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THE INFLUENCE OF SWEAT ABSORBENT LINERS ON HELMET COMFORT AND COMPARISON WITH FABRIC HAND

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ABSTRACT

The prime purpose of a safety helmet is to protect the head against occupational hazards. However, a comfortable and ergonomic design is an important requirement in order for a helmet to be accepted by its users. We have proposed that the design and manufacture of a sweat absorbent Liners (SAL) is necessary for the creation of a comfortable helmet.

The purpose of this study is to clarify the relationship between helmet comfort and the physical properties of the SAL, and to compare forehead feel with hand feel. Sensory test using the semantic differential (SD) method was carried out in order to evaluate fabric hand and helmet comfort, and adjective pairs to describe the surface touch, thermal sense, and absorbency were prepared as evaluation terms. Test subjects were asked to exercise on a bicycle type ergometer until perspiration while wearing a helmet with the SAL. Sensory tests with seven scales using the SD method were carried out in order to evaluate helmet comfort. This test was evaluated at four stages; before exercise, at initial perspiration, at maximum perspiration, and after a break. A helmet comfort rating evaluation of 0 to 5 points was assigned to the helmet. The physical properties of the SAL fabrics were measured by KES and JIS testing methods: surface properties, compression properties, warm/cool touch, and absorbency. As a result of correlation analysis between the sensory tests and the helmet comfort evaluations, we were able to determine that the "gentle on skin" and "smooth" feels

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are related to helmet comfort, and also that the "smooth" feel of a helmet can be predicted using a fabric hand test, as evaluations were consistent regardless of the level of wetness or contacted regions. Surface friction properties and absorbency correlated strongly with helmet comfort. Therefore, the SAL is able to create a comfortable helmet by optimizing the surface roughness properties and absorbency. However, we have summarized that it is difficult to improve the thermal comfort of the helmet through changes to its physical properties.

Keywords: *helmet comfort, safety helmet, sweat absorbent liner, sensory test*

1. INTRODUCTION

Since the main role of a safety helmet is to protect the head against occupational hazards, most countries require that a safety helmet be worn through laws and regulations. Wearing a safety helmet is now mandatory and has been enforced for workers through supervision of these law and regulations. However, workers are likely to remove their helmets during uncomfortably hot weather if they experience discomfort, such as heat stress, while wearing them [1, 2]. Therefore, it is necessary for safety helmets to not only offer protection, but also comfort.

1.1. Previous Helmet Comfort Studies

In 1989, Nagata proposed the following requirements for a hat or cap to be worn during the summer: (1) good reflection of heat rays from the surface, i.e., white or light in color with a flat and smooth surface; (2) low heat transfer coefficient for the shell material; (3) ventilation or enough dome space to prevent increase in temperature and humidity between the helmet and head [3].

In 1988, Abeysekera and Shahnavaz investigated the benefits of ventilated helmets in both laboratory and field settings. In the field study, ventilation helmets were found to be less hot and cause less perspiration than unmodified helmets. However, during laboratory tests, they found no significant differences in the subjects' heart rates and skin temperatures based on whether they wore the ventilated or unventilated helmets. In fact, the unmodified helmets were found to be preferred by the users, presumably, because of the added protection they offer [1].

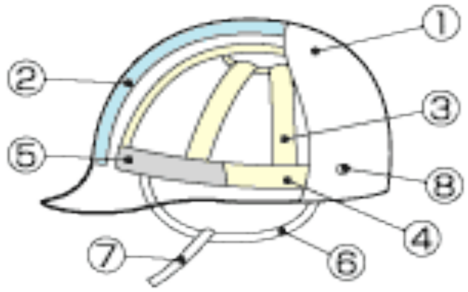
In 1976, Fonseca investigated the effects of ventilation slits in helmets on evaporative heat transfer. He determined that the total head coverage area needed to be reduced from 67% to 47% to significantly increase evaporative heat transfer. In addition to this, the benefits of ventilation were negated when a large air space existed between the helmet shell and the head [4].

