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# Analysis of the Influence Factors of Safety Helmet Comfort

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**Abstract.** Safety Helmet comfort factor analysis is the foundation of safety helmet comfort design.This paper analyzes the characteristics of safety helmet comfort, adopts questionnaire investigation of safety helmet comfort requirements of each component system is analyzed, at the same time build the factors that affect safety helmet comfort level analysis model, and the various influence factors of safety helmet comfort of importance. The relevant research results can be used as the basis for the comfort design of the helmet.

## 1. Introduction

Safety helmet is a protective equipment [1] which is used to reduce or avoid impact on the head when the object strikes. As a personal labor protection equipment, wearing a safety helmet correctly can help prevent and control collision damage. However, in the actual operation, there are still some workers who are affected by the uncomfort of safety helmet, and they are not willing to wear safety helmet. The related research shows that in the workplace more than 15% of injuries are caused by not wearing safety helmet[2]. Some domestic scholars have carried out a certain research on the comfort problems of safety helmet, for example, Bian Xing [3] used safety requirements analysis and product characteristics list of safety helmet to guide safety helmet design practice, which provided a theoretical basis for comfort design of safety helmet. Li Luoming [4] used the biological heat transfer theory to build the heat transfer model of safety helmet,and carried out the numerical simulation of the temperature field inside the helmet, the temperature field distribution inside the helmet is intuitively grasped. To some extent, these studies have filled the deficiency of safety helmet comfort research, but have not further studied the influencing factors of safety helmet comfort.

## 2. Structure of safety helmet

The safety helmet is mainly composed of three parts: cap shell, cap hoop and lining belt,[5]the caps are mainly subjected to shock, and separated the falling objects from the human body.The hoop keeps the safety helmet at a definite position on the head.The liner is mainly to reduce the friction between the head and the cap shell, and at the same time, it has the effect of absorbing sweat.

## 3. Analysis of the comfort characteristics of safety helmet

### *3.1Analytic hierarchy process of safety helmet comfort*

The safety helmet's comfort is the research content of ergonomics. According to its research hierarchy theory, the research level of helmet can be divided into 4 levels, as shown in Figure 1.Comfort research is a high-level demand based on the safety of the first class and the efficiency of the second level.

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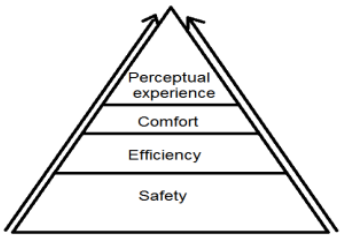


Figure 1 Schematic of 4 levels of safety helmet research

*3.2Safety helmet comfort characteristics*

The comfort of safety helmet should be embodied in [6], which satisfies users' physiological and psychological needs and wears stability. Specifically, a comfortable helmet should contain the following characteristics:

(1) The structure of the helmet is in line with the physiological characteristics of the human body. Only the safety helmet that meets the physiological characteristics of the human body can make the wearer get a better comfort experience. On the contrary, the unreasonable structural design of the helmet can cause the discomfort of the wearer.

(2) The material of the helmet is in line with the psychological needs of the human body. In the course of operation, the psychological needs of workers are mainly realized by sensory experience, and the material of safety helmet affects workers' sensory experience directly. For example, the safety helmet material has a bad smell, and users can not get good sensory experience, which directly affects the realization of their psychological needs.

(3) The safety helmet wears well. Safety helmet as a personal protective equipment, its stability will also affect its comfort. For example, a larger safety helmet will affect the normal operation of workers.

## 4. A questionnaire survey on the comfort requirement of safety helmet

*4.1Selection of research objects*

There are many factors that affect the safety helmet comfort, and regional differences, working environment changes and individual differences may affect it. According to the actual situation, this paper selects the most frequent construction workers as the research object, and carries out investigation and research on two construction sites in Anhui and Xiamen. In the survey, according to the basic principles and methods of investigation and research, the work age distribution of the research objects is determined from 1~20 years, and the results of the investigation are adjusted properly.

*4.2Questionnaire design*

Based on the analysis results of comfort characteristics of safety helmet, considering the rationality of the research work, we designed attitudinal type and opinion type questionnaires for safety helmet comfort. The attitudinal type questionnaire includes the builders' feedback on the industrial safety helmet system compositions, such as heat dissipation performance, contact sense and comfort. The opinion type questionnaire includes the workers' views on the comfort of the current safety helmet and the suggestions for improving the strategy.

