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RELATIONS AMONG COMFORT OF FABRICS, RATINGS OF COMFORT, AND VISUAL VIGILANCE[1]

RICK BELL AND ARMAND V. CARDELLO

Behavioral Sciences Natick Soldier Center, Natick, Massachusetts

HOWARD G. SCHUTZ

Department of Consumer Sciences
University of California at Davis

Summary.—Little is known about the relationship between perceptions of comfort and cognitive performance. In the present study, 40 subjects (20 men and 20 women) participated in a computerized cognitive task of visual vigilance. The computer task was completed under three conditions of clothing and tactile comfort: one condition was that of extreme discomfort, effected by the wearing of wool clothing material on the arms and neck in addition to each subject's normal clothing, including a short sleeve shirt; a second condition was that of minimal discomfort, effected by the wearing of cotton clothing material on the arms and neck, in addition to each subject's normal clothing, including a short sleeve shirt; and a third condition was a control, wherein no experimental material was added to each subject's normal clothing, including a short sleeve shirt. Comfort was assessed prior to, during, and after testing. Reaction time and accuracy of 400 trials of a visual vigilance task were assessed under each of these three conditions. Analysis indicated a significant difference in perceived comfort between the wool and each of the other conditions. In addition, both reaction time and accuracy declined in the wool condition. This study is among the first to identify a direct significant relationship between perceptions of clothing comfort and cognitive performance.

Cognitive performance research has been conducted for several decades, with studies examining such effects as mental practice (Halvari, 1996), physical exercise (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996), anxiety and expectations (Wiggins & Brustad, 1996), and aging (Delorme & Marin-Lamellet, 1998) on individuals' ability to process information and react to stimuli. While mental practice has usually been shown to improve performance, these other variables studied have tended to produce decrements in performance.

Research on the effects of human comfort on performance has also received some attention during recent years, with the comfort variable usually being manipulated by thermal conditions (Epstein, Keren, Moisseiev, Gasko, & Yachin, 1980; Nunneley, Reader, & Maldonado, 1982), physical motion

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(Rinalducci, 1980), the introduction of visual discomfort (Rechichi, DeMoja, & Scullica, 1996), and the mediating effect of measures of anxiety associated with decision making (Halvari, 1996). All of these manipulations of comfort also resulted in decrements to human performance and decision-making.

One specific variable that the general public and fabric and clothing manufacturers might assume has an effect on general comfort is the tactile comfort of clothing. Yet, despite the obvious nature of the relationship, little serious research attention has been paid to it. Rather, the focus of relationships between clothing and performance has been on either the insulation properties of clothing and their effects on thermal stress (for a review, see Levin, 1995; Brooks & Parson, 1999), or the effects of sizing and fit on range of motion (Gordon, Churchill, & Clauser, 1989), thereby interfering with motor tasks and reducing cognitive reaction time. While thermal stress effects may impair cognitive performance directly, the sizing effect may be a direct physical limitation leading to an indirect cognitive effect. However, in the literature related to clothing comfort, no research could be found that focused on the individual's subjective rating of comfort, independent of thermal and fit considerations, and its association with cognitive performance. In the context of the U.S. military, it is important to understand the relationship between the comfort of different types of clothing and cognitive performance, as it could have ramifications for the selection of material that would provide the least amount of interference with soldiers' ability to perform physical or cognitive tasks.

When attempting to study subjective ratings of comfort, the initial consideration is how to define clothing comfort. Is it a lack of awareness of the presence of material on the body or is it the presence of a pleasant sensation on the body deriving from a contact with the material? In fact, it may be either, leading to the possibility that any tactile or other sensory characteristic that either draws attention to the presence of material on the skin or disrupts an existing pleasant sensation may lead to discomfort and an associated shift in a subject's focus of attention on an ongoing task. This shift in attention may be sufficient to affect performance measurably on a cognitive task. In the present study, we sought to examine this phenomenon, using test materials made of cotton and wool to effect differences in comfort.

