helmet in China prompted a case study on comfort aspects in helmets. The subjective impressions of the wearers of test helmets provided useful information for design changes to improve comfort. The heat transfer measurements through helmets indicated the need for ventilation openings to be provided on the shell of plastic helmets. Due to the advantage of low weight and good ventilation, it is recommended that cane helmets be further developed to improve protection, wearability and durability, and subsequently be produced in large scale.

The head can be considered more vulnerable and most susceptible to disabling injury than any other part of the body. According to the National Safety Council of North America, in 1971 the head was involved in 7% of all industrial injuries and 8% of all farm accidents. More recently, in a postal questionnaire survey of 35 industrially developing countries, it was revealed by the respondents that head injuries accounted for 17% of all occupational accidents (ABEYSEKERA and SHAHNAVAZ, 1988a).

Various types of head gear or devices are used today to protect the head. Industrial safety helmets are used by industrial workers, crash helmets by motorcycle riders and sports helmets in ice hockey, football, ski-ing, etc. Safety helmets used to protect the head from impacts or severe hazards are usually covered by protection

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standards (e.g., shock absorbing, penetration, flame and electrical resistance, water absorption, etc.). But no matter how efficiently a helmet protects, the purpose is lost if the helmet is not worn properly by the workers due to discomfort or other shortcomings in wearability.

The importance of the comfort or wearability of industrial helmets to improve their user acceptability has been investigated in several past studies (Abeysekera and Shahnavaz, 1988b; Hickling, 1984; Väyrynen, 1983; Thomas, 1981; Smith and Anderson, 1978; Kamin and Scalone, 1974). Discomfort due to hotness or coldness, lack of proper fit and the weight to be carried on the head seem to be the major problems that require design improvements in helmets. Hotness is a significant problem in helmet wearing in tropical countries including southern China.

THE CASE STUDY IN CHINA

Industrial safety helmets are used by millions of workers in China. It has been observed that the helmet designs in China undergo rapid changes. It is a common sight in Chinese workplaces that different types of helmets are worn by workers in one work establishment. These observations reveal that an optimum helmet is yet to be designed. Rattan and cane helmets (made from dried stem of a creeping palm) were first used in China in the 1960s. Plastic helmets became popular in the 1970s. According to Safety Regulations in China, rattan and cane helmets are not allowed to be used near furnaces.

According to work accident statistics in China, head injuries are one of the chief causes for fatal accidents at work (SEPRI, personal communication, 1992). The hot and humid conditions in the working environment and the inadequacies of wearability characteristics in the helmets available in China have discouraged Chinese workers to wear helmets at work. The above reasons encouraged a case study to be conducted in Chinese workplaces with a view to improve comfort in helmets for use in China.

Methods

The study consisted of both subjective investigations in workplaces in China and objective tests carried out in a climatic chamber in Sweden using plastic and rattan helmets. Two types of helmets with plastic and rattan shells popularly used in Chinese workplaces were used in the study. The specifications of the 3 helmets (A, B, and C) used in this study are given in Table 1 (See also Fig. 1).

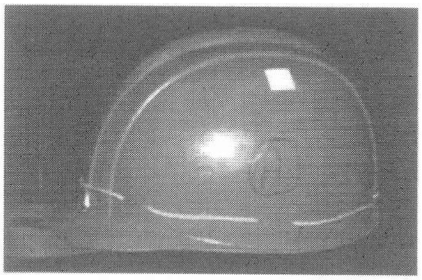
Thirty-two subjects from a steel mill in Wuhan, China, wore the 3 helmets for short (1 day) and long (6 days) periods. Thirteen subjects wore each of the 3 helmets for one day and another 19 subjects wore one of the 3 helmets continously for 6 days (during work shifts).

The subjects were questioned at the end of each day during short-period testing and the others were questioned at the end of 6 days after long-period testing.

