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EXPERIMENTS ON PERSONAL EQUIPMENT FOR LOW SEAM COAL MINERS: IV. INCORPORATING COILED CORD INTO CAP LAMP BATTERY CORDS

Prepared for:
United States Department of the Interior
Bureau of Mines

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Contract No. J0387213
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31 January 1980

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This report describes a study designed to evaluate a proposed modification in the cap lamp battery cord intented to reduce the incidence of snagging and catching of the cord. A three phase evaluation was performed comparing a prototype with the standard, currently available cord. First, a "pull test" equipment was run. The second evaluation was a body conformity study. The third evaluation involved subjects performing common tasks in a low seam coal mine simulator.

The results of these evaluations clearly demonstrated significant safety advantages of incorporating coiled cord into the design of the cap cord. The coil cord presented less of a snagging hazard, allowed the wearer more time to respond to a snag, and transmitted lower levels of force to the helmet when snagged.

The research team recommended that cap lamp cords be commercially developed which incorporate coiled cord at the battery and helmet.

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1.0 INTRODUCTION

1.1. Purpose

This report is one of a series produced under Bureau of Mines Contract J0387213 entitled, "Use of Personal Equipment in Low Coal." The objective of the project is to determine optimal personal equipment design for use in low coal, based on ergonomic, biomechanic, and safety considerations.

The purpose of the study described in this report was to evaluate a modification in the design of cap lamp battery cords to reduce the potential and consequences of snagging the cap lamp cord on protrusions, machine controls, etc.

1.2. Background

During Phase I of this contract, an extensive review of the literature pertaining to personal equipment design was prepared (Sanders, Beith, and Blake, 1978). The following background material was taken, in part, from that report. Additional information can be found in the Phase I literature review.

The current cap lamp system (light, cord and battery) has remained virtually unchanged since it was first introduced. There are only two manufacturers of MSHA approved systems and both are almost identical. The cap lamp cord presently used is .3125 inches (.79 cm) in diameter and is 4 feet (19 cm) in length. It is rigidly attached to the battery and the lamp. The cord contains two 18 gauge insulated wires inside a shielded rubber coating. This design makes the cord somewhat stiff.

Site visits and interviews with miners revealed two problems with current cap lamp cords. First, the cords come in only one size but the miners do not. The important body dimension for assessing cord length is sitting height (i.e. the verticle distance from the seat to the top of the head). In the general population (Stoudt, Damon, and McFarland 1965), the range for sitting height of the 5th to 95th percentile is approximately 5 inches (12.7 cm). Thus, the cord can be too short for the tallest miners, and will tend to pull their helmets back. It can be too long for the shortest miners, and thus result in an excess of cord flopping about.

The second problem with cap lamp cords is that they present a distinct catching hazard. The cords tend to bow out away from the body on all but the tallest miners. This loop of cord can, and does, catch on machine controls, moving equipment and protruding hazards. The result is that the miner's head is jerked back and often his helmet is pulled off. Machines are accidently activated, and occasionally the miner can even be dragged into moving machine parts or pulled along behind moving equipment, both with potentially severe consequences.

The ideal cord design must be durable, strong, and electrically safe. The present cords appear to be excellent on all three of these criteria. In addition, however, the cord should conform as closely to the body as possible to minimize catching hazards and interference with work. The cord should also be designed to fit the 5th to 95th percentile miner comfortably and allow for variation in the manner in which it is worn (e.g. right or left side, under the arm or down the back).

One potential design concept which might meet these requirements would be the incorporation of coiled sections (like the cord on a telephone) in the cap lamp cord. Coiled cord is made in several gauges and is as strong, durable, and electrically safe as the current cord being used. In addition, it is flexible and should conform closer to the miner's body. The cord will also stretch to accommodate the entire miner population. Further, in the event that a cord is caught, the stretching action of the cord should give the miner additional time to take corrective action before the full impact is delivered to the helmet.

1.3. Experiments

A prototype cord was constructed incorporating coiled sections into it. A three phase evaluation was performed comparing the prototype with the standard, currently available, cord. The evaluation focused on the human factors aspects of the design rather than the durability or electrical properties of the cord. First, a "pull test" experiment was run. The cords were snagged while the subject crawled along a predetermined route. The subjects reaction time (time to stop) and the maximum force delivered to the helmet were measured. It was hypothesized that less force would be transmitted to the helmet with the coiled cord because of its stretch characteristics.

The second evaluation was a body conformity experiment. A 5th and 95th percentile subject wore the cords and assumed standard work postures. The cords were photographed to ascertain if the cords conformed differently to the subjects' bodies.

The third evaluation experiment involved subjects performing common manual tasks in a low seam coal mine simulator. Task completion time and subjective evaluations were obtained. The purpose of this was to determine if the experimental cord interferred in any unexpected way with work performance.

After a description of the prototype cord, each of the evaluations will be discussed separately.

2.0. DEVELOPMENT OF COILED CORD

Cap lamp systems must meet requirements set forth in CFR 30:19.0. The only specific standard set forth for the cord is a durability test defined as follows:

> Ten cords, assembled with the cord armor and outlet of the lamp with which it is to be used, are slatted at least 100,000 times through an arc of 50 degrees at approximately 90 slattings per minute.

Several manufacturers of coiled cord indicated that commercially available coiled cord should be able to pass this durability test. In fact, manufacturers indicated that technology exists which could produce a smaller diameter, lighter weight straight cord than that currently used with cap lamps without sacrificing strength or durability.

Several prototype configurations involving coiled cord were informally tested and evaluated. It quickly became apparent that the entire cord could not be coiled. This would greatly increase the weight of the cord, it would add height to the helmet where the cord runs over the top to the lamp, and it was uncomfortable to wear under the arm. Further, very little coiled cord is required to allow for anthropometric differences in miners. Most commercially available coiled cord will stretch to four times its resting (coiled) length. Therefore, it was decided to keep the coiled sections to a minimum. This would also reduce the cost of production. The logical step was to combine small sections of coiled cord with standard straight cord. The question then became where to place the sections of coiled cord. Observations of test subjects performing simulated manual tasks revealed that the cord bulges out principally at the battery pack, and to a lesser extent at the base of the helmet. Therefore, these two sites were selected for placement of small sections of coiled cord.

After discussions with manufacturers and informal testing of cord samples, the coiled cord selected for use was a 22 gauge two wire cable manufactured by Belden. The 22 guage coiled cord is smaller in diameter (.1875 in; .48 cm) than the standard 18 gauge cord (.3125 in; .79 cm) but can still handle the power requirements of the cap lamp.