For the purposes of this study, clothing comfort was defined as the level of perceived comfort resulting from the wearing of particular fabrics and their contact with the body. We controlled the confounding variables of thermal effects and fit by the nature of the clothing article's design and the conditions of testing. The goal of the study was to assess how perceived comfort affects an individual's ability to perform a cognitive task. We hypothesized that the cotton material could be used to effect either a neutral or mildly uncomfortable tactile sensation, while the wool material would effect more extreme uncomfortable tactile sensations in the test subjects. We further hypothesized that mild discomfort would have a slight negative effect on performance, and that extreme discomfort would have a large negative effect on performance.

Method

Subjects

Forty subjects (20 male, 20 female) took part in a three-condition cross-over design. Subjects ranged in age from 23 years to 45 years (*M* age = 36.2 yr.) and were recruited via random selection, stratified by sex, from a list of more than 1,000 employees from the U.S. Army Natick Soldier Center, in Natick, Massachusetts. Subjects were admitted to the study if they were in good physical health and had at least two years of experience working regularly with computer monitors; and they were excluded if they claimed to suffer from skin conditions or allergies to the test materials, if they possessed poor eyesight for reading from a computer monitor, or if the flexed forearm and flexed bicep circumferences exceeded 39 or 37 cm, respectively. Based on testing conducted, these circumferences were the maximum limit that would allow for the proper fit of the test materials.

Cognitive Performance Task

There are several available approaches to measuring cognitive performance (Dinges, 1992; Kennedy, Berbaum, & Smith, 1993; Kennedy, Dunlap, Turnage, & Wilkes, 1993), most of which have been incorporated into several different computer software packages. The program chosen for this study was E-Prime (Psychology Software Tools, Beta Version 1.0, November 1999), primarily because this software program allows customizing the test design.

The task chosen was a standard visual vigilance task administered by computer, wherein simple reaction time and accuracy could be assessed. In the task, a blank screen was interrupted at various intervals by the random appearance of either the letter 'A' or the letter 'B'. The letters appeared in Times New Roman Font, 14-point type, and were .64 centimeters in height on the screen. A Dell® computer and 15-in. Dell® computer monitor were used, with a distance between subject's eyes and the screen of approximately 60 centimeters.

When the subject saw the letter 'A', the number '2' on the computer keyboard was to be pressed; when the subject saw the letter 'B', the number '1' on the computer keyboard was to be pressed. Once the subject gave a response, the next presentation of the stimulus randomly appeared at an interstimulus interval of between 500 and 2000 msec., and the procedure was repeated for the duration of the vigilance task. This task was chosen for use primarily because of the brief learning curve associated with the task, with a

5-min. practice session prior to the actual test sufficient to reach a performance plateau (Psychology Software Tools, Beta Version 1.0 Guide, November 1999). No clothing or tactile comfort variation was introduced during this practice session.

The vigilance task for this test consisted of two repetitions. Each lasted approximately eight minutes and was composed of 200 trials of the visual vigilance task. In addition to a baseline and pretest comfort rating, subjects rated perceived comfort immediately upon completing the first half of the design and then continued immediately with the repetition and another 200 trials. At the completion of the second repetition, subjects again rated perceived comfort.

Clothing Comfort

After investigating a variety of methods for manipulating the tactile comfort of clothing items through material choice or starching, we judged that most methods resulted in associated variations in either thermal comfort or fit. Thus, we decided to fabricate an article of clothing in which tactile comfort could be easily manipulated yet still controlled for sizing and fit. The articles of clothing we fabricated were sleeve extensions and neck dickies that could be easily constructed from a variety of fabrics to manipulate perceived comfort without affecting thermal comfort or fit. To create the sleeve extensions, Extra Large size commercial socks (Wigwam® Super cushioned athletic socks made from 80% cotton/20% stretch nylon and Wigwam® wool athletic socks made from 85% wool/15% nylon, Wigwam Mills, Inc., Sheboygan, Wisconsin) were purchased and the toe sections removed to allow the sock to be slid over the hand and forearm so that it covered from approximately the mid-bicep to the wrist.

Neck dickies were fabricated from the same commercial sock material by cutting the sock tube lengthwise and then stitching a hook and loop closure at the ends to create a length of material that could be wrapped around the neck and fastened to form a collar or dickie. By creating these clothing articles, we were also able to design them in such a way as to allow freedom of airflow and to cover only a small, circumscribed area of the body.