In 2001, Davis et al. evaluated subjects' physiological and psychophysical responses to a standard helmet, a passive ventilation helmet, and an active ventilation helmet in a high-temperature environment. They found that none of the tested helmets added significant burden based on physiological variables, but that dome space temperature varied significantly among the helmets tested. The active ventilation helmet in particular maintained a significantly lower dome space temperature than either the standard helmet or the passive ventilation helmet. However, despite having the lowest dome space temperature, it was not preferred due to its excessive weight and uncomfortable fit. Psychophysical results showed that ventilation contributed to greater helmet comfort, and that weight and fit were important factors in helmet design [5].

As this survey shows, hygrothermal properties must be an important factor in helmet comfort. However, ventilation holes (or slits) in the safety helmet are not considered to be a necessary or sufficient condition for enhancing helmet comfort when safety helmets are selected by users.

1.2. Purpose

In our study, we investigated the effects of the physical properties of the sweat absorbent liner (SAL) on helmet comfort and compared forehead feel with hand feel. Because helmet fit is one of the major factors of helmet comfort and much related to a head band with SAL has been attached to contact the forehead (see Fig. 1). In addition to this, the hand feel plays an important role in expectations for helmet comfort both when helmet makers design a helmet and when users purchase a helmet.



⊖ Shell
⊜ Impact Absorbing Liner
⊛ Hammock
④ Head Band
⑤ Sweat Absorbent Liner
⑥ Ear Strap
⑦ Chin Strap
⑧ Connected Tack

Figure 1: Structure of safety helmet

2. EXPERIMENTAL

To study the influence that the SAL had on helmet comfort, the following experiment protocols were implemented.

1. *Brainstorming:* to outline evaluation terms for the preliminary sensory tests.
2. *Preliminary sensory tests:* comparison between the hand feel and wearing feel during different states of wetness.
3. *Factor analysis:* decision of evaluation terms for the main sensory tests.
4. *Main sensory tests:* helmet comfort tests when exercising to perspiration.
5. *SAL Physical properties tests*
6. *Partial correlation analysis:* to determine the relationship of helmet comfort, fabric hand, and physical properties.

2.1. Brainstorming for Evaluation Terms

Panelists held a brainstorming session regarding the texture of the prepared SAL fabric samples. 16 adjective pairs were created for use as evaluation terms for the preliminary sensory tests (see Table 1).

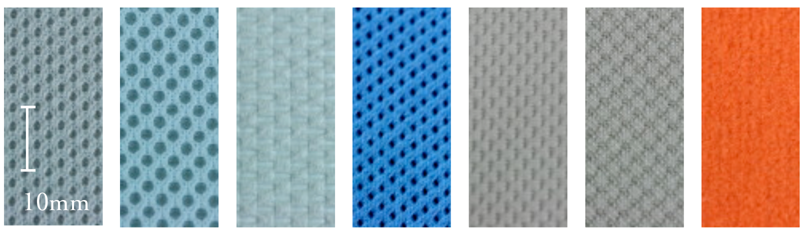
Table 1: Evaluation terms for sensory tests using the SD method

Roughness			Mugginess			Resilience		
Rough	⇔	Smooth	Muggy	⇔	Fresh	Not resilient	⇔	Resilient
Itchy	⇔	Not itchy	Humid	⇔	Not	Not cushioned	⇔	Cushioned
Hard	⇔	Soft	Clammy	⇔	humid	Not fluffy	⇔	Fluffy
Coarse	⇔	Fine	Warm	⇔	Smooth			
Lumpy	⇔	Not lumpy	Damp	⇔	Cool			
Feels bad	⇔	Feels good			Not damp			
Rough on skin	⇔	Gentle on skin						
Stiff	⇔	Flexible						