Figure 1 illustrates the prototype cord configuration. A straight piece of cord extends over the cap lamp to the base of the helmet, where it becomes coiled for seven complete turns before straightening again. Just before entering the battery it is again coiled 21 complete turns and enters the battery directly. The coiled cord has an elasticity ratio of 4 to 1. This means that the 5.75 in (14.6 cm) length of coiled cord used could be stretched to a maximum length of 23 in (58.5 cm). This, then, is the coiled cord configuration that was used in the three evaluation experiments.

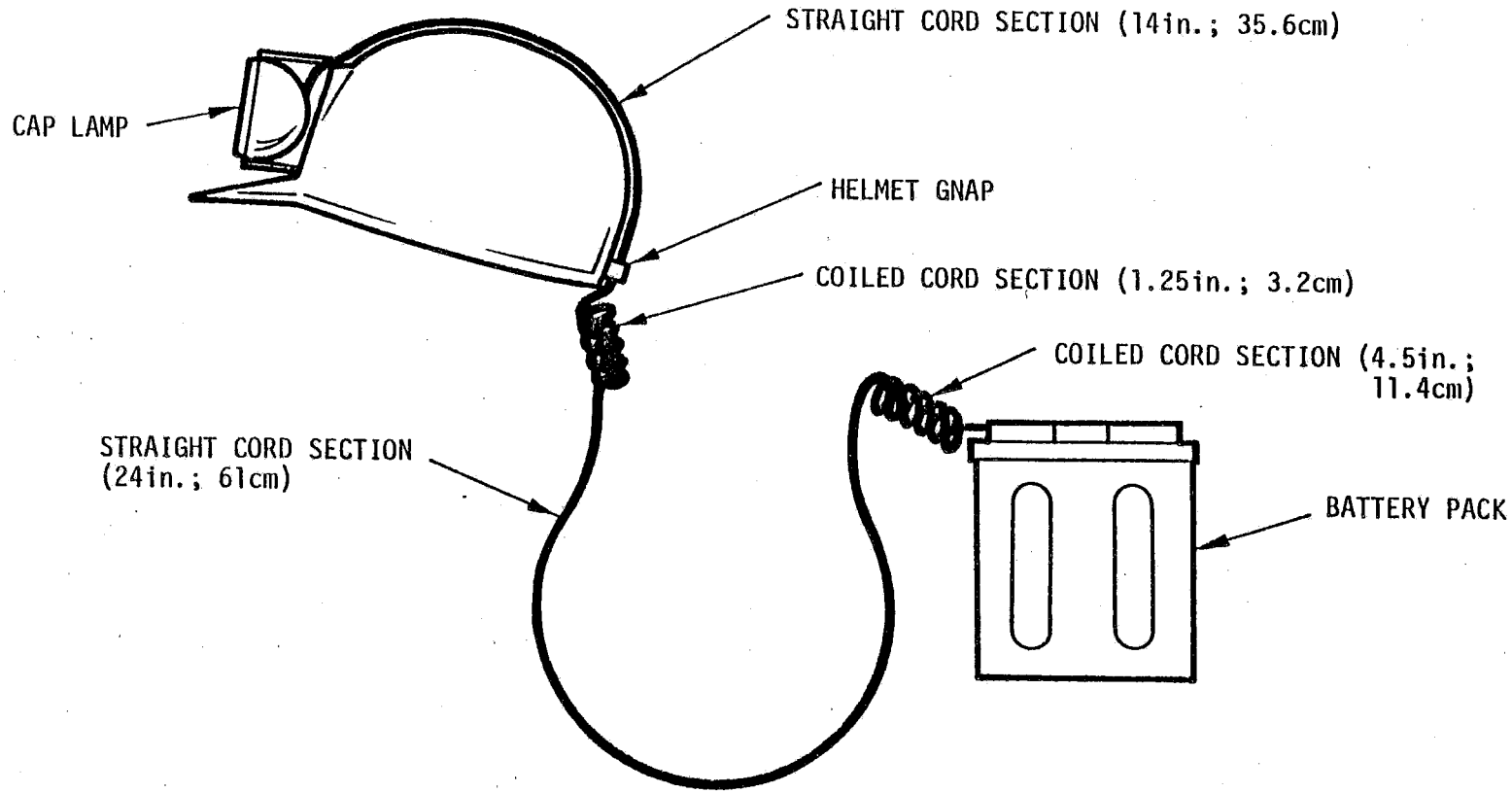


Figure 1. Illustration of Prototype Cap Lamp Cord Used Showing Sections of Straight and Coiled Cord.

3.0. PULL TEST EVALUATION

3.1. Purpose

The current cord is, of course, not elastic. As such, any time the cord is snagged the full force is transmitted to the helmet almost immediately. The coiled cord, on the other hand, will stretch and should provide a gradual build up of force at the helmet when snagged. This gradual buildup could allow the wearer to respond before the full force of the snag is transmitted to the helmet.

This experiment was designed to test this hypothesis. Subjects crawled along a route at a constant speed. At random locations, the cord was snagged and both maximum force on the cord and subject's reaction time to stop were measured.

3.2. Method

3.2.1 Subjects

Eight male subjects were used. The subjects represented the extremes (1-15th and 85-99th percentile) of the general population in height and weight. Subjects ranged in height from 64 to 75 inches (163-190 cm) and in wieght from 135 to 190 lbs (61-86 kg). Subjects were paid to participate.

3.2.2. Pull Test Apparatus

The route followed by the subjects was a straight path 18 ft (5.5 m) long. A dashed white line ran the entire length of the path. This helped the subjects stay on the path and maintain a consistent pace.

The force measuring equipment, a rope 22 ft (6.7 m) in length, was attached, adjacent to the track, on the wall 4 ft (1.2 m) off the floor. The rope was stretched and held taut by a spring and stationary hook at one end, and a memory torque wrench secured at the other end. When the rope was pulled, the peak force would be recorded on the torque wrench. (The reading on the torque wrench (in in - lbs) would later be converted to force (lbs) using a standard engineering formula).

A metal ring was placed so as to slide along the rope. A length of fishing line was attached to the ring and tied to the cap lamp cord of the subject. The line was attached to the cord 13 in. (33 cm) above the battery pack. This corresponds closely to the apex of a typical loop formed by any excess cord.

A curtain blocked the subject's view of the rope. This prevented him from seeing where the snag would occur.

3.2.3. Questionnaire

At the completion of the experimental section each subject completed the questionnaire shown in Figure 2.

Use the following scale to indicate your response; circle the appropriate number after each question.

5 - Standard cord much more
4 - Standard cord somewhat more
3 - Standard and coil cord are the same
2 - Coil cord somewhat more
1 - Coil cord much more

1.	Which cord was more uncomfortable?	1	2	3	4	5
2.	Which cord interfered more with your movement or work?	1	2	3	4	5
3.	Which cord, when snagged, made your helmet loose or fall off?	1	2	3	4	5
4.	Which cord, when snagged, resulted in a more forceful jerk to the neck?	1	2	3	4	5
5.	Which cord allowed you to stop crawling before a snag jerked your neck?	1	2	3	4	5
6.	With which cord did you feel safer?	1	2	3	4	5
7.	Which cord would you recommend?	1	2	3	4	5

Figure 2. Questionnaire used after completion of the pull test experiment.