*4.3Questionnaire issuance*

*4.4*A random sampling method is adopted for the issuance of questionnaires,colligated the "13th Five-Year plan" for the development of construction industry issued by the Ministry of housing and urban rural development,and the development of construction industry in Anhui and Fujian provinces.100 questionnaires and 120 questionnaires were distributed to each province by e-mail,a

total of 220 questionnaires,130 questionnaires were recovered, and the recovery rate was 59.09%，among them,there were 98 effective questionnaires, and the effective rate was 75.38%.

*4.5Statistical analysis of questionnaire survey results*

Taking into account the comfort characteristics of safety helmet, from three aspects of safety cap shell, safety cap hoop, safety cap lining belt, the statistical frequency is shown in table 1 by weight, odor, heat dissipation, stability and contact sense.

Table 1 Survey results of safety helmet influencing factors

| Survey content | | Influence factors | | | | | |
|---|---|---|---|---|---|---|---|
| | | Weight | Odor | Heat dissipation | Stability | Contact sence | Size |
| Cap shell | Frequency | 31 | 28 | 37 | 1 | 0 | 1 |
| | Percentage % | 31.63 | 28.57 | 37.76 | 1.02 | 0 | 1.02 |
| Cap hoop | Frequency | 0 | 3 | 39 | 23 | 31 | 2 |
| | Percentag% | 0 | 3.06 | 39.80 | 23.47 | 31.63 | 2.04 |
| Lining belt | Frequency | 0 | 23 | 21 | 0 | 40 | 14 |
| | Percentag% | 0 | 23.47 | 21.43 | 0 | 40.82 | 14.28 |

The results of questionnaire survey show that there are great differences in the ranking of influencing factors of comfort factors at different structural locations of helmets. Among them, the main factors affecting the comfort of the cap shell are weight, odor and heat dissipation, and the factors affecting the comfort of the cap hoop are mainly heat dissipation, stability and contact sense, and the factors affecting the comfort of the lining belt are mainly odor, heat dissipation, contact sense and size. Therefore, the comfort requirement of the safety helmet can be determined as shown in Table 2.

Table 2 Comfort requirement table for different structural parts of safety helmet

| Structural parts of safety helmet | Content of comfort demand |
|---|---|
| Cap shell | Strengthen ventilation and heat dissipation, and strive for lighter weight, with sunshade function. |
| Cap hoop | It needs a good sweat or sweating, good softness, and a tight fit with the head. |
| Lining belt | It has good sweat absorption, sweat and air permeability, soft contact and convenient adjustment. |

## 5. Analytic hierarchy process (AHP) and weight determination of influencing factors for safety helmet comfort

*5.1Analytic hierarchy process*

The correlation between the influencing factors of the safety helmet comfort is more complex, and it is difficult to use the quantitative index to analyze. This paper uses the grey analytic hierarchy process to construct the hierarchical structure model among the factors, and the concrete method steps are as follows:

- Clear the question. The main problem of this paper is to sort out the factors affecting the comfort of the helmet, so as to analyze the correlation among the factors. It is difficult to analyze the factors with the quantitative index, so the expert scoring method is selected to carry out the research.

- Building a hierarchical structure model. According to the preliminary analysis of the evaluation index system, the evaluation system is composed of a tree structure based on hierarchical structure. Generally speaking, analytic hierarchy process can be divided into three levels: target level, standard level and index level. The first level is the target level, which represents the decision maker's goal. The second level is the standard level (factor level), which is a measure of whether or not to achieve the goal. The third level is the index level, which represents some factors related to the goal.
- Determine the level of importance. The expert scoring method is based on a given grading standard, scoring the importance rank of each factor, and the specific grading standard is shown in Table 3.

Table 3 Expert scoring standard table

| Number | Rank of importance | Meaning |
|---|---|---|
| 1 | 1 | **i**, **j** two elements are equally important |
| 2 | 3 | The **i** element is slightly more important than the **j** element |
| 3 | 5 | The **i** element is obviously more important than the **j** element |
| 4 | 7 | The **i** element is strongly more important than the **j** element |
| 5 | 9 | The **i** element is extremely more important than the **j** element |
| 6 | 1/3 | The **i** element is slightly less important than the **j** element |
| 7 | 1/5 | The **i** element is obviously less important than the **j** element |
| 8 | 1/7 | The **i** element is strongly less important than the **j** element |
| 9 | 1/9 | The **i** element is extremely less important than the **j** element |

In the multi factor safety helmet distribution assessment, the degree of importance of each factor is different, and the degree of correlation is also very different. According to the characteristics of safety helmet distribution, AHP defines its importance as follows[7]: Relative comparison is the most important: from the second level, we compare the two elements in the next level and evaluate them according to their importance.Notice that the i element is more important than the j element, mark $\alpha_{ij}$ for the importance of the i element to the j element.,table 4 gives 9 important levels.Among them, $\alpha_{ij} =$ {2,4,6,8,l/2/,l/4/,l/6,1/8} signify the level of importance were situated between the corresponding values of $\alpha_{ij} =$ {l,3,5,7,9,l/3,l/5/,l/7,l/9}.