2.2. Preliminary Sensory Tests

These tests consisted of the fabric hand, i.e., hand feel and the wearing feel tests for comparing each other. The Semantic Differential (SD) method employing five rating scales was used for these sensory tests. Seven SAL fabric samples, shown in Fig. 2, were prepared for these tests. All samples were made from polyester, though each used different fabrication methods. Sample #1, #2, and #4 are three dimension knitted fabric and thicknesses are respectively 1.8mm, 2.3mm, and 2.1mm. Sample #3 is nonwoven fabric and thickness is 0.8mm. Sample #5 and #6 are warp knitted fabric and both thicknesses are 1.1mm. Sample #7 is warp knitted velour fabric and thickness is 1.5mm. The thicknesses of all samples are measured at a pressure of 0.049kPa. The sample size was 20cm×20cm and each sample was subjected to three different conditions: dry, wet 2g ($0.005g_{water}/cm^2$), and wet 10g ($0.025g_{water}/cm^2$). Subjects assessed the fabric hand using the end of their finger and palm without grasping the sample, based on evaluation terms (see Table 1). In addition to this, subjects evaluated the wearing feel of safety helmets with an SAL attached to the head band while in a dry state. The experiment environment was at a temperature of 20±2℃ and a relative humidity of 65±5% .

Japanese male and female university students participated as subjects in this study voluntarily. Appendix A summarizes subject details.



#1 #2 #3 #4 #5 #6 #7

Figure 2: Surface features of the samples

2.3. Factor Analysis

Factor analysis was necessary in order to find factors from the results of the preliminary sensory tests that could be used to describe the helmet comfort properties of the various states of the SAL samples used in this study. The analysis conditions included data for four extracted factors, using the varimax rotation method.

The results of the factor analysis, shown in Table 2, show that adjective pairs related to "roughness", "mugginess", and "resilience" were the main factors which could be used to describe psychological responses in both dry and wet SAL states. However, in the wearing feel tests, adjective pairs related just to the "roughness" and "mugginess" were the main factors. The "resilience" factor of had no contribution to wearing feel.

Table 2: Factors and contributions as a result of factor analysis.

Test	Condition	Factor / Contribution Ratio (%)		
		No. 1	**No. 2**	**No. 3**
Hand Feel	Dry	Rough / 40.2%	Muggy / 33.4%	Resilient / 22.3%
	Wet 2g	Muggy / 35.0%	Rough / 24.6%	Resilient / 19.0%
	Wet 10g	Muggy / 37.1%	Rough / 31.0%	Resilient / 19.3%
Wearing Feel	Dry	Muggy / 32.6%	Rough / 30.1%	Cool / 28.0%

2.4. Main Sensory Tests; Helmet Comfort Tests

SAL samples: #1, #4, #5, and #7 were used in these tests. The terms lined out underbars in Table 1 are the helmet comfort test terms. The total number of subjects was forty three male university students. Appendix A shows subjects details.

Subjects exercised to perspiration using an ergometer while wearing safety helmets with SAL attached, and sensory tests with seven rating scales using the SD method were carried out for helmet comfort evaluation. The evaluation was checked at four stages decided based on the judgment of the subject: before exercise, at initial perspiration, at maximum perspiration, and after a 10 minute break. After the trial, subjects scored the comfort of the helmet on a scale of 0 to 5 points based on their entire impression of the safety helmet with SAL they wore. Each subject participated in this test only once in a day. The experiment environment was at a temperature of 24±2℃ and a relative humidity of 65±5% to stimulate perspiration.

2.5. Physical Properties Test

Surface properties (KES-FB4), compression properties (KES-FB3 DC), warm/cool feel (KES-F7), and absorbency (JIS L 1097) were measured in order to investigate the effect of SAL's physical properties on helmet comfort. Table 3 shows the details of the physical properties test. The experiment environment was at a temperature of 20±2℃ and a relative humidity of 65±5%.