3.2.4 Procedure

Warm up trials. Subjects were asked to locomote over the track while counting backwards by two's from a number provided by the experimenters. The counting served to distract the subjects from their cap lamp cords. They were instructed to follow the track and to move at a comfortable consistent "moderately quick" pace. Subjects were asked to adopt a comfortable head posture, and to maintain that position as closely as possible during the experimental trials. It was suggested that they note the point where their cap lamp beam shined on the track, and that they try to keep the beam at roughly the same distance ahead of them as they crawled. The experimenter recorded the time required to complete each trial. When the subject's time did not vary more than 2 seconds for three runs, the actual data collection trials were begun. All but one subject achieved consistency on the first three trials. The other subject required four trials.

Data Trials. Before each data trial, the subjects were asked to close their eyes and face away from the track while the experimenter walked down the entire length of the track and installed a metal clip at a pre-determined point on the rope. The clip could be placed at any one of 20 positions on the rope (or not at all in the case of a "false" trial). The position of the clip on any trial was provided by a predetermined random order. When the subjects crawled, they pulled the metal ring along the rope. When the ring struck the clip it stopped and pulled the cap lamp cord, thus simulating a snag. The subject was instructed to stop the instant he realized his cord was snagged. A piece of foam rubber was attached to the side of the metal clip to muffle the sound of the ring hitting the clip.

The experimenter started a silent stop watch when the ring hit the clip and stopped the timer when the subject stopped crawling. A large piece of foam rubber was placed on the back of the subject and the cord rested on the pad. This prevented the subject from sensing the tactile cue of the cord lifting off their back when the cord was snagged. The subjects also wore overalls, helmet, battery pack and cap lamp, self-rescue device and knee pads.

Each subject ran 18 trials with each cord. The order in which the cords were worn was counterbalanced across subjects. Six of the 18 trials were "false" trials in which no snag occured. The false trials served two purposes. First, they prevented the subjects from anticipating snags as they approached the end of the track. Second, they provided an opportunity for the experimenter to record the time required for the subject to crawl the length of the track. The experimenter could then determine if the subjects were maintaining a consistent pace and if not, could advise the subject to speed up or slow down. Subjects maintained remarkably consistency paces (+ 1.5 sec. per run) and seldom had to be coached.

3.3. Results

It is important to establish that the subjects were crawling at the same speed when wearing the two cords. A difference in crawling time might result in different forces being transmitted to the helmet when the cord was snagged. The time required to locomote the length of the track was recorded on the six false trials in which no snag occurred. These six locomotion times for each subject were averaged for each cord. The average across all subjects was 7.76 seconds while wearing the standard cord, and 7.78 seconds while wearing the coiled cord. Any differences in force or reaction time found between the cords cannot be due to two-one hundreds of a second difference in locomotion time.

3.3.1. Peak Force

Sandler's A statistic (Sandler, 1955) was used to compare performance with the coiled and standard cords. Sandler's A is derived directly from the "t" test, but is computationally simpler. The results of an analysis using the A test will be the same as the "t" test for related measures.

The peak forces recorded on the twelve trials in which a snag occurred were averaged for each subject, for each cord. The mean peak force for all eight subjects when wearing the standard cord was 7.81 lbs (34.7 N) compared to only 4.52 lbs (20.1 N) when wearing the coiled cord. This difference is statistically significant (Sandler's A = .188, $p<.01$). Thus the force delivered to the helmet when wearing the coiled cord was averaged only 58% of the force typically delivered when wearing the standard cord.

3.3.2. Reaction Time

The mean reaction time (time from snag to detection) while wearing the standard cord was 622 msec, compared to 994 msec while wearing the coiled cord. This difference is statistically significant (Sandler's A = .160, $p<.01$). Thus, the subjects were slower to react to the snag when wearing the coiled cord.

Although there was some error introduced into the reaction time measure because the experimenter started and stopped the timer, it is believed that it would not bias the results for two reasons. First the reaction time scores used for each subject were an average of twelve

trials, thus allowing much of the random fluctuation to average out. Second, there is no reason to believe that the experimenter's reaction time would be systematically different when the subject wore the different cords. Therefore, the .372 m sec difference probably indicated a true difference in reaction time to snags with the two cords.

3.3.3. Questionnaire Results

Table 1 contains the means and standard deviations for each question on the questionnaire. The mean of each item was tested using the parametric, "t" test (Winer, 1971) to determine if it was reliably different from 3.0 ("Standard and coil cord are the same"). The results of these "t" tests are also contained in Table 1. The results showed that, on the average, subjects felt that the standard cord was more uncomfortable, interfered more with their movement, was more likely to make their helmet loose or come off when snagged, and resulted in a more forceful jerk to the neck than the coiled cord. Further, they felt safer wearing the coiled cord and would recommend it much more than the standard cord. These results are in keeping with the peak force data. Item 5 was the only item not to show any significant opinion toward either cord. The authors believe that it is because the question is ambiguous with respect to the force of the jerk. In essence, the subjects only stopped when they felt a jerk so the question has no answer.

3.4. Discussion of Experiment I

The results clearly show that the coiled cord delivers considerably less force to the helmet than the standard cord under the conditions simulated. Further, subjects were slower to respond to a snag while wearing the coiled cord. This is logical when the following is realized. First, subjects have a threshold force below which they can not perceive a snag. Second, the force to the helmet builds up more slowly in the case of the coiled cord due to its inherent elasticity. Third, there is a certain reaction time between the sensing of the snag and the cessation of crawling. In the case of the standard cord, the force is sensed; but it builds up so quickly that by the time the subject stops, he has endured considerable more force. In fact, the subjects' heads often snapped back from the force of the snag while wearing the standard cord. With the coiled cord, on the other hand, the force is sensed and, because of the slow build up of force, only a relatively small increase in force has resulted before the subject stops crawling.

There are, then, obvious safety advantages to wearing a coiled cord, as opposed to a standard cord, if it is snagged while the miner is moving. The miner's head is not jerked back and there is more time to take corrective action and free the cord.