The choice of these two commercial items was made as a result of pretesting. A separate set of 10 subjects, including two men whose average circumference of the flexed bicep was 39 cm (normal M for men = 32 cm), and whose average flexed forearm circumference was 37 cm (normal M for men = 29.6 cm), pretested six potential materials representing a range of stretch and comfort, including the two test clothing articles. Of the six materials tested, the two commercial sock materials for this study were chosen on the basis of the large difference in their perceived tactile comfort when worn as described and while subjects sat and read a book for 25 min. Pretest subjects reported no differences in thermal comfort between wearing the two test articles and wearing no articles at all on their arms and neck. In addition, all subjects reported that the test articles fit appropriately, including the subjects with the largest bicep and forearm circumferences. The fact that socks of one size could adequately fit such a range of forearm and bicep sizes was likely due to the material of both socks providing adequate stretch to avoid negatively affecting fit. For the pretesting and the study, all subjects were asked to wear their normal clothing but to include a short-sleeved shirt with no high neck coverage.

Subject Conditions

Forty subjects took part in a three-condition crossover design. For the testing, subjects were asked to wear 'normal clothing', described to them as being their own clothing but ensuring that they wore short sleeve shirts with no neck coverage. Subjects completed both repetitions of the cognitive task in all three of the following conditions during the course of a 90-min. period: (1) a control condition, during which no sleeve extensions or neck dickies were added to their 'normal clothing'; (2) a cotton condition, during which cotton sleeve extensions and neck dickies were worn added to their testing clothing; (3) a wool condition, during which wool sleeve extensions and neck dickies were added to their 'normal clothing'. There was a 5-min. rest interval between test conditions. The testing took place in an air-conditioned room in which temperature and relative humidity were held constant during all three testing conditions (22° Celsius and 50% relative humidity). Each subject participated in all conditions, and the orders of condition were balanced using a complete block procedure.

Perceived Comfort Ratings

Perceived comfort ratings were collected via the use of a labeled visual magnitude scale of comfort developed specifically for the purposes of assessing clothing comfort (Cardello, Bell, Marshall, Winterhalter, Meiselman, & Schutz, 1998; Cardello, Schutz, & Winterhalter, 2002). This scale, with a possible range of -100 to $+100$, has been shown to possess good reliability for a 5-day interval between judgments of clothing material and for descriptions of material ($r = .68$ and .84, respectively) and has been validated by comparing judged clothing materials to judged written descriptions of clothing material designed specifically to vary in comfort (Cardello, *et al.*, 2002). A sample of the scale is available in Appendix A (p. 67).

Comfort ratings were made at four time intervals during the wearing of each of the test materials: (1) prior to putting on each of the sleeve extensions and neck dickie (baseline); (2) immediately after putting on the sleeve extensions and neck dickie, but just prior to beginning the first half of the test (pretest); (3) at the interval between the two repetitions of each test (during test); and (4) at the completion of the second repetition of each test (posttest). These time intervals were chosen to allow separate assessments for each of the test materials of any changes in perceived comfort throughout the cognitive task.

After completing the cognitive tasks with the three test materials, subjects were interviewed and asked several specific questions about whether their ratings of comfort were due to the test materials, to their 'normal clothing', to anxiety about ability to see the screen, or to visual fatigue.

Results

Mean ratings of comfort at pretest, during the test (interval between the two repetitions), and at posttest across conditions (Table 1) were compared using a multivariate GLM (SPSS, 1998) procedure with repeated measures. The analysis showed a main effect of condition on comfort ratings ($F_{2,39}=16.55$, $p<.001$), indicating lower perceived comfort in the wool condition compared with either the control or cotton conditions. A significant interaction in perceived comfort was also found between time and condition ($F_{4,39}=10.65$, $p<.001$). *Post hoc* Bonferroni-adjusted tests indicated that comfort ratings were similar in the control and cotton conditions from pretest through posttest, but in the wool condition significant differences were found between baseline and each of the three testing times and also between the pretest and posttest times.