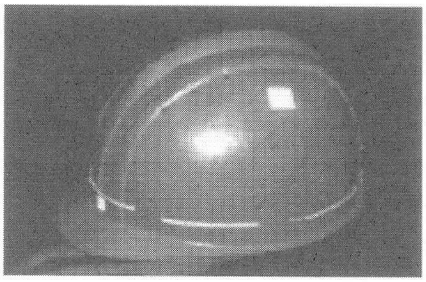
Table 1. Specifications of the three helmets used in the case study.

	Helmets* A & B (each)	Helmet C
Weight (g)		
Harness	70	35
Shell	332	265
Material		
Harness-head band	artificial leather with cotton lining	cotton with rubber lining
-cradle	cotton/canvass (thick)	cotton with rubber lining
-chin strap	cotton/canvass (thin)	cotton twine
Shell	plastic	rattan
Standards		
Protection	conform to impact absorption & penetration resistance	—

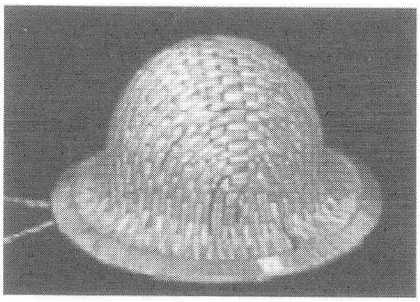
* Helmets A and B were identical except that the shell of helmet B was provided (modified) with ventilation holes (16 holes in two rows in the crown area, 6 holes in one row on the part that fits the forehead and another 8 holes, 4 on each side above the ears. The holes were circular and 4–5 mm in diameter.).



Helmet A



Helmet B



Helmet C

Fig. 1. Plastic helmets A and B and rattan helmet C used in the study.

Answers were recorded on the subjective impressions of each helmet worn. The subjective assessment included a questionnaire with rating scales on the comfort parameters, viz. general comfort, hotness, heaviness and fit of the helmets and their harnesses. Five point bi-polar rating scales were used. The short-period testing results were also used in a pair comparison analysis.

The experiment in the laboratory was designed to measure the heat transfer characteristics of the helmets used in the field study. Ability to dissipate heat through the helmet shell is an important characteristic in helmets used in hot environments. Another helmet made from cane (bamboo), also used popularly in China, was tested for heat transfer characteristics. The cane helmet which had a fibre glass-reinforced lining in the crown area satisfied the protection performance requirements (e.g., impact absorption and penetration resistance). The influence of the shell material and ventilation holes of the helmet were assessed for total heat transfer. A dry thermal manikin was used to simulate the human head in testing the dry-heat transfer (heat transferred through convection, conduction and radiation). A thermal manikin head, lined with an evenly wetted cloth was used to simulate the wet or evaporative heat transfer through the helmets.

To ascertain the fit of the helmets used on Chinese workers, comparisons were made of the head measurements of Chinese adults (National Standard measurements), with the relevant measurements taken on the helmets used in the survey.

Results

Results of the subjective judgments of the short-term and long-term tests were analyzed using the Kruskal-Wallis test of one way ANOVA using rank sums. The results are shown in Table 2a.

Paired comparison analysis of subjective impressions in the short-term test indicated that helmet B (+0.69) was preferred for comfort. Helmet C was felt as least hot (+1.61) and least heavy (+2.06) (EDWARDS, 1957) (Fig. 2). The long-term test provided the following results. Helmets A and B were more comfortable and better fitting than helmet C, but helmet C was rated least hot and least heavy. The ventilated helmet, B (with holes), was rated slightly less hot, with an average rating of 3.2, than the unventilated helmet, A (without holes), with an avearge rating of 2.9 (Table 2b).

The results of the dry-heat transfer test indicated that cane and rattan helmets transferred heat significantly better than plastic helmets (ABEYSEKERA et al., 1991). Heat losses in the wet-heat transfer test under 'no sun no wind' conditions indicated slightly higher heat transfer through the plastic shell with ventilated holes than the other identical plastic helmet but without holes (LIU, 1993). The cane helmet was the best for wet-heat transfer. Results of the heat losses (W/m^2) are shown in Table 3. For dry and wet-heat transfer measurements in the studies carried out by ABEYSEKERA and others (1991) and LIU (1993), respectively, helmets identical to A, B, and C have been used.