TABLE 1. QUESTIONNAIRE RESULTS FROM PULL TEST EXPERIMENT

	Mean Response[1]	Standard Deviation	Mean versus 3.0 t[2]	p[3]
1. Which cord was more uncomfortable?	4.0	.93	3.04	<.05
2. Which cord interfered more with your movement or work?	4.0	.73	3.87	<.05
3. Which cord, when snagged, made your helmet loose or fall off?	4.2	.88	3.85	<.05
4. Which cord, when snagged, resulted in a more forceful jerk to the neck?	4.3	1.03	3.57	<.05
5. Which cord allowed you to stop crawling before a snag jerked your neck?	3.2	1.72	<1	Not Significant
6. With which cord did you feel safer?	1.7	.70	5.25	<.01
7. Which cord would you recommend?	1.5	.75	5.66	<.01

[1] Scale used for responses:

5. Standard cord much more
4. Standard cord somewhat more
3. Standard and coiled cord are the same
2. Coiled coil somewhat more
1. Coiled coil much more

[2] df = 7
[3] Two Tailed Test

4.0. BODY CONFORMITY EVALUATION

The pull test evaluation clearly indicated that when the cord is snagged, the coiled cord gives the subject more time to respond thus allowing the subject to stop at a lower force level than with the standard cord. Beside this safety feature, it was also postulated that the coiled cord would conform more closely to the body than the standard cord and thus would be less likely to snag in the first place. This was tested by photographing an anthropometrically large and an anthropometrically small subject wearing the coiled and standard cords in various work postures.

In virtually every comparison, the coiled cord conformed more closely to the body than did the standard cord. Figure 3, for example, shows the large and small subjects in a kneeling posture wearing the coiled and standard cord. The large subject is not sitting as is the small subject, but the important upper torso is erect in both sets of pictures. As expected, the difference between the cords is most striking with the small subject. The kneeling posture places the cord in the same position as would be found if the subjects were standing erect.

Figure 4 shows the large and small subject in a crawling posture. The differences between the cords are less apparent, but none the less, noticable.

The coiled section at the battery pack allows the cord to assume just about any angle as it leaves the battery instead of projecting straight out and away from the battery as is the case with the standard cord.

From a safety standpoint, therefore, the coiled cord creates a smaller catching and snagging hazard than the standard cord.

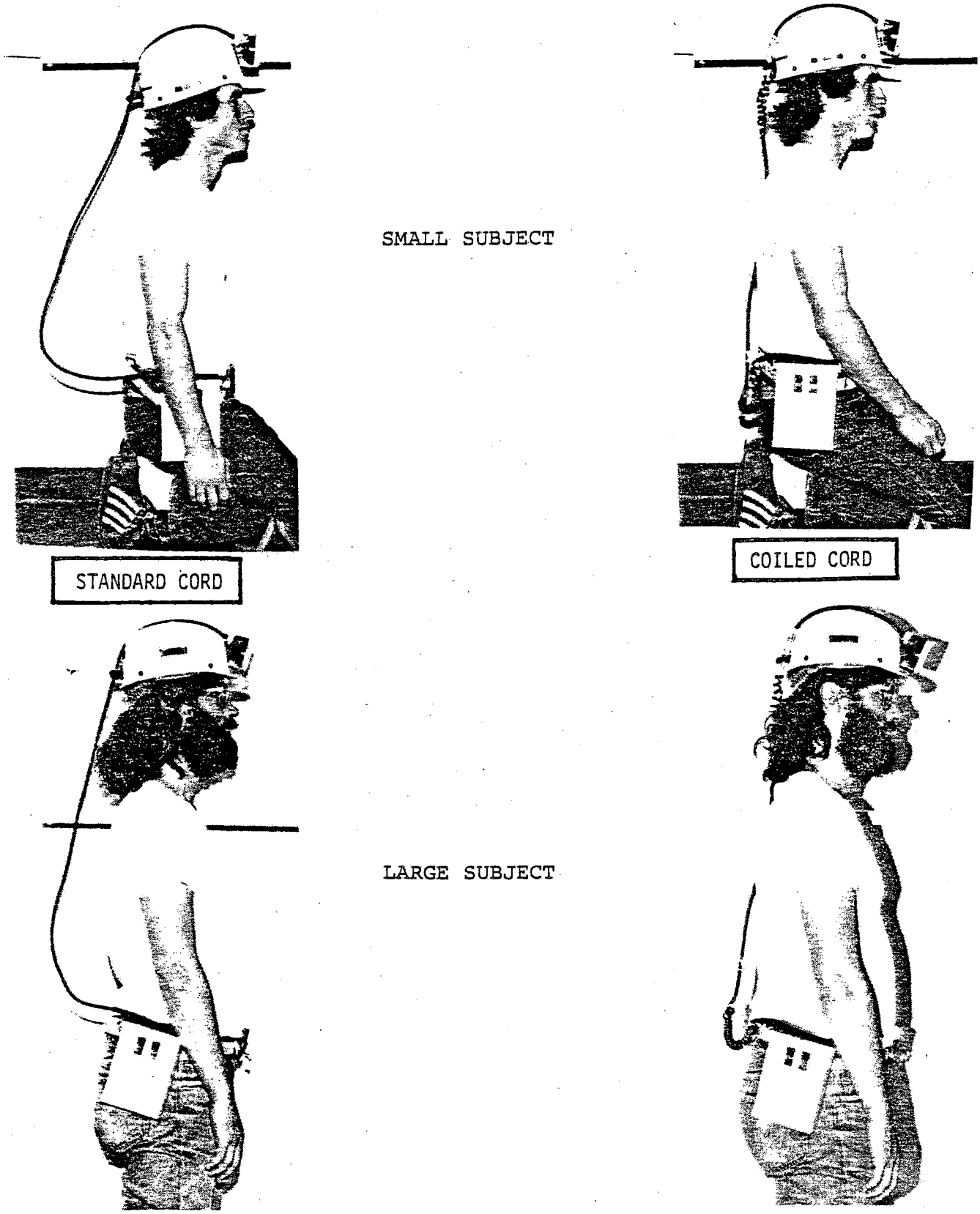


Figure 3. Body Conformity of the Cords With Large and Small Subjects in a Kneeling Posture