TABLE 1

Mean Comfort Ratings at Four Time Intervals During Testing

Condition	Baseline		Pretest		During Test		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	52.8^a	12.4	52.4^a	10.9	46.1^a	9.5	50.7^a	12.3
Cotton	52.8^a	12.4	46.9^a	10.0	41.2^a	10.1	44.0^a	11.9
Wool	52.8^a	12.4	-13.4^b	9.2	-23.2^{bc}	8.8	-28.7^c	9.7

^{abc}Means with different letters are different at $p<.05$, *post hoc* Bonferroni-adjusted $p_{.05}$.

Percent accuracy and mean reaction times were recorded for the two repetitions across conditions (Table 2). A multivariate GLM procedure with repeated measures was used to analyze the percent accuracy during the two repetitions of the task. Results suggest a main effect of condition on accuracy ($F_{2,39}=7.56$, $p<.01$) and a main effect of repetition on accuracy ($F_{1,39}=6.35$, $p<.01$). A significant interaction in accuracy was also found between condition and the first and last half of the task ($F_{3,39}=5.73$, $p<.01$). *Post hoc* tests with Bonferroni-adjusted $p_{.05}$ indicated that percent accuracy dropped significantly from the first half to the second half of the task between the control and wool conditions. Although the percent accuracy in the cotton condition was lower in the second half when compared to the first half, the difference was not large enough to be significantly different from the percent accuracy in the first and last halves of the task in the control condition; nor were significant differences evident in percent accuracy from first to second half of the task between the cotton and wool conditions. Percent accuracy was highest in the control condition, and although the data directionally suggest that accuracy was lower for cotton, this difference fell short of statistical significance. In addition, *post hoc* tests suggest no statistically significant difference in accuracy between the cotton and wool conditions during either the first half or the last half of the task.

TABLE 2
MEAN PERCENT ACCURACY AND REACTION TIME IN FIRST AND LAST HALF OF TASK

Variable and Condition	First Half of Task		Second Half of Task	
	M	*SD*	*M*	*SD*
Percent Accuracy				
Control	97.2^{a}	1.8	96.8^{a}	1.7
Cotton	96.2^{ab}	1.4	94.4^{ab}	1.7
Wool	94.6^{ab}	1.7	93.1^{bc}	1.6
Reaction Time, msec.				
Control	539^{d}	28.1	511^{d}	25.0
Cotton	544^{d}	22.6	530^{d}	30.5
Wool	597^{e}	22.2	615^{e}	27.6

^{abc}Percent accuracy means with different letters are different at $p < .05$. ^{de}Reaction Time means with different letters are different at $p < .05$.

A multivariate GLM procedure with repeated measures was used to analyze the reaction times in the two repetitions (Table 2). Results suggest a main effect of condition on reaction time ($F_{2,39} = 8.34$, $p < .01$) but no significant main effect of repetition on reaction time. A significant interaction in reaction time was also found between condition and first and last half of the task ($F_{3,39} = 7.02$, $p < .001$). With *post hoc* Bonferroni-adjusted $p_{.05}$ testing a significant difference in reaction time between the control and wool conditions and between the cotton and wool conditions in both the first and last half of the task was noted. Although there was an increase in reaction time in the last half of the task in the wool condition, the effect of repetition was not significant. There were also no significant differences in reaction time between the control and cotton conditions or a significant effect of repetition for these two conditions.

To assess the relationships between comfort ratings and the measures of reaction time and percent accuracy, comfort ratings were correlated with percent accuracy and reaction time, combining both repetitions. Pearson correlation coefficients indicated that comfort ratings were significantly associated with both reaction time ($r = .34$, $p < .001$) and with percent accuracy ($r = .46$, $p < .001$).

Discussion

We had hypothesized that minor discomfort would negatively affect performance, and that extreme discomfort would have a more extreme negative effect on performance. Results support the notion that more extreme discomfort negatively influences cognitive performance. This is evidenced by the results in Tables 1 and 2. In Table 2, there are significant differences in both accuracy and reaction time between the control and wool conditions, but not between the control and cotton conditions. We had hypothesized that the cotton condition would produce minor discomfort and that this would affect performance. Even though pretesting suggested that the cotton condition was mildly uncomfortable, test results suggested that the cotton material chosen did not produce a significant difference in perceived comfort or in cognitive performance. Therefore, the results of this study do not support the hypothesis that minor discomfort negatively influences performance. However, failure to support this hypothesis is likely the result of not introducing a condition that effected minor discomfort during the performance of this task.

