PARAMETERIZATION OF TEMPERATURE PERCEPTION OF VENTILATION CHANGES IN FULL-FACE MOTORCYCLE HELMETS

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INTRODUCTION

Temperature perception and thermal comfort of headgear have most often been studied with thermal manikin headforms. An underlying assumption of these measurements is that of a direct relationship between thermal perception of subjects and a measure obtained from such headforms (e.g. heat loss, temperature, heat flux, or airflow). Several studies found that in warm environments the categorization of headgear based on manikin headform measurements is comparable to the categorization based on temperature perception or thermal comfort by human subjects [1-4], supporting this assumption. A clear understanding of the sensitivity of subjects to heat transfer fluctuations has yet to be achieved.

This study aimed to evaluate which parameters related to air flow and heat transfer predict the response behavior of subjects while operating the ventilation system of motorcycle helmets, focusing on the scalp section.

METHODS

Eight healthy male subjects aged 28.0 ± 5.4 years and with head circumferences of 57.5 ± 0.5 cm participated in the study. Each subject visited the laboratory on three different days starting at the same time of day, once for a familiarization trial and twice for experimental trials. The subjects were dressed comfortably with respect to the thermal environment. Each subject attested to have refrained from consuming alcohol, nicotine, and caffeine during the 12 hours preceding each trial, and did not conduct any panting-inducing exercise between waking and the start of the trial. The study was approved by the Cantonal Ethics Committee of St. Gallen (Switzerland).

For the trials, the subjects sat at the exit of a wind tunnel, which projected an air stream on the upper torso, neck and head, during the entire experiment. A 19’ LCD screen was positioned under the Plexiglas bottom of the wind tunnel, which allowed the subject to see the screen clearly. A keyboard and mouse were positioned in front of the screen. The setup is described in more detail elsewhere [5].

All measurements were conducted in a climate chamber at ambient temperatures (T_a) (± one standard deviation) of 23.7 ± 0.4 ºC and 27.5 ± 0.3 ºC, referred to as neutral and warm, respectively. Both T_a were presented in a balanced order to the subjects. At both ambient temperatures the two different wind speeds (v_w) were applied, labeled moderate (39.2 ± 1.9 km/h) and high (59.3 ± 1.4 km/h); v_w was measured beside the head as described elsewhere [5]. The relative humidity (RH) was kept at 50 ± 2%, and measured at the same location as the temperature in the wind stream.

The trials consisted of the following phases, during which the subject sat still at the exit of the wind tunnel: i) 60 min acclimation, for which a full-face motorcycle helmet was worn, and v_w = 39.2 ± 1.9 km/h, ii) perception examination 1 (~20 min), and iii) perception examination 2 (~20 min). The wind speed was different between the examination phases and randomly assigned. During each examination four helmets (in random order) were examined in the following manner: i) the helmet worn by the subject was removed and the subject was fitted with another helmet, during which no wind was applied; ii) wind was applied while the subject sat still at the exit of the wind tunnel in order to regain values close to thermal steady state, for which 3 min was taken; iii) the experimenter manually changed the vent configuration in the scalp section. After each change in vent configuration the subject was asked to assess his perception in a manner described below. The examination of one helmet took approximately 5 min. The initial vent configuration (open or closed) was chosen randomly. Directly after a change in vent configuration, the subject indicated if the temperature perception on the scalp was changed relative to before the change, choosing from one of the following responses: 'warmer', 'indifferent', or 'cooler'.

Four full-face motorcycle helmets were selected for this study, coded 110, 130, 201, and 210, taken from among 27 helmets characterized for vent-induced heat loss on the scalp section ($\Delta\dot{Q}_S$) [6]. The selected helmets exhibited the largest (110 and 130), intermediate (201), and smallest values of $\Delta\dot{Q}_S$ (210). Helmets 110, 130, and 201 were equipped with eight temperature sensors, and two RH sensors. These sensors were integrated in two rows, always only installed on the left side of the helmet, each row with four evenly-spaced sensors starting at the top of the ear; a vertical row (spacing ~4 cm), and a horizontal row (spacing ~3.5 cm). The face skin temperature was measured using thermistors placed at the following locations: i) the middle of the chin (mental protuberance), ii) the middle of the forehead 1 cm above the eyebrows, iii) 3 cm in front of the ear at the level of the ear channel.

To get accurate estimates of the steady state heat loss experienced by the subjects, headform measurements were carried out under conditions closely simulating those experienced by the subjects. The specifications of the headform are given elsewhere [7], and details on the protocol for assessing helmets on the headform was identical to that reported previously [6, 8]. The position and orientation of the headform was based on subject examinations.

Logistic regression was employed for creating models predicting the response behavior of the subjects. The goal here was to quantify the importance of the measured parameters in describing the response behavior of the subjects. The following parameters were considered: $\Delta\dot{Q}$, subject, helmet, ambient air temperature (neutral or warm), applied wind speed (moderate or high), the vent configuration in the other section, and facial skin temperature. To estimate the effect of the vent manipulation on the microclimate parameters, the corresponding thermal data were represented by the slope of the data over a period of 50 s following the change in vent configuration. More information on logistic regression is given, e.g., by Menard [9]. Statistical analysis was carried out using SPSS 14.0.1 for Windows.