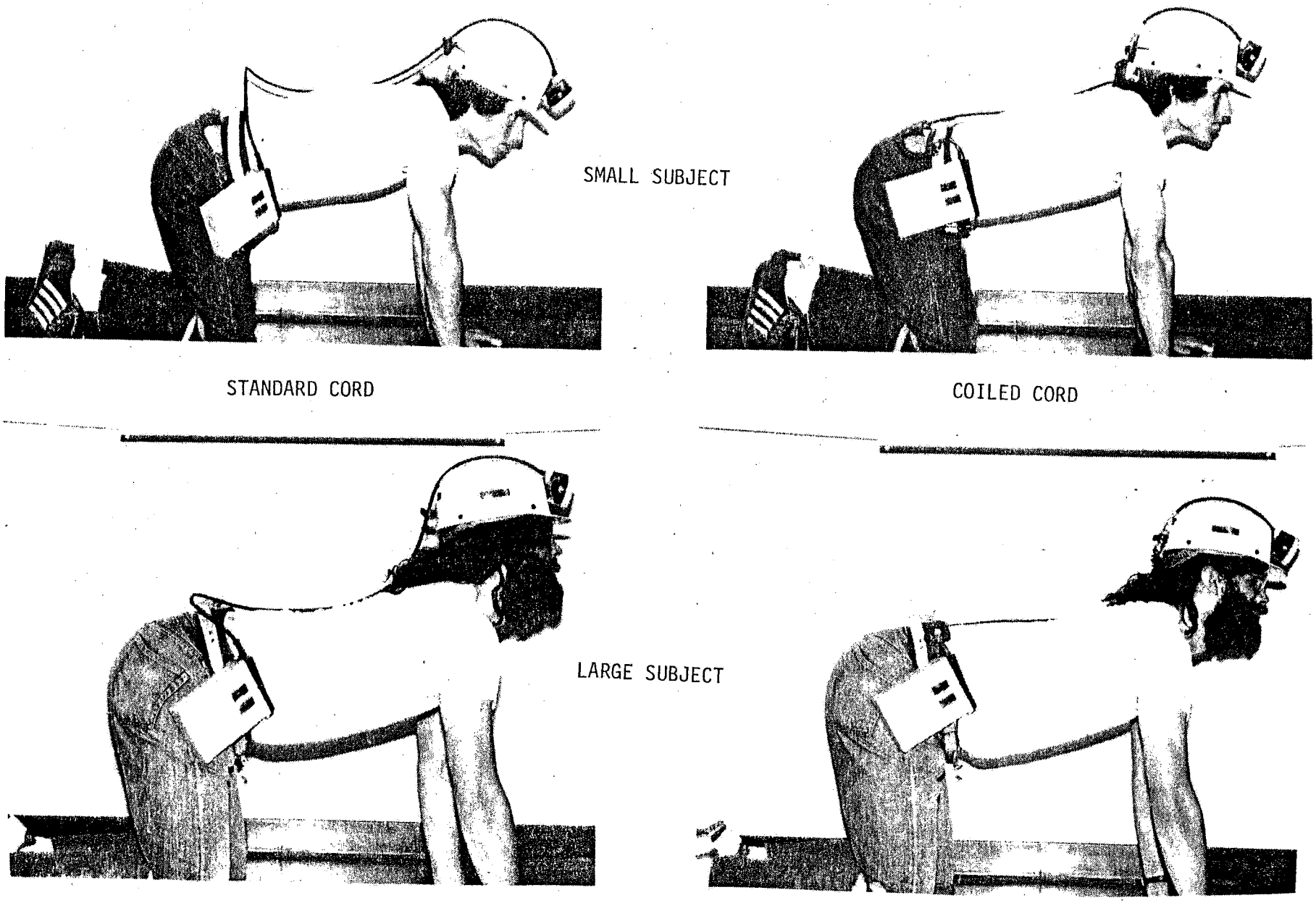


Figure 4. Body Conformity of the Cords With Large and Small Subjects in a Crawling Posture

5.0 SIMULATOR EVALUATION

5.1. Purpose

The pull test and body conformity evaluations clearly demonstrated the hazard reduction potential of the coiled cord design. The purpose of this simulator evaluation was to assess whether the coiled cord created any interference while the miner performed typical manual tasks in a low seam mine environment. A small number of subjects was used in this evaluation as it was not anticipated that any interference effects would be obseved. If anything, the closer contour of the coiled cord might actually present less interference than the standard cord.

5.2. Method

5.2.1. Subjects

Four male subjects were used in this experiment. Two subjects were selected from the 1 to 15th percentile in height and weight for the general population. The other two subjects were selected from the 85-99th percentile. Subjects ranged in height from 64 to 75 inches (163-190 cm) and in weight from 135 to 190 lbs (61-86 kg). All subjects had, previous to this experiment, worked in the simulator a minimum of five hours. Subjects were paid for their participation.

5.2.2. Simulator and Experimental Tasks

A simulator, designed to recreate the essential features of a low seam coal mine was constructed for this project. The general configuration of the simulator is shown in Figure 5. It consisted of an 8 x 36 ft. (2.44 x 11.0 m) main tunnel and three separate 6 x 8 ft. (1.83 x 2.44 m) alcove areas. The simulator was constructed of plywood with stucco covered walls. This provided a highly irregular and realistic surface. The entire simulator was painted flat black with dark gray modelling.

The roof consisted of interchangeable, irregular panels which varied in height ≠ 6 inches (≠ .15 m). The roof was adjustable to either a 36 in. (.92 m) or 42 in. (1.06 m) average height. For this experiment, the roof was set at 36 in. (.92 m). The roof also contained simulated roof bolts, cross beam timbers and rock outcroppings. The location of the roof hazards are shown in Figure 5 and some can be seen in Figure 6. The floor was irregular with bumps, dips, inclines, and "rock plates" (see Figure 7). Ten wooden posts, 6 in. (.15 m) in diameter, were fixed in various locations to simulate temporary roof timbers.

No light penetrated the simulator. Ventilation was achieved by fans and air conditioning. Temperature was maintained at 65-75°F (18-24°C). Observation portals allowed visual access to the simulator for the experimenter.

