

TECHNICAL REPORT
NATICK/TR-22/005

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FURTHER EVALUATION OF THE RELIABILITY AND VALIDITY OF THE CALM SCALE FOR ASSESSING THE TACTILE COMFORT OF FABRICS

by
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January 2022

Final Report
May 2005 – August 2008

Approved for public release; distribution is unlimited

**Prepared for
U.S. Army Combat Capabilities Development Command Soldier Center
Natick, Massachusetts 01760-5020**

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1. REPORT DATE (DD-MM-YYYY) 11-01-2022		2. REPORT TYPE Final		3. DATES COVERED (From - To) May 15, 2005 - August 31, 2008																									
4. TITLE AND SUBTITLE FURTHER EVALUATION OF THE RELIABILITY AND VALIDITY OF THE CALM SCALE FOR ASSESSING THE TACTILE COMFORT OF FABRICS				5a. CONTRACT NUMBER																									
				5b. GRANT NUMBER W911QY-04-1-0001																									
				5c. PROGRAM ELEMENT NUMBER																									
6. AUTHOR(S) John D. Pierce, Jr.				5d. PROJECT NUMBER																									
				5e. TASK NUMBER																									
				5f. WORK UNIT NUMBER																									
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Laboratory for Engineered Human Protection Philadelphia University School House Lane and Henry Avenues Philadelphia, PA, USA 19144-5497				8. PERFORMING ORGANIZATION REPORT NUMBER																									
				PHILA-LEHP-BP-TR-08-01																									
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Combat Capabilities Development Command Soldier Center ATTN: RDNS-SES (C. Winterhalter) 10 General Greene Avenue Natick, Massachusetts, USA 01760-5020				10. SPONSOR/MONITOR'S ACRONYM(S) DEVCOM SC																									
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) NATICK/TR-22/005																									
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release: distribution unlimited.																													
13. SUPPLEMENTARY NOTES © 2008 Laboratory for Engineered Human Protection, Philadelphia University.																													
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a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code) (508) 206-3936																								

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PHILA-LEHP-BP-TR-08-01

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Prepared for

**U.S. ARMY NATICK SOLDIER RESEARCH,
DEVELOPMENT & ENGINEERING CENTER
Natick, Massachusetts, USA 01760-5020**

Under W911QY-04-1-0001

For the Period

May 15, 2005 to August 31, 2008

Submitted by

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1. Preface

The purpose of the present study was to provide further assessment of the reliability and validity of the Comfort Affect Labeled Magnitude (CALM) scale and to expand the knowledge base of the comfort assessment of fabrics.

This study was composed of three experiments. Experiment 1 was designed as a strict replication of the original work on comfort assessment of fabrics for military use performed at U.S. Army Natick Soldier Research, Development & Engineering Center (Cardello, Schutz, and Winterhalter, 2002) with the goal of providing an additional assessment of the reliability of measurement of the CALM scale.

Experiment 2 extended use of the CALM scale to a wider variety of fabrics.

In Experiment 3, the construct validity of the collected CALM data was further assessed by a comparison of fabrics rankings for comfort derived by a different methodology: direct paired comparisons of fabric samples. In this study, the rankings derived from these direct paired comparisons were compared to the rankings obtained from the CALM data to provide an alternative measure of validity.

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2.1 Background – Scientific Study of Fabric Comfort

The identification of apparel features that determine comfort and use has been a long-standing goal of military apparel design, reflecting the considerable importance of comfort on performance in the military arena. A series of studies conducted by the Science and Technology Directorate and the Individual Protection Directorate of the U.S. Army Natick Soldier Research, Development & Engineering Center has examined the variables that influence comfort and the impact of comfort on soldier performance. A prime focus of their long-term research project has been the development of psychophysical methods to measure accurately participants' assessment of the comfort of selected military fabrics. This research focus resulted in the development of a psychophysical scale for assessing the tactile comfort of fabrics, the Comfort Affect Labeled Magnitude (CALM) scale.

The scientific study of fabric comfort extends over eighty years (reviewed by Cardello, Schutz, and Winterhalter, 2002), as numerous researchers have investigated comfort in military and non-military fabrics. As with many psychological concepts, however, an objective definition of comfort accepted by all has been elusive. Viewed broadly, comfort can be defined as a human emotional response that accompanies the perception of the tactile and thermal environment. This definition reflects the generally accepted view that what determines comfort is more than the fabric itself. Rather, the perception of comfort is a complex one (Goldman, 2005), reflecting characteristics of three critical dimensions: the person, the garment, and the environment (ex., LaMotte, 1977; Slater, 1986; Li, 1998). A further complication to understanding comfort emerges when one considers the different types of comfort. Wong, Li, and Yueng (2002) tested the comfort of garments worn by professional athletes in a cycling task. Their results revealed that overall garment comfort reflected the contributions of three major comfort factors: moisture, thermal-fit, and tactile comfort. Each comfort factor can be manipulated and studied separately to assess its contribution to overall comfort perception.

These three major comfort types represent a fertile area of research for investigation with respect to military garments. Whereas thermal and moisture comfort have received considerable experimental attention (Endrusick, Gonzalez, Gonzalez, 2005), tactile comfort of military garments has been less well researched. The dearth of studies on the tactile comfort of military fabrics is surprising, given the importance of the need for comfortable, responsive garments. In a mission environment where a soldier might be exposed to nuclear, biological, chemical, thermal or ballistic threats, the impact of comfort on performance can determine mission success and even survival. Most currently available protective garments are generally perceived as uncomfortable and might thus compromise mission performance. Accordingly, for maximal task performance, the protective garment user must be comfortable and without distraction as the threat materializes and/or persists.

The limited research on tactile comfort in military fabrics is further unexpected, given that the influence of tactile cues in determining perceived apparel quality and acceptance has long been recognized in consumer apparel design. Holbrook (1983) suggested that tactile aspects of apparel (i.e., the feel of the garment) are more influential determinants of quality perception and consumer acceptance than are visual cues. Similarly, Abraham-Murali, and Littrell. (1995) included

tactile effect as an attribute of physical appearance affecting consumers' perception of apparel quality and acceptance. Goldman (2005) identified "feel," the feeling of the fabric when held, as one of the four primary factors in clothing comfort. In recognition of the importance of tactile attributes, the apparel industry has evaluated the tactile comfort of fabrics for many years. The Kawabata Evaluation System was developed specifically to correlate measurable physical parameters to the subjective evaluation of "hand" (e.g. Kawabata and Niwa, 1992; Kawabata, Niwa, and Wang, 1994) and is widely used throughout the industry.