Table 2a. Results of subjective judgments of the 3 test helmets (Kruskal-Wallis test one way ANOVA, rank sums).

	Helmet A		Helmet B		Helmet C	
	L.T	*S.T*	L.T	*S.T*	L.T	*S.T*
1 2 3 4 5 (Very Uncomfortable – Not at all Uncomfortable)	85	*227*	69	*276*	36	*237*
1 2 3 4 5 (Very Hot – Not at all Hot)	57	*114*	55	*282*	78	*345**
1 2 3 4 5 (Heavy – Not at all heavy)	73	*196*	46	*211*	71	*333***
1 2 3 4 5 (Bad Fit – Fits Well)	73	*260*	71	*302*	45	*179*

L.T.: Long-Term Test (Total 19 ratings). Helmet A: 7 ratings; Helmet B: 6 ratings; Helmet C: 6 ratings. *S.T.: short-Term Test (Total 39 ratings). 13 ratings each for Helmet A, B and C.* * Significantly less hot ($p<0.001$). ** Significantly less heavy ($p<0.04$).

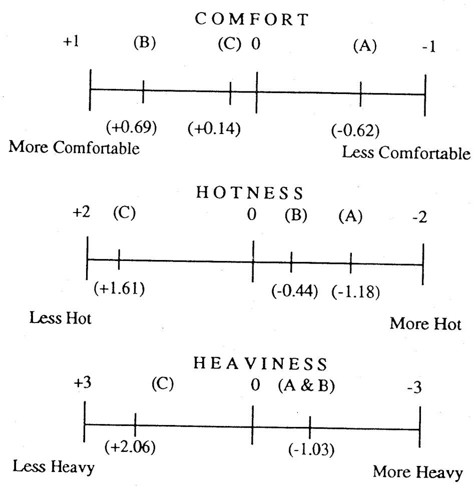


Fig. 2. Paired comparison results of the 3 helmets.

Table 2b. Results of subjective judgments of the 3 test helmets for the long-term test (average ratings).

	Helmet A	Helmet B	Helmet C
1 2 3 4 5 — Very Uncomfortable … Not at all Uncomfortable	3.3	3.3	2.5
1 2 3 4 5 — Very Hot … Not at all Hot	2.9	3.2	4.0
1 2 3 4 5 — Heavy … Not at all heavy	4.4	4.0	4.7
1 2 3 4 5 — Bad Fit … Fits Well	3.0	3.5	2.3

Table 3. Heat losses (W/m^2) through helmet shells.

	With sun & wind		No sun & wind	
	Dry	Wet	Dry	Wet
No helmet	89	124	107	116
Plastic (helmet A)	69	143	64	72
Plastic (helmet B)	72	121	67	74
Cane	82	146	68	84
Rattan (helmet C)	79	118	64	69

A comparison of the head dimensions of Chinese adults (National Standard GB 1000-88 of 18–60-year-old males) and the relevant dimensions of the 3 helmets and their harnesses used in the study revealed that the helmets and harnesses used in the study were too large and bulky in all respects. The helmet fit and retention were poor for the average Chinese. The results appear in Table 4.

DISCUSSION

Comfort is an important parameter which has to be compromised with safety in helmet manufacture and use. It is of no use providing a safety helmet with

Table 4. Head dimensions of Chinese adults and measurements of the test helmets and their harnesses (all measurements in millimeters).

	Humans			Harness*			Shell	
	Mean	5th	95th	Plastic		Rattan	Plastic	Rattan
				Min	Max			
Head length	184	173	195	174	247	205	240	210
Head breadth	154	145	164	158	184	175	197	180
Head circum.	560	536	586	540	655	590	700	635
Coronal arc	361	338	383	315	315	280	400	360
Head height	223	206	241	118	118	100	145	136

* Only the harness of the plastic shell helmet was adjustable.

excellent protection performance but lacking in wearability needs, thereby discouraging people to use it. However, in any protective wear there is a small component of unavoidable discomfort to which the wearers must adapt. According to Abeysekera and Shahnavaz (1990), significant adaptation to discomfort in helmets can be achieved by long-term and constant use of helmets which were originally uncomfortable.