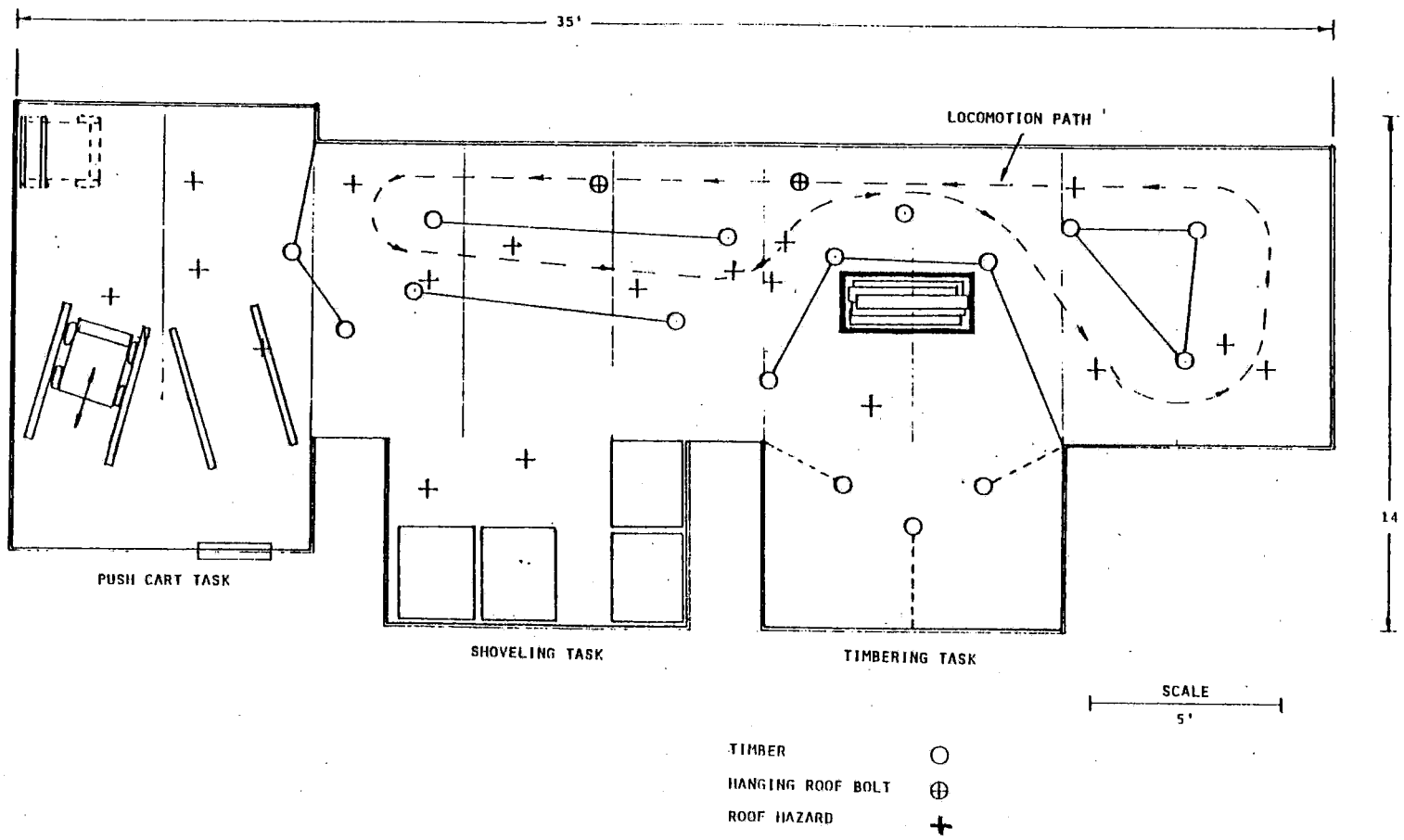


Figure 5 . Schematic Top View of Simulator (Drawn to Scale).

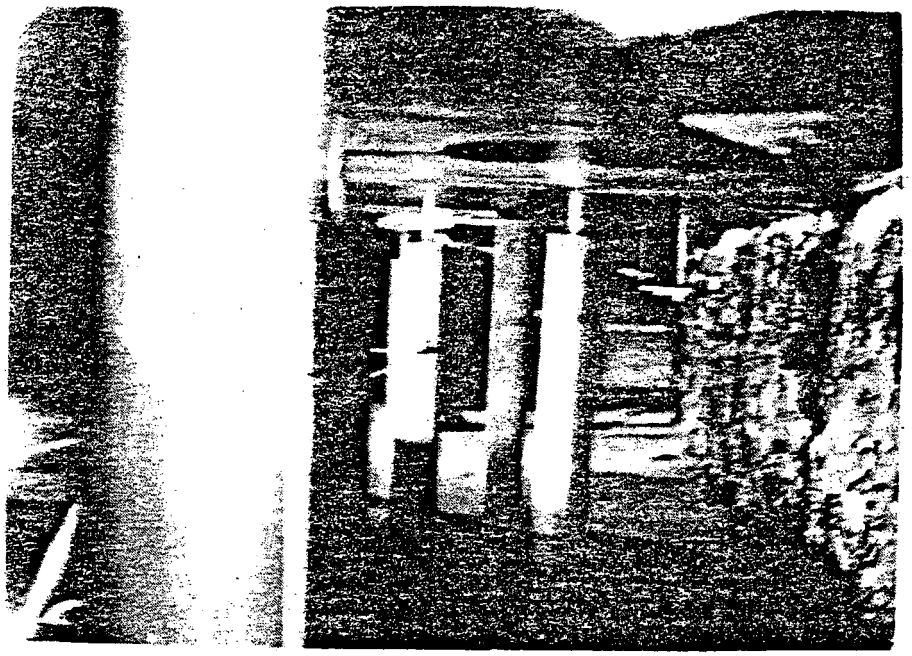


Figure 6. View from Front Door Down Locomotion Path.

Figure 7. Simulated Rock Plate Floor Hazard.

The mine simulator was constructed around four manual tasks commonly performed by low seam coal miners. These tasks were selected because they require the greatest range of body positions, are the most physically demanding tasks, and represent the worst case situations with respect to personal equipment usage. These tasks were: timbering, shoveling, cart pushing and locomotion. Figure 8 a,b,c, and d show a representative picture of each task.

Cart pushing. A 70 lb (31.75 kg) cart, simulating a fire boss's shot cart or a small face drill was used for this task. One trial consisted of alternatively pushing the cart ten times down two 5 ft. (1.52 m) pathways. A digital counter kept track of the repetition and was activated when the cart touched the switch at the end of the pathways.

Removing and replacing the cart in the far corner of the simulator started and stopped a timer.

Locomotion. Subjects crawled 350 ft. (106.75 m) around a circumscribed 50 ft. (15.25 m) route in the simulator. The subject activated a timer when starting and stopped the timer at the end of the trial.

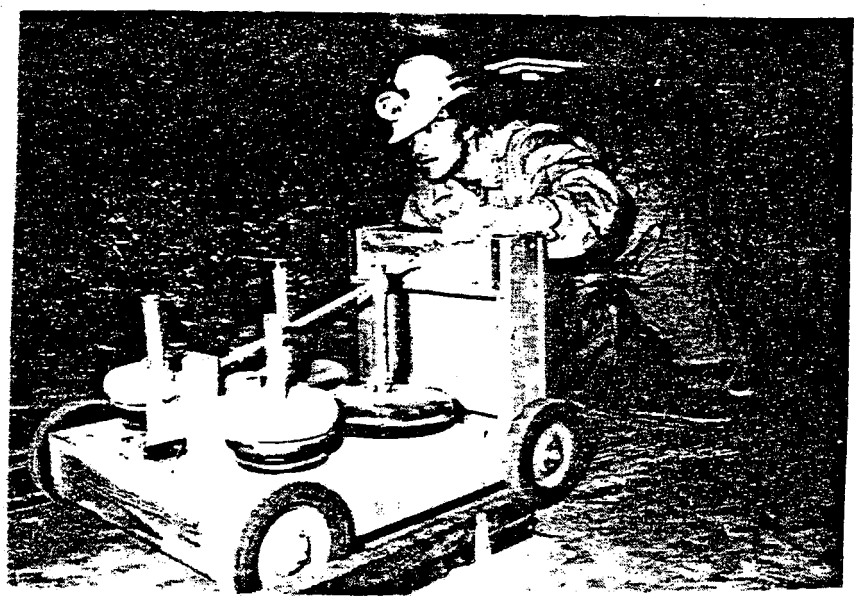
Shoveling. As shown in Figure 5 two bins, containing large gravel were positioned side by side. To the left, were two empty bins. A trial consisted of the subject lowering the bin door, starting the timer and shoveling the contents of one bin into the empty bin. After emptying the bin, the timer was stopped. The second bin was used for the second trial.