It was not until recently that the tactile comfort of military fabrics was given its due, with a series of pioneering research studies conducted at the U.S. Army Natick Soldier Research, Development & Engineering Center (Cardello, Schutz, and Winterhalter, 2002; Bell, Cardello, and Schutz, 2003; Cardello, Winterhalter, and Schutz, 2003; Schutz, Cardello, and Winterhalter, 2005). These researchers developed an extensive research program based on psychophysical evaluation of the tactile comfort of existing military fabrics.

2.2 Background – Psychophysical Assessment

Psychophysics is the study of the relationship between physical properties of stimuli and the resulting sensory experience (Coren, Ward, and Enns, 2004). Only rarely is there a one-to-one correspondence between physical change and sensory experience. Rather, sensory systems typically compress physical changes, so that large physical changes produce relatively small changes in sensory perception (as in the perception of brightness). Less often, sensory systems expand physical changes (as in the perception of the heaviness of objects). Psychophysical measures (such as magnitude estimation or labeled magnitude scales) allow quantification of individual perceptual experience by providing an objective and standardized method to describe subjective experience. Psychophysical methods have been used to understand perceptual experiences across all sensory modalities (vision, audition, touch, etc.).

The gold standard of psychophysical assessment has been the method of magnitude estimation, a pioneering technique developed by S.S. Stevens (1964, 1971) in which participants assign a number of their own choosing to a particular stimulus (the standard) and then rate subsequent stimuli relative to the original stimulus. Although this method has successfully been applied to numerous assessments of perceptual experience, its proper use requires extensive training and

practice for participants to be skilled at the task. Further, its use requires considerable mental effort to remember previous estimates while rating multiple stimuli in a single session or across sessions. For these reasons, alternative methods of expressing perceptual experience have been investigated.

Among the more successful alternatives are labeled magnitude scales, a variation on traditional category scales. Labeled magnitude scales, line-based scales with verbal labels to express the intensity of sensations, were originally developed by Borg (1982, 1990, 1998) to measure perceived exertion. Subsequent applications have been made for diverse sensory experiences, including oral sensations from chemosensory irritants (Green, Shaffer, and Gilmore, 1993), gustatory and olfactory sensations (Green et al., 1996; Mattes, 2007), paradoxical heat sensations (Green, 2002), and food preferences (Schutz and Cardello, 2001).

2.3 Background – Development of CALM Scale

Psychophysical methods can likewise be used to address issues related to the perceptual experience of comfort. The Natick researchers developed a labeled magnitude scale of measurement for the assessment of fabric comfort. This scale, the Comfort Affective Labeled Magnitude (CALM) scale, is a reliable, easy-to-use scale for quantifying the human experience of tactile comfort. The CALM scale is a standardized labeled magnitude scale, 100 mm in length and bounded by the labels “Greatest Imaginable Discomfort” and Greatest Imaginable Comfort” (see Appendix A). Participants indicate their rating of comfort by placing a mark across the vertical line scale at the point corresponding to their rating. The measurement from the bottom of the scale to the point marked by the participant provides the numeric estimate for comfort. This easy-to-use scale quantifies the human experience of tactile comfort and can readily be used to evaluate the tactile attributes in fabrics, as well as comfort perception and individual acceptance of fabrics.

The initial development and validation of the CALM scale followed protocols established by previous researchers who have developed labeled magnitude scales for perceptual use (ex., Green, Shaffer, Gilmore, 1993; Schutz, Cardello, 2001). Participants (35 Natick employees) provided ratings of 43 phrases (such as “greatest imaginable” and “oppressively uncomfortable”) using conventional magnitude estimation procedures (Cardello, Schutz, and Winterhalter, 2002; Cardello, Winterhalter, and Schutz, 2003). Mean ratings of each

phrase were then used to determine the specific phrases used and their appropriate locations for the derived CALM scale (as shown in Appendix A). Following scale construction, the derived scale was tested in three subsequent experiments to assess two key psychometric properties: reliability (the consistency of measurement across multiple situations; Kaplan and Saccuzzo, 2001) and construct validity (the extent to which a test measures what it purports to measure; Kaplan and Saccuzzo, 2001).

In one experiment, 27 participants rated comfort on the CALM scale in response to six written scenarios describing assorted clothing and varied environmental conditions (such as “Hot Denim Garment” and “It is 100 °F and 60% humidity, no wind. You are outside walking to the grocery store for 10 minutes”). In the next experiment, 37 participants rated the comfort of gloves made from different fabrics. Results from both experiments demonstrated strong reliability of measure and excellent construct validity.

In the final experiment to assess the psychometric properties of the CALM scale, the Natick researchers asked 40 participants (Natick employees) to provide comfort ratings for 30 cm x 30 cm swatches of 13 military test fabrics of different materials (cotton, nylon polyester, wool/polyester, etc) in a single testing session. Participants handled the fabric *ad libitum* on the testing (outer) side of the fabric only, and then provided a single rating of comfort by marking the scale at the appropriate point. The order of presentation of the fabrics was randomized across participants, and each fabric was presented singly in succession. Participants then repeated the procedure in a second testing session five days later. Results indicated an acceptable level of test-retest reliability ($r = 0.68, p < 0.01$). The comfort data were then compared to Kawabata physical measurements and sensory handfeel properties of the same fabrics to obtain a predictive relationship among these measured variables. Comfort ratings were significantly correlated with both measures of distinct sensory handfeel attributes (“gritty”, “tensile stretch”, etc.) and, importantly, with hand measurements derived from Kawabata mechanical testing. These findings provide an essential measure of construct validity to the scale and suggest that the comfort of a garment may be predicted by its physical and sensory characteristics. Overall, the results of the initial assessment of the CALM scale revealed that the scale was easy to use and provided accurate measurement of comfort across a wide variety of tested fabrics.