The case study in China revealed that, though the rattan helmet was lighter and more ventilated, the overall discomfort after long-term wear was higher than the plastic helmets, which were heavier and less ventilated. In the short-term test, the plastic helmet with ventilation holes was rated most comfortable both in the rating scale and the paired comparison test.

In tropical countries, hotness is a common complaint among helmet wearers. The greenhouse effect (Kamin and Scalone, 1974) of unventilated helmets, radiant heat from the sun when helmets are used outdoors and the body heat due to physical activity can all contribute to a hot sensation on the head.

According to subjective judgments from long-term and short-term wearing of helmets, ventilated shells (e.g., helmet C), seem to reduce the hot sensation. From the results of the short-term test, the ventilation holes in the plastic helmet seem to contribute towards a reduction in heat discomfort.

From the judgments of heaviness of helmets, it is revealed that the perception of weight on the head is directly proportional to the actual weight carried on the head. Perhaps if the center of gravity of the helmet shell coincided with or is closer to the center of gravity of the human head, the weight may be percieved less than the actual weight (Abeysekera and Shahnavaz, 1988b).

According to the comparisons of human head dimensions and relevant helmet measurements, there seem to be large or significant differences (Table 4). Fit of the helmet is an important consideration for comfort, perhaps even more important than thermal comfort, particularly for long-term wear. The comments made by the wearers of helmets for long periods in the case study revealed that the harness of the rattan helmet had very poor retention characteristics, and that it was the harness of the rattan helmet that caused discomfort. Therefore, it can be concluded that inspite of the advantages of the low weight and better ventilation of the rattan helmet, the harness material, construction and fit can significantly influence the overall feeling of comfort or discomfort of a helmet.

Plastic helmets are more durable and can provide better protection against impacts, chemical splashes and electrical hazards to the head. In plastic helmets, if the ventilation could be improved by means of, for example, ventilation holes in the helmet shell, it may be possible to reduce the helmet bulk or volume, which in turn can reduce the weight. A low crown, less projections and low weight will also improve the helmet fit, retention and balance on the head. If rattan or cane helmets can satisfy the protection requirements, these helmets have great advantages due to their low weight and good ventilation. Finally, the helmet harness material, design and fit can provide a major contribution to improving the wearability of helmets.

DESIGN RECOMMENDATIONS FOR COMFORTABLE SAFETY HELMETS

The following design recommendations are suggested based on the case study carried out in China, laboratory tests on heat transfer characteristics of helmets conducted in Sweden and the doctoral research work on comfort of safety helmets carried out by the first author during 1986–89 (Abeysekera, 1989). A recommended prototype plastic helmet is illustrated in Fig. 3.

Helmet shell

Conformation to the prevailing protection standards for head gear is a basic requirement for both plastic and cane helmets.

Material. (a) Plastic: Acrylonitrile-Butadiene-Styrene (ABS)/PVC copolymer: This material has the advantage of low weight and was rated best for heat transfer

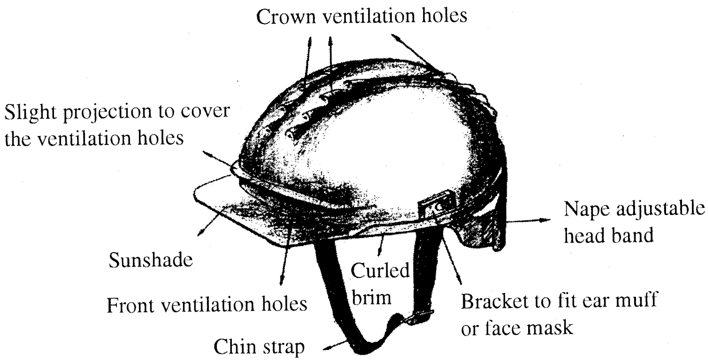


Fig. 3. The recommended prototype plastic helmet.