Timbering. A trial consisted of the subject putting up and taking nine timbers. The roof and floor fixtures were installed to hold the timbers so that each subject would set the timbers in exactly the same place. A small simulated wedge was placed above each timber and hit twice with a rubber mallet. The timer was started when the timbers were removed from the storage area and stopped when all timbers and materials were returned.

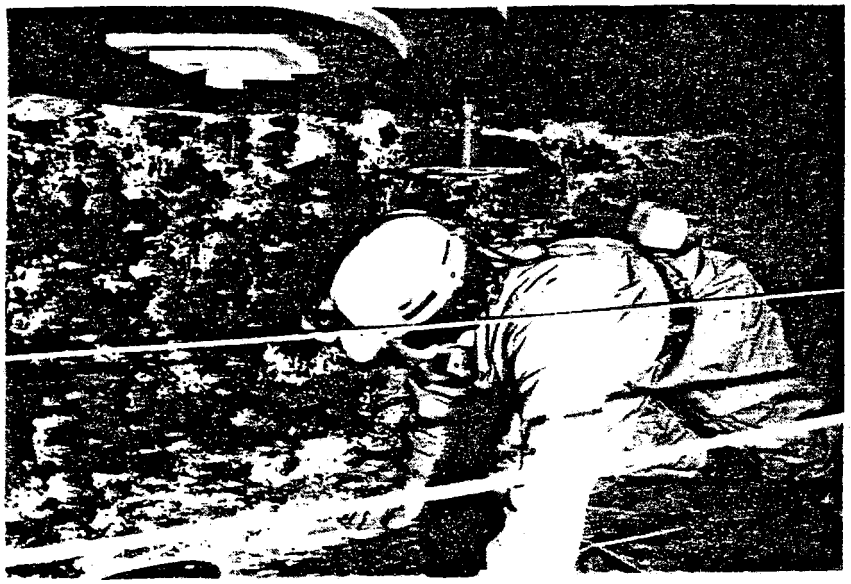
5.2.3. Procedure

A repeated measures design was used with each subject completing two "cycles" on each task: one cycle using the standard cap lamp cord and one using the experimental coil cord. The order was counterbalanced across subjects.

One cycle consisted of a subject performing two trials on each task. The two trials of a task were performed consecutively before moving onto the next task. Thirty (30) seconds separated each trial of a task.



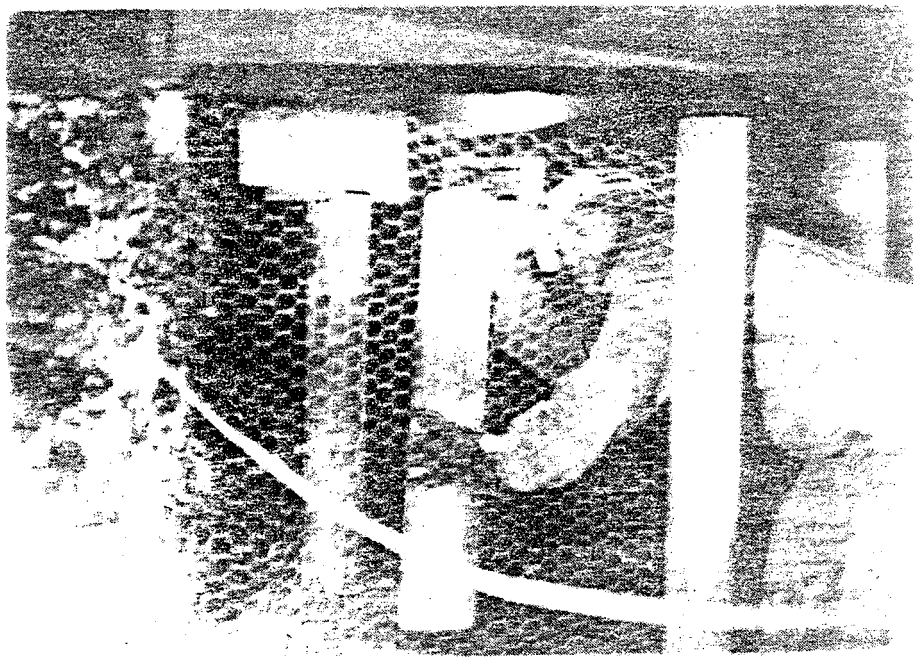
a. Cart Pushing



b. Locomotion

Figure 8. Illustrations of Each Simulator Task.

c. Shoveling



d. Timbering

Figure Illustrations of Each Simulator Task (Continued)

During the first trial of each cycle, the subject wore the cap lamp cord under their arm. That is, the cord coming off the back of the helmet ran over the shoulder across the breast pocket and under the arm to the battery pack. During the second trial, the cord was worn straight down the back.

Fifteen (15) minutes was alloted to finish the two trials of each task; unused time was rest. This amounted to approximately five (5) minutes rest between each task. A ten (10) minute rest was given at the beginning of each cycle. At the end of the experiment, the subject was questioned concerning the two cords on comfort and interference while performing each of the tasks in the simulator. In addition, the following six overall questions were asked:

1. Which cord did you reposition or readjust more?
2. Which cord caught on your belt, battery, or your self-rescuer more?
3. After being repositioned, which cord shifted out of position more quickly?
4. Which cord tugged or pulled more at the back of your helmet when you twisted or turned?
5. Which cord would you feel was safer?
6. Which cord would you recommend?

5.3. Results

5.3.1. Task Completion Time

Figure 9 presents the mean task completion times for each task while wearing each of the cords. The differences between cords, with the small sample size used were not statistically reliable for any task. Further, the direction of the differences were not consistent. On two tasks performance was faster with the coiled cord, and on two tasks performance was faster with the standard cord.

Even with this small sample size, it is safe to assume that the coiled cord does not adversely effect task completion time on the tasks simulated in this experiment. Thus, any safety or comfort advantage which the coiled cord might possess should not be offset by any expected degradation in performance.