2.4 Background – LEHP Research

The Laboratory for Engineered Human Protection (LEHP) has recently embarked on a long-term, multidisciplinary research project to study the relationships between comfort, protection, performance, psychophysical perceived value factors, and mission requirements to determine which unique combinations of these factors can be used to develop military and civilian first-responder protective garments. In the current phase of the project, the researchers have begun to study the relationship between physical fabric characteristics and the resulting comfort evaluation as part of our multidisciplinary approach to designing military garments. The initial step of this research was to verify the psychometric properties of the CALM scale in assessing tactile comfort in military fabrics. These psychometric evaluation studies are the focus of this technical report.

2.5 Arrangement of Report

Following this introduction, this report contains:

- a description of three experiments, including the methods, procedures, results, and discussion of those results
- a presentation of conclusions drawn from the results
- recommendations for further study
- a list of works cited
- appendices containing the CALM scale, the prescreening questionnaire for experiments 1 and 2, and the informed consent form used for comfort panelists

3. Methods

3.1 Experiment 1 – Replication of Natick Study

3.1.1 Experiment 1 Introduction

Experiment 1 was designed as a strict replication of the original Natick work on comfort testing of fabrics for military use (Cardello, Schutz, and Winterhalter, 2002) with the goal of providing an additional assessment of the reliability of measurement of the CALM scale. Nine of the fabrics evaluated in the original study were obtained from the Natick researchers and used in this replication.

3.1.2 Experiment 1 Methods

A total of 50 participants (34 females and 16 males) were recruited from faculty, staff, and students of the Philadelphia University community. Potential participants were recruited via a Request for Participation e-mail sent globally to the Philadelphia University community and by individual solicitations of unit heads, such as deans.

All respondents were pre-screened for any hand disorders or medical conditions that might affect tactile sensitivity. Prescreening was done through an online questionnaire on the LEHP website. (A copy of the online questionnaire is in Appendix B.) All individuals that successfully passed the prescreening were eligible for the study, as there were no further restrictions on participation. Volunteers could participate only once for this evaluation. University approval to conduct the study was obtained from the University's Institutional Review Board. All participants provided informed consent prior to participation. (A copy of the consent form is in Appendix C.) All participants were treated in accordance with the American Psychological Association's Code of Ethical Conduct for researchers (American Psychological Association, 2002).

Nine fabrics evaluated by the Natick researchers as part of their original validation of the CALM scale were selected for this replication. Samples of these original Natick fabrics were obtained through the Individual Protection Directorate of the U.S. Army Natick Soldier Research, Development & Engineering Center. The textile laboratory team assumed primary responsibility for the care and preparation of the fabric samples. All samples were washed, cut into testing swatches, and coded with the original Natick three-digit code in the upper right corner of the fabric. Samples were placed individually

in manila testing folders that were also marked with the three-digit identification code. At this time data sheets (containing the CALM scale) coded with the appropriate sample number were also inserted into the folder with the fabric sample. A total of 20 sets of samples were created using this procedure and were used for testing.

The order of presentation of fabric samples to each participant was determined in advance, and a randomized presentation sequence was generated for each participant. Samples were arranged in order of presentation specified by the sequence. Samples were kept in a covered plastic container, and stored in the temperature- and humidity-controlled laboratory space of the Philadelphia University Research Center until distributed for testing.

On the day of testing, samples were transported to the testing facility on the Philadelphia University campus. The testing researcher for each session had primary responsibility for ensuring the samples were delivered to the testing room 30 minutes prior to testing. Upon delivery to the testing room, samples were double-checked to ensure they were in the proper order of presentation for each participant and that the appropriate data sheet (containing the CALM scale) was contained in each folder. Following testing, samples were re-sequenced for the next series of participants.

Participants provided comfort ratings using the Comfort Affective Labeled Magnitude (CALM) scale (Appendix A). The scale was enlarged to a vertical dimension of 200 mm. Each participant received a copy of the CALM scale with each fabric presentation.

The testing researcher arrived for testing 30 minutes prior to the start of the session. The researcher removed the Dickson TR320 Temperature and Humidity Data Logger from the testing container and allowed the logger to equilibrate for 15 minutes prior to measurement. Immediately prior to the start of each session, the temperature and humidity level of the testing room was recorded. This information was recorded on the Session Information Form along with the relevant information for each participant (initials, age, and gender).

Participants were scheduled for arrival within a three-hour block on testing day. Participants were tested in groups that started at the same time, with the start of testing every 90 minutes during a three-hour testing block. Upon arrival, participants were assigned to specific seats in the testing room, with the provision that no two participants sat close enough to allow for possible sharing of information. The researcher provided introductory comments regarding the study.

Participants read and signed the consent form, then washed their hands with alcohol gel hand sanitizer prior to testing.

When all participants arrived for testing, the researcher collected the consent forms and verified that the consent forms were properly completed (age and gender information) and signed. The researcher then assigned participant numbers and noted the numbers on the session testing sheet. Thus, by the start of each session, the Session Information Form was completed with all relevant information (participant number, initials, age, and gender of each participant; date and time of testing; and temperature and humidity measurements). The testing session then began.

Participants in a group were given the following instructions:

Thank you for agreeing to participate in this study. We are going to give you fabric samples and ask you to rate the comfort of each fabric. You may handle the fabric as long as you would like. Please feel, hold, touch, or squeeze the material ONLY on the numbered side of the fabric. After feeling the fabric, please rate the COMFORT on the provided scale. You can rate comfort by drawing a single horizontal line across the scale at the point corresponding to your rating. You may mark the scale at any point along the vertical line, not just at the verbal labels found on the scale. Please remember that there are no right or wrong answers. We are interested in your perception of the comfort of the fabric. When you are finished the rating, please raise your hand. We will then provide you with the next fabric to be rated. In all, you will be rating 9 fabrics and then your participation will be finished. Do you have any questions?

Participants were then given the testing folder containing the first fabric sample to be rated. Testing folders were distributed one at a time to each participant. As a participant finished one testing folder, the researcher removed the folder, examined the datasheet to ensure that it was marked correctly, and provided the next testing folder.¹ The procedure was repeated until the participant completed all trials. The researcher removed all data sheets from the testing folders upon the completion of the trial and inserted a new data sheet into the folder. The folder was then placed in a pile of similar fabric samples for re-use. All data sheets from a single participant were collected and stored together.