The mean comfort ratings for all three conditions suggest that wearing the wool material produces an immediate and extremely uncomfortable sensation. Also, subjects report slightly decreasing comfort over the next 16 min. of testing. This suggests that no adaptation to the material occurred during the testing period, i.e., there was no return to baseline comfort levels, and could provide support for the idea that this discomfort kept attention on the contact of the material with the skin and away from the cognitive task. If no effect on performance were found, it could have been because subjects were able to focus on the task until asked to rate comfort. At that time, they would have diverted their attention from their task long enough to attend to the sensation of the material, then returned to their task. Given the drop in accuracy and increase in reaction time noted only in the wool condition, it is more likely that the presence of the material diverted attention from the cognitive task. After testing was completed, subjects were asked if their ratings of comfort were indeed related to the test materials and not to their 'normal clothing', anxiety about seeing the screen, or visual fatigue. All subjects confirmed that comfort ratings were directly related to the sensation produced by wearing the test materials.

Both reaction time and percent accuracy followed a pattern that supports a relationship between perceived comfort and performance. It appears that, regardless of the material being worn, subjects react equally quickly in both repetitions, but in all conditions, accuracy drops over time, although not significantly in all conditions.

There are some limitations that need to be considered in this study. As stated earlier, the cotton material used did not produce the desired changes in perceived comfort; therefore, we are only examining effects caused by presumably extreme clothing discomfort in the wool condition. It is uncertain whether minor changes would produce these effects. This is a subject for further investigation. In addition, even though ambient temperature was controlled for in each test condition and pretesting suggested no change in perceived thermal comfort, no body temperature or other physiological markers were collected during the testing; hence, thermal comfort cannot be ruled out as having mediated the discomfort effects noted in the wool condition. It is also possible that fit could have mediated the effects; however, pretesting suggested that both the wool and cotton materials provided adequate fit. In visual vigilance tasks there is also the possibility of fatigue or habituation effects. In this study, the significant interactions in both reaction time and percent accuracy indicate that decrements in performance were not consistent, but instead, were greater in some conditions, ruling out the potential of boredom or fatigue as accounting for all of the effects noted in the study. Although fatigue might have operated to lower accuracy in subjects over the 90-min. testing session, these effects were different based on condition, suggesting that the effects of the materials on performance account for at least some of the variability.

There are several military implications of these findings. This study suggests directions for material developers to ensure that protective clothing designs do not compromise perceived comfort, so as not to risk decrements to cognitive performance. Several of the current materials used in the military need to be durable enough to withstand the high physical activity and exposure to the environmental elements that military personnel must endure. Unfortunately, wearing higher durability garments often produces lower comfort. This tradeoff needs to be better understood to ensure the safety of military personnel without limiting their ability to perform their tasks. These findings also have nonmilitary implications, such as the potential importance for students to wear more comfortable clothing when taking examinations or for workers to wear more comfortable clothing to optimize cognitive performance on the job. Further research is warranted to examine these relationships.

In this study, the wearing of the wool neck dickie and sleeve extensions produced discomfort. We have argued that this discomfort drew the attention of the subject to the presence of the material on the skin, thereby shifting the subject's attention away from the ongoing task, decreasing performance. The wool material was the only condition that affected both reaction time and percent accuracy in both repetitions of the vigilance task. This suggests that ratings of discomfort, as mediated by the wearing of material determined by psychophysical testing to be uncomfortable, are associated with decreased cognitive performance of this task. Given the design of the study and counterbalancing of conditions, we can argue that there was a causal relationship between manipulations of clothing comfort, perceived comfort, and cognitive performance.

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APPENDIX A

Comfort Rating Form: Line Scale

Place a mark on the scale to indicate the comfort/ discomfort level of the test material.