5.3.2. Interview Results

The results of the interview indicated that the subjects detected no difference between the cords in terms of comfort or interference on any of the tasks. The overall questions also showed no differences between cords in terms of repositioning, catching, reshifting, and

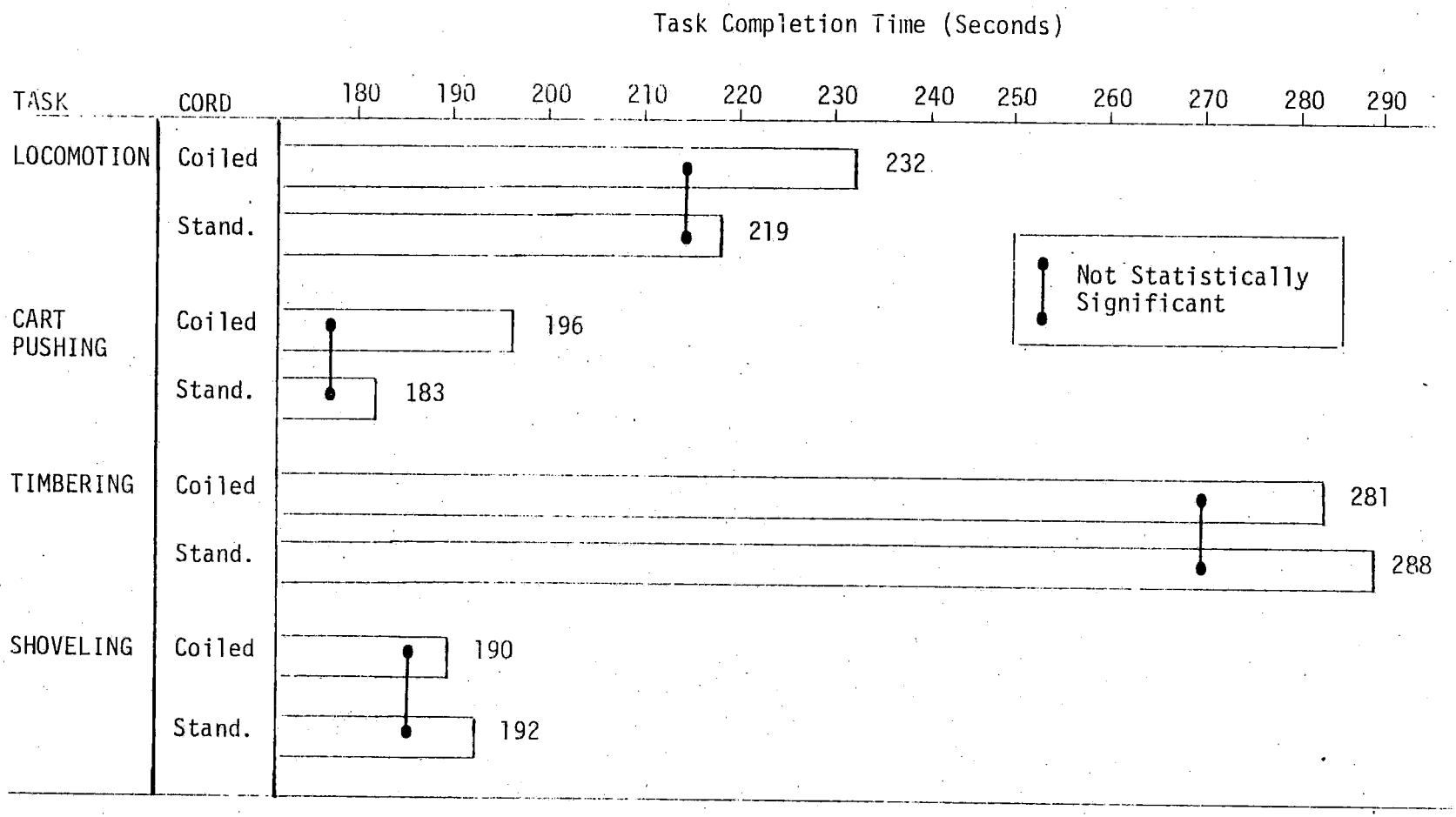


Figure 9. Mean Task Completion Times (Seconds) For Each of the Simulated Tasks While Wearing the Coiled and Standard Cords.

tugging at the helmet. There was, however, a clear preference among all four subjects for the coiled cord and they clearly felt safer (from catching) wearing the coiled cord.

In summary, no major objections to the coiled cord were found and a consistent trend indicated that it may be found preferable to the standard cord in subjective evaluation.

5.4. Discussion of Simulator Evaluation

This mini-evaluation of the coiled cord in the simulator confirmed the hypothesis that there would be no negative impact on task completion times. Although the simulator does simulate salient low seam mine features, it is probably not as hazardous (in terms of catching and snagging of cords) as is a real mine. It is possible, therefore, that in the real mine situation, any reduction in snagging by using the coiled cord could translate into reduced task times.

6.0. CONCLUSIONS AND RECOMMENDATIONS

6.1. Discussion

The results from the three evaluations were very consistent. The coiled cord appears to have a significant safety advantage over the standard cord. In addition, it can accommodate both large and small wearers equally well.

The particular design of coiled and straight cord used in these evaluations is probably not the optimal design. More than likely, less coiled cord could be used at the battery and at the helmet and still achieve the same results. (It was beyond the scope of the current contract to further modify and reevaluate other variations on the basic design tested.)

The coiled cord used in the test was hung on a wall to determine the amount of "stretching out" which would develop over time from the weight of the cord itself. After five months, there was virtually no additional stretching than had already occurred during the various evaluation tests.

6.2. Conclusions

The results from the pull test, comformity, and simulator evaluations clearly demonstrate significant safety advantages of incorporating coiled cord into the design of the cap lamp cord.

The coiled cord, compared to the standard cord,

1. Presents less of a snagging hazard;

2. Allows the wearer more time to respond to a snag; and

3. Transmits lower levels of force to the helmet when snagged.

6.3. Recommendations

It is the strong recommendation of the research team that cap lamp cords be commercially developed which incorporate coiled cord at the battery and helmet. These cords should be fully tested to meet MSHA requirements and field tested at several mines. The cost of switching from a straight cord to a coiled cord would be minimal but the potential safety benefit would be large. In addition, conversations with miners revealed a strong willingness to try such a cord with a belief that it might well prove superior to their current cord. User acceptance may, therefore, not be a major problem.

6.4. Synopsis

This report describes a study designed to evaluate a proposed modification in the cap lamp battery cord intented to reduce the incidence of snagging and catching of the cord. A three phase evaluation was performed comparing a prototype with the standard, currently available, cord. First, a "pull test" experiment was run. The second evaluation was a body conformity study. The third evaluation involved subjects performing common tasks in a low seam coal mine simulator.

The results of these evaluations clearly demonstrated significant safety advantages of incorporating coiled cord into the design of the cap lamp cord. The coil cord presented less of a snagging hazard, allowed the wearer more time to respond to a snag, and transmitted lower levels of force to the helmet when snagged.

The research team recommended that cap lamp cords be commercially developed which incorporate coiled cord at the battery and helmet.

7.0 REFERENCES

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