¹ Occasionally a participant had not used the form correctly. In this case, the participant was given further instruction on the proper completion of the datasheet and reissued the sample.

Upon the completion of the study, the researcher thanked the participants for their time and explained the general purpose of the study:

Thank you for your time and effort in completing this study. The goal of our research project is to develop uniforms for military personnel and emergency responders that provide the necessary protection yet are as comfortable as possible. Your work today provides us with valuable information concerning the comfort of different fabrics that can be used to make these uniforms. Your data will be compared to previous findings to help determine the best fabric for comfortable, protective uniforms. Do you have any questions?

When all questions had been answered, the participants were thanked again, and invited to have snacks and sodas. Testing was completed in approximately 30 to 45 minutes for each session.

3.1.3 Experiment 1 Results and Discussion

Data points for each rating were calculated by measuring the length in millimeters from the bottom of the scale to the mark that the participant placed on the scale. This measure thus varied between -100 to +100 with 0 representing the midpoint of the scale (“Neither Comfortable nor Uncomfortable”). Data points for each rating were entered into a Microsoft® Excel® spreadsheet and double-checked for accuracy. Table 1 lists the means and standard errors for the ratings generated in the present study and the ratings obtained in the original Natick study.

Scale reliability was assessed by two comparisons to the original Natick data. In the first analysis, the comfort data generated in the present study were compared using a Pearson’s r correlational analysis to the original means reported by the Natick researchers for the same fabrics. The comparison revealed a significant correlation ($r = 0.76$, $p < 0.02$) between the two sets of comfort data, demonstrating a strong and consistent measurement across the two studies. For the second analysis, a ranking of fabrics from most comfortable to most uncomfortable was derived from the CALM ratings for each set of results (see Table 2). Analysis using a Pearson’s r comparison for ranks revealed a highly significant relationship between the rankings of comfort derived in each study ($r = 0.83$, $p < 0.001$).

Table 1. Fabric Mean Comfort Ratings with Standard Deviations for Original Natick Study and Current Experiment 1

Fabric	Mean (s.d.) from the Original Natick Study	Mean (s.d.) from the Replication Study
10R	28.9 (25.7)	14.8 (35.1)
11A	47.2 (27.8)	32.9 (29.0)
12T	23.6 (27.1)	13.4 (32.0)
13P	37.4 (25.3)	20.7 (34.6)
14N	24.2 (30.8)	-6.4 (38.2)
15B	46.4 (22.5)	47.0 (22.0)
16C	22.0 (26.2)	12.4 (38.2)
17C	-1.4 (40.3)	2.8 (45.4)
19N	28.5 (36.1)	28.7 (28.0)

Table 2. Fabrics Ranked by Natick and LEHP CALM Scores; Ranking from Most to Least Comfortable.

Fabric	Natick Rank	PhilaU Rank
10R	4	5
11A	1	2
12T	7	6
13P	3	4
14N	6	9
15B	2	1
16C	8	7
17C	9	8
19N	5	3

The strong correlations demonstrate the robustness of the CALM scale in providing consistent, reliable measurement of tactile comfort across a range of fabrics. The high correlations were obtained despite the fact that replication was conducted five years later on a participant sample

(university students and staff) substantially different from that originally tested (Natick employees) in settings that also differed substantially (university versus military center). Informal debriefing with participants after testing confirmed that the scale was intuitive and easy-to-use.

3.2 Experiment 2 – Extending Study to a Wider Variety of Fabrics

3.2.1 Experiment 2 Introduction

Following the replication of the original Natick study, the next goal was to extend these findings by assessing comfort using the CALM scale across a wide variety of fabrics. In Experiment 2, the tactile comfort of 39 additional selected fabrics was assessed using the CALM scale.

3.2.2 Experiment 2 Methods

The CALM scale was used to provide evaluations of perceived comfort of 39 test fabrics. These fabrics were identified by the textile researchers at the LEHP Materials Evaluation Laboratory and selected to provide a broad range of fabrics with different sensory characteristics. Fabrics were tested in 4 different testing sets ranging from 13 to 15 different fabrics (4 of the fabrics were tested with 11 additional fabrics not included in the present study). Each set was evaluated by 50 participants in individual testing sessions consisting of 2 to 12 participants.

The procedure for evaluation was the same as that used in Experiment 1. Preparation of samples and their order of presentation were completed prior to the study as described above, with the exception that samples were not laundered prior to testing. Participants were instructed regarding the use of the CALM scale and rated each fabric individually until all fabrics in the set had been rated. Upon the completion of the study, the researcher thanked the participants for their time and explained the general purpose of the study.

3.2.3 Experiment 2 Results and Discussion

Data points for each rating were calculated in a similar fashion to the procedure described in Experiment 1. Data points for each rating were entered into a Microsoft Excel spreadsheet and double-checked for accuracy. Table 3 lists the means and standard errors for the ratings generated for the 39 fabrics assessed across the different testing sessions. Fabrics are listed in order from most to least comfortable. Brief Fabric Descriptions are included in the table. A fuller description of these fabrics, including fabric structure, fiber content, fiber weight, and construction characteristics, can be found in companion technical report *Consolidated Data On Fabric Construction* (Brady, 2008).

Table 3. Mean Comfort Ratings with Standard Deviations for 39 Selected Fabrics Assessed in Experiment 2

Fabric	Fabric Description	Mean (s.d.)
22J	Knit Single Jersey	81.0 (14.0)
58D	Knit Fleece	69.5 (34.3)
86H	Woven Cotton Flannel	66.9 (23.6)
65C	Tricot Knit	53.0 (32.2)
45X	Knit PBI/Kevlar [®]	49.2 (32.1)
21K	Interlock Knit	49.0 (29.7)
14V	Woven Twill Lightweight	48.1 (28.6)
11J	Single Jersey Knit	46.7 (29.5)
94K	Monopak Knit	36.2 (33.7)
11S	Woven Cotton	33.0 (28.9)
64E	Woven Quilted to Nonwoven	29.3 (32.7)
98N	2/1 Twill	23.4 (30.2)
53N	Woven Cotton	23.3 (34.4)
34G	Woven Plain Weave	21.5 (32.7)
69W	Nonwoven Tyvek [®] Spunbond	13.0 (48.3)
73C	Woven Broad Cloth	2.7 (28.4)
53H	Triliminate	2.6 (41.9)
39I	Terry Cloth	1.3 (39.1)
91S	Knit-Textured Polyester Double Knit Jersey	1.1 (46.5)
51U	Satin Weave	-4.4(38.3)