Table 3: Physical Properties Test

Item	Parameter	Remark
Surface Properties	Average Friction Coefficient Geometric Roughness Friction Coefficient Variance	MIU SMD MMD
Compression Properties	Compression Linearity Compression Work Compression Resilience	LC WC RC
Warm/Cool Feel	q-max	
Absorbency	Water Absorption Length	WA

3. RESULTS AND DISCUSSION

3.1. Helmet Comfort Sensory Tests

Sensory test terms concerning the "roughness" factor had a tendency to be rougher in the evaluation stages "before exercise" and "initial perspiration". We determined that small amounts of perspiration increased the response of the SAL surface roughness properties. However, test results were divided into more rough and less rough groups in the evaluation stages "initial sweat" and "maximum sweat", and "maximum sweat" and "after a break". We determined that response to the "roughness" factor could be influenced by the amount of perspiration contained in the SAL, and that it could play either a positive or negative role in the response to surface roughness based on its physical properties (refer to Fig. 3). The terms related to the "mugginess" factor received a negative evaluation value as the amount of perspiration increased, and although these went up during the "after break" stage, they did not reach a positive evaluation. There were no statistically significant differences in the terms. This showed that the hygrothermal comfort of safety helmets is difficult to enhance with modification of the SAL.

In the results for helmet comfort rating, the samples were rated in the following order (from highest comfort to lowest): #5, #7, #4, and #1. However, none of the differences in the tested scores were statistically significant when tested by ANOVA ($p<0.05$).

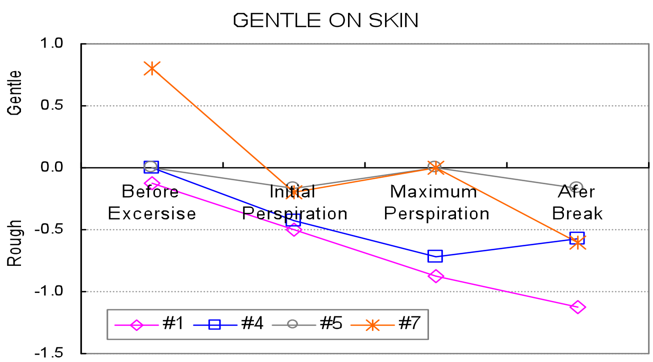


Figure 3: Profile of helmet comfort tests using the SD method: "Gentle on skin"

3.2. Physical Properties Test

Table 4 shows the results of the physical properties test.

Table 4: Results of physical properties test

Item	Unit	#1	#4	#5	#7
MIU-w[1]	N/A	0.02	0.18	0.21	0.33
MIU-c[2]	N/A	0.25	0.23	0.28	0.34
MMD-w	N/A	0.024	0.026	0.014	0.018
MMD-c	N/A	0.043	0.047	0.024	0.019
SMD-w	μm	3.4	3.7	5.4	15.2
SMD-c	μm	12.9	12.7	15.7	8.3
LC	N/A	0.69	0.61	0.61	0.50
WC	gf·cm/cm^2	0.57	0.22	0.30	0.96
RC	%	63.5	66.8	49.1	47.9
q-max	W/m^2	0.081	0.094	0.075	0.043
WA-w	mm	90	118	127	84
WA-c	mm	109	131	141	105

[1]w: wale direction of fabric, [2]c: course direction of fabric

3.3. Correlation Analysis of Helmet Comfort with the Sensory Tests and the Physical Properties Test

We analyzed the relationship of the helmet comfort rank with the sensory tests and the physical properties test using partial correlation analysis. The evaluation terms with calculated coefficients over ±0.7 were considered to show a strong correlation with helmet comfort. Table 5 shows the correlation coefficients of the partial correlation analysis.

From correlations with the helmet comfort sensory tests, we confirmed that psychological factors related to the SAL that affected helmet comfort consisted of the following: (1) “cool” and “feels good” before exercise, i.e. when putting on the safety helmet; (2) “gentle on skin” at the start of perspiration; (3) “feels good” and “gentle on skin” at maximum perspiration; (4) “fine”, “not lumpy”, and “gentle on skin” when put on again after a break. It was determined that the SAL’s forehead feel both while dry and while wet, and also when the helmet was put on again after being taken off, were important factors when judging helmet comfort.

The result of correlation with the physical properties test shows that the friction coefficient variance (MMD) and the water absorption length (WA) affected helmet comfort. MMD is known to indicate a rough fabric feel and to show strong negative correlation with all terms determined to affect helmet comfort based on the results of this study (see Fig. 4).