Follow the principle of consistency: when i is more important than j, and j is more important than k, it is considered that i is more important than k.

(1) Structure judgment matrix.

At each level, according to the corresponding standard of the previous level, the elements of the level (index) are compared by their comparison and quantized according to the specified importance level, and then they are written into the matrix form.Namely, $A = [\alpha_{ij}]$,A is a judgment matrix.Among them: $\alpha_{ij>0}$ , $\alpha_{ii=1}$ , $\alpha_{ij} = 1/\alpha_{ji}$ And, that is, A is a positive reciprocal matrix.

(2) The calculation of hierarchy and the calculation of weight.

Hierarchical ranking and weight calculation include hierarchical single ranking and weight calculation, layer total ranking and weight calculation. The essence of hierarchical single order and weight calculation is to calculate the maximum eigenvalue of the characteristic matrix. $\lambda_{max}$ and its

corresponding eigenvector $\omega=(\omega_1,\omega_2,\cdots,\omega_n)^T$ .After $\omega_1,\omega_2,\cdots,\omega_n$ were being homogenized, they get the weight of all factors (or factors) at this level.The overall ranking and weight calculation can be obtained by $\omega^{(s)}=P^{(s)}P^{(s-1)}\cdots P^{(3)}P^{(2)}\omega^{(2)}$ .Among them, the s is the total number of layers, and the p is the weight matrix.

*5.2Comfort helmet hierarchical structure model and related calculation*

*5.2.1The hierarchy structure model of safety helmet comfort*

Taking the comfort of the helmet as the target layer (A), the main factor that affects the comfort of the helmet is selected as the standard layer (B), and several factors in each factor are used as the index layer (C). Based on the analytic hierarchy process, a hierarchical structure model for the comfort of the helmet is constructed, as shown in Figure 2.

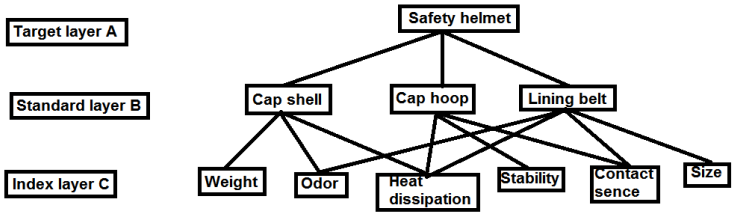


Figure 2 safety helmet comfort hierarchy model

*5.2.2Calculation of index weight of influence factors of comfort degree*

The index weight of the influencing factors of the safety helmet comfort reflects the importance of each factor in the index layer to the criteria of the standard layer, and is an important basis for the analysis of the comfort requirements of the different structure of the helmet. In order to determine the relative importance of each factor in the index layer, it is necessary to find the relative importance of each factor in the standard layer to the target layer, and to calculate the weight of the factors in the index layer by the expert scoring table.

(1) The importance of the factors of the standard layer to the target layer

The relative importance of cap shell, cap hoop and lining belt in target layer of the safety helmet is calculated. The importance of each factor is calculated by comparing each other. The weight is calculated by the sum product method or the square root method and the maximum eigenvalue is calculated. The importance matrix of factor level is shown in table 4.

Table 4 importance judgment matrix for each factor of the standard layer

| Target layer A | $B_1$ | $B_2$ | $B_3$ |
|---|---|---|---|
| $B_1$ | 1 | 3 | 1/2 |
| $B_2$ | 1/3 | 1 | 1/5 |
| $B_3$ | 2 | 5 | 1 |

Calculate the weight vector approximate value of evaluation factor by sum product method.

The first step: the comparison matrix A is normalized by the column.

$$\overline{\alpha_{ij}}=\alpha_{ij}/\sum_{i=1}^{n}\alpha_{ij} \quad (i,j=1,2,\ldots\ldots,\ n) \qquad (1)$$

The first step: standardized results for the first step add by line and get the sum number $\overline{\omega_i}$

$$\overline{\omega_i}=\sum_{i=1}^{n}\overline{\alpha_{ij}} \qquad (2)$$

They were calculated that:

$$\overline{\omega_1}=1.145,\quad \overline{\omega_2}=0.406,\quad \overline{\omega_3}=2.154$$

Third step: standardize the weight coefficients for the second step results.