RESULTS

The largest change between open and closed vents was 6.1 W. Therefore, $\Delta\dot{Q}_S$ ranged from -6.1 W to 6.1 W, for which negative values indicate closing, and positive values opening of the vents. Values within this range occur with similar frequencies, except for values near zero.

A total of 93 responses were collected, summarized in Figure 1. The response 'indifferent' was given most often. The value of $\Delta\dot{Q}_S$ corresponding to the mean response (M) is also indicated for each response category of every question. Since opening the vents results in $\Delta\dot{Q}_S$ > 0 W, it follows that, if M > 0, a given response category corresponds best to the perceived effect of opening the vent, and similarly for M < 0. Thus, opening the vent is related to perceptions of 'cooler', and closing the vents with 'warmer'.

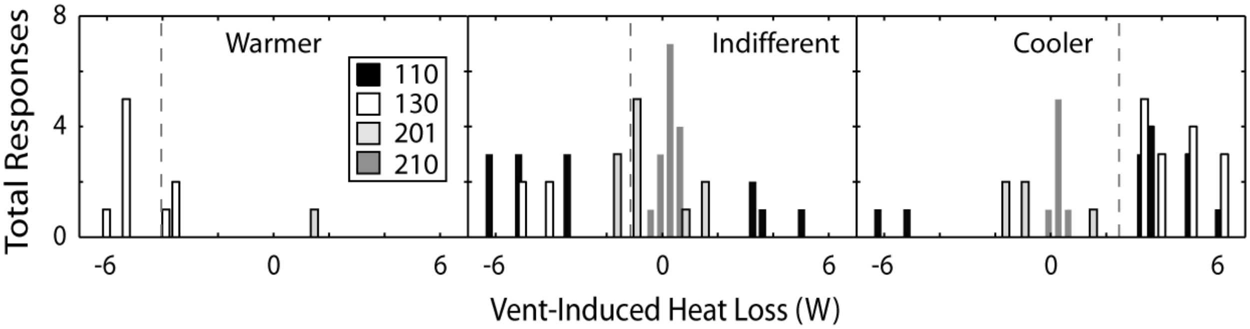

Figure 1: Number of responses for temperature perception for the scalp section with respect to vent-induced heat loss ($\Delta\dot{Q}_S$), for helmets as indicated. The dashed lines indicate the value of $\Delta\dot{Q}_S$ corresponding to the mean response for all helmets combined, for each response category.

Table 1 gives the performance of these models, and shows the parameters included. It can be observed that both models predict more than 80% of the response correctly. In addition, the McFadden r^2 coefficients, which is comparable to the Pearson's r^2 for linear regression analysis, is larger than 0.6. Taken together, one could argue that these models are highly-performing. The parameters in order of decreasing importance were, $\Delta\dot{Q}_S$, subject, and helmet. These parameters will be put into context with the original responses below.

***Table 1**: Details of the multinomial logistic regression models for the scalp section for temperature perception. Column MP indicates whether the thermal Microclimate Parameters are included in the parameter pool. In such cases, only three helmets are included, since one helmet was not equipped with sensors; otherwise all four are included. Parameter definitions and further information is provided in the text.*

	Model Performance Parameters		p-value of the likelihood ratio test of the full model omitting the indicated parameter*		
	Correctly Predicted	McFadden r^2			
MP			$\Delta\dot{Q}_S$	Subject	Helmet
no	85%	0.61	$<10^{-6}$	$<10^{-3}$	$<10^{-4}$
yes	86%	0.65	$<10^{-6}$	$<10^{-2}$	$<10^{-2}$

*Smaller p-values indicate greater importance of the parameter for the performance of the model, more details on this method are given under Methods.

Notably, $\Delta\dot{Q}_S$ alone does not completely predict the response of the subjects for temperature perception. For instance, the response 'warmer' shows a dependence on $\Delta\dot{Q}_S$ only for helmet 130, and not helmet 110, even though $\Delta\dot{Q}_S$ is similar for both. This indicates helmet-specific sensitivities, which is confirmed by the inclusion of the parameter 'helmet' in these models.

The importance of the predictor subject is consistent with the general expectation that each subject has a unique sensitivity. A detailed analysis of this predictor will not be undertaken, since we examined a small pool of subjects and obvious subject-specific characteristics, e.g., hair style (not described in detail here), did not appear consistent with differences in the responses among the subjects.

DISCUSSION

The results from the present study indicate that $\Delta\dot{Q}_S$ is the most important determinant for the response behavior of the subjects for temperature perception. Such a relationship can be observed for most helmets in Figure 1, and is in addition confirmed through multinomial logistic regression modeling. Nevertheless, the difference between helmets 110 and 130 suggests that other factors are also important. In results presented elsewhere [5] it is indicated that differences in airflow patterns are correlated with these helmet specific sensitivities, and may therefore (partially) explain them. In the same work [5], a first attempt has been made in deriving the perception threshold for perception of heat transfer fluctuations while wearing a full-face motorcycle helmet.

CONCLUSIONS

We find that subjects are able to systematically perceive effects caused by changing the vent configuration of motorcycle helmets, under simulated riding conditions. Furthermore, the main determinant of the response behavior of the subjects was the vent-induced heat loss. However, the relationship between vent-induced heat loss and response behavior varied among the helmets. These results confirm that a thermal manikin headform is a useful tool for investigating and optimizing temperature perception of headgear.

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