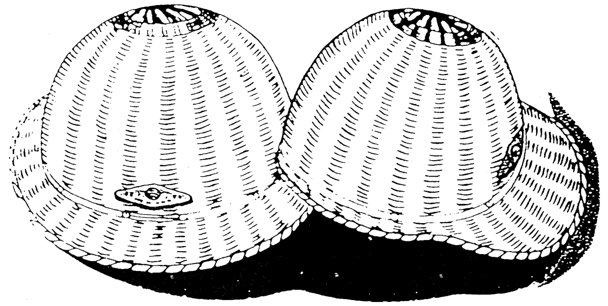
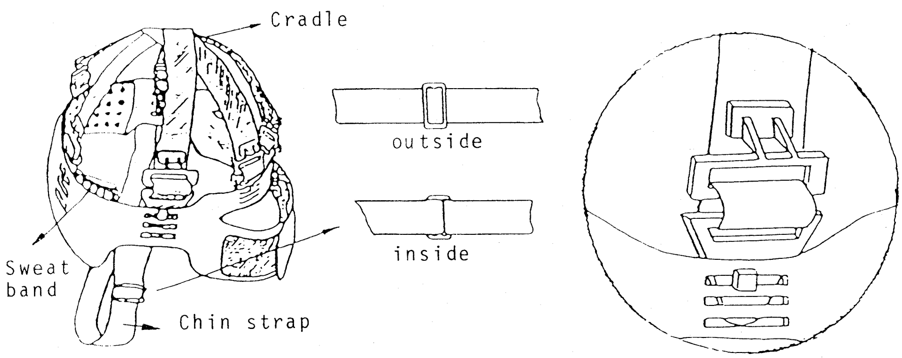


Fig. 4. Cane (bamboo) helmet shells (helmets popular in China).



Suspension and chin strap

Adjustable fitting of cradle

Fig. 5. The recommended harness specifications.

when compared with other plastic material (ABEYSEKERA et al., 1991). (b) Bamboo (Cane) (see Fig. 4): This material is lighter, has the advantage of good ventilation and heat transfer and has similar characteristics as the rattan helmet, which was rated less hot and less heavy than plastic material.

Weight. Plastic: Maximum 300 g with harness, Bamboo: 250 g with harness. The center of gravity of the shell must be as close as possible to the apex of the human head.

Shape. Should be cap shaped. The shape should conform to the profile of the head of the user population. Low crown, short and adjustable sunshade and a curled brim are other requirements.

Ventilation. Two rows of ventilation holes arranged longitudinally along the crown area and one row of holes arranged over the forehead area transversely. Ventilation clearance of 10 mm between the shell and harness of the circumference and a stand-off distance of 30–35 mm at the top.

Surfaces. Bright, glossy metallic outer. Surfaces should be smooth and round both inside and outside. Glossy outer surfaces have proved to improve heat transfer (ABEYSEKERA et al., 1991).

Compatibility. Facilities to fit other protective wear (e.g., ear-muffs).

Helmet harness (See Fig. 5)

Designed to fit the anthropometric data of the heads of the user population. Head measurements such as circumference, length, breadth, height and the bitragion coronal arc are important.

Head band. Compliant material (not rigid; e.g., artificial or natural leather). Adjustability over the range of the 5th to 95th percentile head circumference measurement of the user population.

Cradle. Flexible type of material. Fit over the ears and having 2 or 3 stages of vertical adjustability. Three-band straps to fit the whole head evenly with six brackets on the shell.

Sweat band. Flexible real or artificial leather material with ventilation holes or perforations.

Chin strap. Elastic material which is soft and broad with a side buckle for adjustability. The chin strap should be able to be turned over the shell when not in use. It should not pull the helmet forward.

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