$$\omega_i = \overline{\omega_i} / \sum_{i=1}^{n} \overline{\omega_i} \quad (3)$$

Calculated that:

$$\omega_1 = 0.309, \quad \omega_2 = 0.200, \quad \omega_3 = 0.582 。$$

A simple algorithm for obtaining the maximum eigenvalue is used to calculate the maximum eigenvalue of the comparison matrix :

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{[A\omega]_i}{n\omega} \quad (4)$$

$$[A\omega]_i = \begin{bmatrix} 1\times0.309+3\times0.200+1/2\times0.582 \\ 1/3\times0.309+1\times0.200+1/5\times0.582 \\ 2\times0.309+5\times0.200+1\times0.582 \end{bmatrix} = \begin{bmatrix} 1.200 \\ 0.420 \\ 2.200 \end{bmatrix}$$

$$\lambda_{\max} = \frac{1}{3}\left(\frac{1.200}{0.309}+\frac{0.402}{0.200}+\frac{2.200}{0.582}\right) = 3.225 \qquad W = (0.309,0.200,0.582)^T$$

(2) The relative importance of each factor in the index layer to the criterion level.

The calculation results of the relative importance of each factor to the criterion layer are shown in Table 5.

Table 5 B1-C Judgment matrix

| $B_1$ | $C_1$ | $C_2$ | $C_3$ |
|---|---|---|---|
| $C_1$ | 1 | 2 | 1/4 |
| $C_2$ | 1/2 | 1 | 1/8 |
| $C_3$ | 4 | 8 | 1 |

$\lambda_{\max} = 3.000$, $W = (0.182,0.091,0.727)^T$

$\lambda_{\max} = 3.040$, $W = (0.637,0.105,0.258)^T$

$\lambda_{\max} = 4.249$, $W = (0.376,0.237,0.237,0.149)^T$

*5.2.3Ranking of safety helmet comfort factors*

The weight of the safety helmet shell on the safety helmet is as follows:

$0.309\times(0.182,0.091,0.727)^T=(0.056,0.028,0.225)^T$

The weight of the safety helmet hoop on the safety helmet is as follows:

$0.110\times(0.640,0.105,0.258)^T=(0.070,0.012,0.028)^T$

The weight of the safety helmet lining belt on the safety helmet is as follows:

$0.582\times(0.376,0237,0.2370.149)^T=(0.219,0.138,0138,0.087)^T$

In summary, the order of correlation between factors and system rationality is shown in Table 6.

Table 6 Weight and comprehensive ranking of various factors

| Target layer | Standard layer | Index layer: Layered | Index layer: Weight | Rank |
|---|---|---|---|---|
| Safety helmet comfort | Cap shell | Weight | 0.056 | 6 |
| | | Odor | 0.028 | 8 |
| | | Heat dissipation | 0.225 | 1 |
| | | Stability | 0.070 | 5 |
| | Cap hoop | Contact sence | 0.012 | 9 |
| | | Heat dissipation | 0.028 | 7 |
| | | Size | 0.219 | 2 |
| | Lining | Odor | 0.138 | 3 |

| | | | |
|---|---|---|---|
| belt | Contact sence | 0.138 | 3 |
| | Heat dissipation | 0.087 | 4 |

The results show that the influence degree of each factor on the comfort of the helmet is: the heat dissipation of the cap shell > the size of the lining belt = the odor of the lining belt > the contact sence of the lining belt > the heat dissipation of the lining belt > the the stability of the cap hoop > the weight of the cap shell > the heat dissipation of the cap hoop > the odor of the cap shell > the contact sence of the cap hoop. This is basically consistent with the survey results, indicating that the analysis results are reliable.

## 6. Conclusion

In this paper, the factors affecting the comfort of safety helmet are qualitatively analyzed by questionnaire and analytic hierarchy process. The importance of the influencing factors of the safety helmet comfort is determined, and the reference is provided for the design and calculation of the safety helmet comfort. The concrete conclusions are as follows:

a. The results of the safety helmet comfort demand survey show that the cap shell part requires high ventilation heat dissipation, light quality and certain sun shading function, and the cap hoop part requires good sweating, sweating function, good flexibility and close fitting with the head, and the lining section requires good sweating, perspiration and air permeability. The contact is soft and easy to adjust.

The influence factor weight analysis shows that,the factors affecting the comfort of safety helmet are sorted from large to small : the heat dissipation of the cap shell > the size of the lining belt = the odor of the lining belt > the contact sence of the lining belt > the heat dissipation of the lining belt > the the stability of the cap hoop > the weight of the cap shell > the heat dissipation of the cap hoop > the odor of the cap shell > the contact sence of the cap hoop.

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