Fabric	Fabric Description	Mean (s.d.)
31F	Plain Weave	-5.4 (42.6)
73R	Nonwoven polypropylene	-8.4 (44.3)
98H	Plain Weave Rip Stop	-9.3 (40.9)
97K	Trilaminate	-15.8 (42.7)
96K	Woven Cotton Poplin	-17.5 (35.0)
43W	Woven Ripstop	-18.0 (40.4)
31A	Woven Polyester	-19.0 (43.8)
61S	Nonwoven Spunbond	-19.9 (35.3)
46P	Nylon Woven with Polyester Knit Liner	-21.0 (41.0)
23T	Plain Weave Rip Stop	-23.4 (35.4)
44J	Woven Nomex Fire Resistant	-23.7 (39.6)
59D	Woven Momie Cloth	-26.9 (36.3)
64C	Woven PBI/Kevlar Fire Resistant	-27.5 (40.0)
52G	Plain Weave Rip Stop	-31.6 (37.9)
54Q	Nonwoven Spunbond	-32.0 (39.8)
73T	Plain Weave Rip Stop	-37.8 (36.1)
75X	Woven Ripstop	-42.4 (38.9)
56L	Woven Cotton Duck #8	-59.1 (45.5)
50Z	Woven Cotton Duck #10	-60.0 (34.3)

Examination of the fabrics by comfort ratings reveals logical relationships between comfort and fabric type. Seven of the nine fabrics most highly rated for comfort were knits (Mean = 48.2 [s.d. = 23.7]). Ratings for both woven (Mean = -3.7 [s.d. = 36.3]) and nonwoven (Mean = -11.9 [s.d. = 19.2]) fabrics were more variable, generally ranging from slightly to moderately uncomfortable. Ratings for wovens, in particular, were wide-ranging: Three wovens (86H, 14V, 11S) were among the ten most highly rated fabrics for comfort, yet the two lowest rated samples were woven cotton duck fabrics with a stiff and unyielding feel. Overall, mean CALM ratings by fabric type were significantly different across the three major fabric classes (knit, woven, nonwoven; ($F(5, 38) = 4.84, p < 0.002$)).

These results demonstrate the utility of the CALM scale across a broad range of fabrics. One important difference between the present study and the original Natick work is the inclusion of uncomfortable fabrics in the present study. The original Natick work was conducted on fabrics already in military use. Consequently, the original analyses were restricted to fabrics already judged at least minimally comfortable; no fabric received strong uncomfortable ratings. The

fabrics used in the present study comprised a broad range extending from extremely comfortable (the top-rated knit fabrics 22J and 58D) to very uncomfortable (the Woven Cotton Duck fabrics 56L and 50Z). Thus, both comfortable and uncomfortable materials can be assessed through use of the CALM scale.

3.3 Experiment 3 – Assessing Construct Validity of Collected CALM Data

3.3.1 Experiment 3 Introduction

In Experiment 3, the construct validity of the collected CALM data was further assessed by a comparison of fabrics rankings for comfort derived by a different methodology: direct paired comparisons of fabric samples. In this study, the rankings derived from these direct paired comparisons were compared to the rankings obtained from the CALM data to provide an alternative measure of validity.

3.3.2 Experiment 3 Methods

Eight fabrics were selected for testing. These fabrics were chosen on the basis of all CALM evaluations to date (from Experiments 1 and 2 plus 11 additional fabrics tested) by rank-ordering all fabrics tested and selecting every eighth fabric for testing. The resulting eight fabrics comprised a representative range of fabrics along the comfort dimension from most comfortable to least comfortable. Preparation of samples for presentation was completed prior to the study as described above.

Ten research participants from LEHP were recruited to provide evaluations and comparisons for these eight test fabrics.²

Each participant was tested individually in a single testing session of about 30 minutes duration. Each participant provided an evaluation of the more comfortable fabric of presented pairs across 28 evaluations and separately provided CALM ratings for each of the 8 tested fabrics. Thus, each participant provided a total of 28 paired evaluations and 8 CALM ratings in a single testing session. Half of the participants completed the paired comparison first, then the CALM assessments. The other participants performed the tasks in the reverse order. Further, the order of presentation for each trial was randomized for all participants to minimize carryover effects due to practice or fatigue.

² This use of non-naïve participants was for the purpose of methods development. Paired comparisons using a large group of naïve participants are underway.

Session preparation was similar to the procedure described in Experiment 1. The researcher removed the Dickson TR320 Data Logger from the testing container and allowed the logger to equilibrate for 15 minutes prior to recording the temperature and humidity level of the testing room. Upon arrival, participants washed their hands with alcohol gel hand sanitizer prior to testing and signed an informed consent form.

Participants were given the following instructions for the completion of the paired evaluations:

Thank you for agreeing to participate in this study. We are going to give you two fabric samples and ask you to decide which is the more comfortable fabric of the two. You may handle the fabric as long as you would like. Please feel, hold, touch, or squeeze the material ONLY on the face-up side of the fabric. After feeling each fabric, tell me which fabric you judge to be the more comfortable of the two fabrics. Please remember that there are no right or wrong answers. We are interested in your perception of the comfort of each fabric. When you have finished the rating, I will then provide you with the next pair of fabrics to be evaluated. In all, you will be rating 28 pairs of fabrics. Do you have any questions?

Following the instructions, the researcher then gave the participant the first pair of fabrics. Each fabric was in its own manila folder with the only identification being the test number. Each pair was administered in a predetermined random sequence that differed for each participant. Ratings were completed at the participant's pace.