Table 5: Correlation coefficients of helmet comfort with sensory tests and the physical properties test

	Item	Condition	R
Helmet Comfort	Fine	After break	0.83
	Not lumpy	After break	0.77
	Cool	Before exercise	0.83
	Feels good	Maximum perspiration	0.89
	Soft	Before exercise	0.99
	Gentle on skin	Initial perspiration	0.93
		Maximum perspiration	0.90
		After break	0.91
Hand Feel	Fine	Dry fabric	0.78
		Wet fabric (2g)	0.83
	Not lumpy	Dry fabric	0.80
		Wet fabric (2g)	0.80
	Cool	Wet fabric (10g)	-0.73
	Feels good	Wet fabric (10g)	0.86
	Not itchy	Wet fabric (2g)	0.89
	Smooth (rough)	Dry fabric	0.85
		Wet fabric (2g)	0.72
		Wet fabric (10g)	0.81
	Gentle on skin	Dry fabric	0.76
		Wet fabric (10g)	0.79
	Smooth (clammy)	Wet fabric (10g)	0.99
Physical Properties	MMD	Wale direction	-0.92
		Course direction	-0.76
		Vertical direction	-0.74
		Horizontal direction	-0.94
	WA	Horizontal direction	0.75

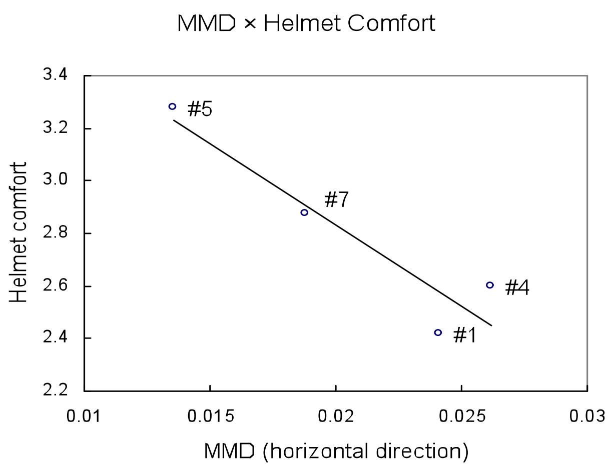


Figure 4: Helmet comfort and friction coefficient variance

4. CONCLUSION

As a result of our experiments, we concluded that the effects of the physical properties of the SAL on fabric hand using hand feel and helmet comfort are as follows.

"Muggy feel" and "rough feel" are the main factors that affect psychological responses to how SAL affects helmet comfort. The roughness factor in particular consists of the following: (a) "cool" and "soft" feel when wearing the safety helmet; (b) "gentle on skin" at initial perspiration; (c) "feels good" and "gentle on skin" at maximum perspiration; (d) "fine", "not lumpy", and "gentle on skin" when put on again after a break.

If we optimize the SAL surface roughness properties, it would be possible to improve helmet comfort. SAL with a lower friction coefficient variance measured by KES-FB4 and good absorbency enhances helmet comfort. However, it is difficult to enhance the hygrothermal comfort of safety helmets through modification the SAL sweat liner.

Hand feel evaluation of the SAL fabric is effective in predicting helmet comfort.

Due to the results showing that SAL containing perspiration played a role in the positive or negative response of surface roughness based on its physical properties, further research and developing for tester is needed to clarify the effects of the surface roughness properties of wet fabrics.

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APPENDIX A. Subject Details

		Condition	No. of Subjects	Age		
				Range	Mean	S.D.
Preliminary Sensory Tests	Hand Feel	Dry	8	21-24	22.5	0.93
		Wet (2g)	7	21-24	22.3	0.58
		Wet (10g)	6	21-24	22.3	1.03
	Wearing Feel	Dry	10	21-24	22.1	0.99
Main Sensory Tests	Helmet Comfort	#1	13	21-33	23.1	3.12
		#4	11	21-24	22.2	0.98
		#5	10	21-33	23.4	3.50
		#7	9	21-24	22.3	1.00

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