Participants were given the following instructions for the completion of the CALM ratings:

Thank you for agreeing to participate in this study. We are going to give you fabric samples and ask you to rate the comfort of each fabric. You may handle the fabric as long as you would like. Please feel, hold, touch, or squeeze the material ONLY on the face-up side of the fabric. After feeling the fabric, please rate the COMFORT on the provided scale. You can rate comfort by drawing a single horizontal line across the scale at the point corresponding to your rating. You may mark the scale at any point along the vertical line, not just at the verbal labels found on the scale. Please remember that there are no right or wrong answers. We are interested in your perception of the comfort of the fabric. When you are finished the rating, please tell me, and I will then

provide you with the next fabric to be rated. In all, you will be rating 8 fabrics. Do you have any questions?

Testing folders were distributed one at a time. A participant was given the first testing folder containing the first fabric sample to be rated. As the participant finished one testing folder, the researcher removed the folder, examined the datasheet to ensure that it was marked correctly, and provided the next testing folder.³ The procedure was repeated until the participant completed all trials.

Upon the completion of the study, the researcher thanked the participants for their time and explained the general purpose of the study:

Thank you for your time and effort in completing this study. The goal of our research project is to compare comfort ratings obtained by the CALM scale with comfort rankings based on paired comparisons. Do you have any questions?

3.3.3 Experiment 3 Results and Discussion

For the CALM ratings, data points for each rating were calculated in a similar fashion to the procedure described in Experiment 1. Data points for each rating were entered into a Microsoft Excel spreadsheet and double-checked for accuracy. For the paired comparisons, a score was tabulated for each fabric; this score was the number of times it was selected as the more comfortable of the two presented fabrics. Fabrics were then ranked in order from most comfortable to least comfortable, based upon the score.

The results were analyzed in two ways to assess reliability and validity. In one analysis, the CALM evaluations in Experiment 3 were compared to the ratings obtained in the previous CALM evaluations (Experiment 1) to provide a measure of test-retest reliability. Table 4 lists the means and standard errors for the ratings generated for the 8 fabrics assessed across the different testing sessions (the original CALM evaluation and the current evaluation). In all, there was a strong correlation between the two sets of evaluative data ($r = 0.84$, $p < 0.009$). The strength of the correlation is even more remarkable given the small number of comparisons (eight fabrics) and the population differences between the two groups (naïve participants in the original CALM evaluations and fashion/textile experts in the

³ Occasionally a participant had not used the form correctly. In this case, the participant was given further instruction on the proper completion of the datasheet and reissued the sample.

current CALM evaluation). As in Experiment 1, the CALM scale yielded consistent measurement of tactile comfort across the rated fabrics.

Table 4. Means of CALM Comfort Scale Ratings from 50 Participants in the Original CALM evaluations (“Original Mean”) and Ten Participants in the Current CALM Evaluation (“Current Mean”) for Eight Fabrics Selected for Evaluation of a Paired Methodology to Assess Comfort.

Higher CALM Numbers Indicate Greater Perceived Comfort.

Fabric	Original Mean (s.d.)	Current Mean (s.d.)
22J	81.0 (14.0)	71.8 (9.9)
11J	46.7 (29.5)	48.2 (22.5)
53N	23.3 (34.4)	19.6 (39.6)
16C	12.4 (38.2)	8.9 (34.4)
51U	-4.4 (38.3)	7.9 (31.9)
36D	-13.8 (42.3)	0.3 (30.6)
61S	-19.9 (35.3)	-27.3 (32.5)
75X	-42.4 (38.9)	-45.1 (25.7)

In the second analysis, the CALM data were compared to the rankings derived from the paired evaluations to provide a measure of construct validity. For each participant, the CALM data was used to rank-order the eight fabrics from most comfortable to least comfortable. A similar ranking of all fabrics was then calculated based upon the results of the individual paired evaluations for each individual. From these individual rankings, a modal ranking across all ten participants was derived. This modal ranking was then compared to the ranking derived from the CALM data. A Kendall’s rank-order (*tau*) correlation revealed a strong positive correlation (0.79, $p < 0.006$) between the rank-ordering produced by the CALM and paired methods; see Table 5.

Table 5. Rank-Order Ratings Based on Paired Comparisons (Paired Ranking) and CALM Comfort Scale Ratings (CALM ranking) for Eight Fabrics Selected for Evaluation of a Paired Methodology to Assess Comfort.

Ranking #1 indicates the fabric perceived to be most comfortable.

Fabric	Paired Ranking	CALM Ranking
22J	1	1
11J	2	2
61S	4	3
53N	5	4
51U	3	5
16C	6	6
75X	7	7
36D	8	8

Analysis of the rankings for each individual fabric showed that CALM assessments and paired comparisons resulted in identical rankings for the two most preferred and three least preferred fabrics. For the fabrics comprising the three middle rankings, the results of the CALM assessments and paired comparisons were not as congruent. It is possible that these middle-ranked fabrics were too similar to be judged effectively by either method. For these middle-ranked fabrics the mean CALM difference was relatively small (a mean difference of 4.3 per pair separated the fabrics comprising the middle rankings of 4 through 6). In contrast, for the fabrics ranked similarly by the two methods (CALM assessment and paired comparison) a large mean difference in CALM scores was found (21.7).

4. Conclusions

The physical variables that govern comfort and protection are generally and inherently in conflict. As might be expected, those factors that enable a textile system to be protective are not necessarily those that might offer comfort and subsequent enhanced performance for the user. For example, it is widely accepted that currently available chemical/biological protective ensembles for both the military and civilian first-responders are relatively uncomfortable and consequently compromise well-being, and ultimately limit the mission performance of the wearer. The very nature of those systems that offer enhanced moisture vapor transport might not offer the required chemical/biological agent performance during a mission threat. The complex task of balancing comfort and protection is challenging and critical. Success depends upon identifying the features of apparel that determine comfort and use; this has been a long-standing goal of military apparel design.

Given the importance of the role of comfort, a critical need is the ability to assess all features of comfort in an easy, comprehensive, and accessible manner. The Comfort Affect Labeled Magnitude (CALM) scale extends the applicability of labeled magnitude scales to quantifying the human experience of tactile comfort. Whereas this scale was rigorously tested in its initial construction, psychometric evaluation of any scale assessing perceptual experiences is an ongoing process (Kaplan and Saccuzzo, 2001).

In the present set of studies, the researchers have confirmed the two key psychometric properties of reliability and construct validity for the Comfort Affect Labeled Magnitude Scale in three experiments. Reliability was established by a test-retest comparison of the comfort ratings derived in Experiment 1 with the ratings obtained for the same fabrics in the original testing of the CALM scale (Cardello, Schutz, and Winterhalter, 2002; Cardello, Winterhalter, and Schutz, 2003). Construct validity was demonstrated by a comparison with an alternative psychophysical means of obtaining comfort rankings, a direct paired comparative method (Experiment 3). These findings complement and extend the original construct validity measures obtained by the Natick researchers who correlated CALM ratings with both physical measurements and sensory evaluations of specific handfeel characteristics of the fabric.

In all, the CALM scale was used in the present set of studies to provide comfort ratings for 50 different fabrics with a wide range of

sensory characteristics. Our results further confirm the utility of the CALM scale in assessing the tactile comfort of fabrics, an important step in the goal of predicting comfort perception and individual acceptance.

5. Recommendations

The importance of tactile comfort in apparel was demonstrated in recent work studying the potentially adverse effects of discomfort on physical and cognitive performance. Bell, Cardello, and Schutz (2005) tested visual vigilance in 40 participants in a repeated-measures design. Each participant completed a visual vigilance task (visual monitoring of and responding to letters displayed on a computer screen) under three conditions of clothing comfort: extreme discomfort (wool coverings on arms and neck in addition to the participant's normal clothing), minimal discomfort (cotton coverings on arms and neck in addition to the participant's normal clothing), and the control condition (the participant's normal clothing only). Performance results indicated a significant decline in vigilance accuracy and a significant increase in reaction time for participants in the wool clothing condition. This study was the first empirical demonstration that the tactile comfort of clothing can negatively affect cognitive performance, perhaps by shifting attention away from the task at hand. These results, consistent with similar decrements in performance associated with thermal discomfort (Endrusick, Gonzalez, Gonzalez, 2005), provide evidence of the importance of considering tactile comfort in the design and manufacture of garments for use by the military and first responders.

Tactile comfort represents just one of the three facets of comfort (moisture, thermal-fit, and tactile) detailed by Wong, Li, and Yueng (2002).

Although the CALM scale was designed for measuring tactile comfort, it is likely to provide an accurate measure of each of these comfort factors. Barndt and Pierce (2008), for example, recently showed a correlation between CALM tactile comfort measures and a physical measurement of thermal transfer.

Further testing should be conducted to establish this ability and the relationships among these several facets of comfort. It will be only through studying the individual components of comfort via complementary perceptual and physical measures that an understanding of overall comfort will be realized.

Ultimately, as in retail apparel design, the final stage in military garment design is consumer (soldier) acceptance of the finished product. It is at this point that a soldier's performance in the developed garment provides the definitive evaluation of the considerable efforts of designers, engineers, and manufacturers.

Whereas designers must focus on the competing issues of protection, performance, and comfort, ultimately it is the comfort factor that largely determines soldier acceptance and garment use. The present study confirms and extends previous findings that tactile comfort is a readily measurable, essential component of military fabrics, and its assessment is critical for understanding the properties of military garments as they affect performance.

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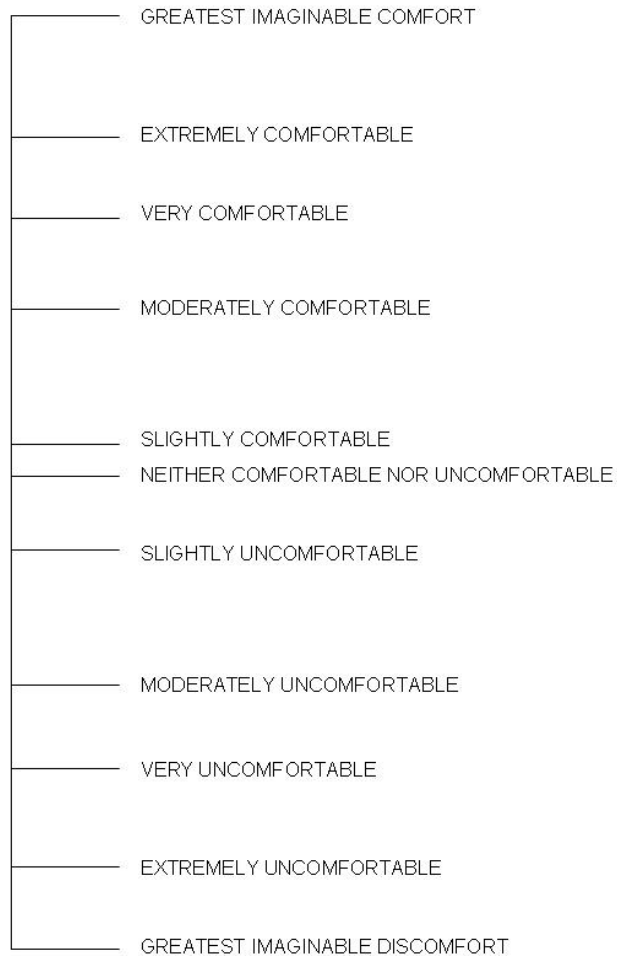
Appendix A – CALM Scale

The Comfort Affective Labeled Magnitude (CALM) scale used for the Comfort Assessment of Fabrics in the present study is shown below.

This representation is not actual size; the scale used in the experiments was 200 mm long.

Participant No: _____ Sample # _____ Date: _____

•Feel, hold, touch or squeeze the material ONLY on the TOP side of the fabric.
•After feeling the fabric, please rate the *COMFORT* on scale below by drawing a single straight line across the scale at the point corresponding to your rating.



Appendix B – Prescreening Questionnaire for Experiments 1 and 2

The prescreening questionnaire used for the recruitment of participants for Experiments 1 and 2 is shown on the following pages.

Fabric Comfort Study Questionnaire—Laboratory for Engineered Human Protection

Session # _____ Date _____ Location _____

Section (please choose one) A (time) [] B (time) [] C (time) []

Respondent Name: _____ Panelist #: _____ (for staff use)

Campus or Local Address or Department in which Employed: _____

City: _____ State: _____ Zip: _____

Campus Extension or Telephone Number: _____

E-mail Address _____

Qualifications

- Students, staff and faculty – All eligible
- Normal tactile abilities
- Willingness to attend session(s) for which you volunteered (a session requires about 30 minutes of your time)

Hello, I'm Prof. Stephen Hirsch from the Laboratory for Engineered Human Protection (LEHP) here at Philadelphia University. We are conducting a study regarding the comfort of fabrics. We are appreciative that you offered to participate and would like to ask you a few questions to determine your suitability for this study.

1. Record gender.

Gender: Male _____ Female _____

1a. If female: Are you currently pregnant or nursing a child?

_____ Yes (If yes, please stop and return this form) _____ No (Continue)

2. For classification only, please tell me which of the following best describes your age.

_____ Under 18 (If under 18, please stop and return this form)

_____ 18 – 21 (Continue)

_____ 22 – 25 (Continue)

_____ 26 – 30 (Continue)

_____ Over 30 (Continue)

3. Please tell me if any of the following apply to you. Consider the entire list—do not identify or respond to the individual items.

_____ Yes (If yes, please stop and return this form) No _____ (Continue)

- Neurological disorders
- Diabetes
- Missing digits (fingers) or missing hands
- Tingling or numbness in the hands or fingers
- Taking medication that could cause loss of sensation in the hands
(Examples include but are not limited to: Chemotherapeutic agents, Chloroquine, D-penicillamine, Isoniazid, Nitrofurantoin, Parenteral gold therapy, Phenytoin)
- Taking medication that could cause super-sensitivity in the hands
- Large scars on the hands or fingers that are less sensitive
- A current injury to your hand or fingers
- Excessive palm sweating
- Eczema or other skin irritations on your hands
- Carpal Tunnel Syndrome
- Untreated Hypothyroidism or treated but still have numbness in hands
- Blood flow disorder causing less blood to flow to hands (ischemia)
- Stroke
- Multiple Sclerosis (MS)
- Arthritis in hands or fingers
- Herniated disk in the neck which causes numbness in the hands or fingers
- Allergies to certain fabrics or fabric cleaners
- Any other medical condition that affects the sensitivity of your hands.

4. As related, we are conducting a study regarding the comfort of fabrics. Some or all of these fabrics may have use as part of protective garments. The study requires you to feel fabric swatches and rate the comfort. A part of the study will require you to use a rating scale to measure comfort of the fabric swatches. Please confirm that you are willing to participate in the study?

___ Yes (Continue) ___ No (If no, please stop and return this form)

5. You have indicated that you would be willing to feel fabric swatches to rate comfort. The study will require about 30 minutes of your time for each session for which you volunteered. Please confirm your willingness to commit this time.

___ Yes (Continue) ___ No (If no, please stop and return this form)

I _____ (printed name) attest that the information I have provided above is true and accurate. I have none of the above conditions and am willing to participate in the fabric comfort study.

Signature: You will sign this form at the panel session

Date: _____

Please return this form as an e-mail attachment to LoftusT@PhilaU.edu at least one week before the (first)⁴ panel session in which you will participate.

Thank you.

⁴ In the event you volunteered for more than one.

Appendix C – Informed Consent Form Used for Comfort Panelists

The consent form signed by comfort panelists is on the following pages.

INFORMED CONSENT FOR COMFORT PANELISTS—LEHP PROGRAM

Philadelphia University

Title of project: Comfort Data for LEHP Program

Person in charge: Prof. Stephen S. Hirsch
Office: Gibbs Hall—x5639
Residence: N/A
e-mail: HirschS@PhilaU.edu

1. This section provides an explanation of the study in which you will be participating:

A. The study in which you will be participating is part of research intended to determine the perceived comfort of fabrics that may be used to design and produce garments. The researcher is a faculty member in Philadelphia University’s Laboratory for Engineered Human Protection, which is in the School of Engineering and Textiles.

B. If you agree to take part in this research, you will be asked to make judgments of the comfort properties of fabrics by feeling them with your hand.

C. Your participation in this research will take a total of about one-half hour for one session of fabric comfort evaluation. You may volunteer for more than one session if you wish. Sessions are scheduled at varying times.

D. In participating in this research, there is a very small likelihood that you could experience some skin sensitivity. This is not expected since the fabrics you examine will have been widely handled by others outside the university—as well as by the LEHP staff—without ill effect.

E. By participating in this research, we hope you will value the benefit of your service to Philadelphia University.

2. This section describes your rights as a research participant:

A. You may ask any questions about the research procedures and these questions will be answered. All questions should be directed to Professor Stephen S. Hirsch, the person in charge of the research. His campus telephone number and e-mail address are on the first page of this consent form.

B. While your participation in this endeavor will be known to your colleagues since you will be working in a group and/or with other panelists coming in and out of the room, all results obtained will be pooled and not identified with any of you individually. Only several persons on the LEHP staff will have access to information that can be associated with your identity. In the event of publication of this research, no personally identifying information will be disclosed. To make sure the results of your participation are confidential, as just noted only the pooled results of your contribution will be revealed to others and not identified with any of you individually.

C. Your participation is voluntary. You are free to stop participating in the research at any time, or decline to participate further in the research without penalty.

D. This study involves minimal risk; that is, no risks to your physical or mental health beyond those encountered in the normal course of everyday life are anticipated. As noted above, there is very slight risk that you could experience a skin reaction from handling some of the fabrics.

3. This section indicates that you are giving your informed consent to participate in the research:

Participant:

I agree to participate in a scientific investigation of Comfort Data for the LEHP Program, as an authorized part of the education and research program of Philadelphia University.

I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best part of my knowledge and belief, I have no physical or mental illness or difficulties that would increase the risk to me of participation in this study.

I understand that I will receive no compensation for participating, and that I am entitled to no compensation.

I understand that my participation in this research is voluntary, and that I may withdraw from this study at any time by notifying the person in charge.

I understand that this informed consent form applies to all comfort panels assembled for the same purpose on which I volunteer to serve (if more than one).

I am 18 years of age or older.

I understand that I will receive a copy of this signed consent form.

Signature

Date

Age Range	Under 18	[]	Gender	Male	[]
	18 to 21	[]		Female	[]
	22 to 25	[]			
	26 to 30	[]			
	Over 30	[]			

Researcher:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

Signature

Date

Revised June 23, 2005