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Fire Tool Ergonomics

Interim Report

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Lois P. Sicking, **Mechanical Engineer***

San Dimas Technology & Development Center
San Dimas, California 91773-3198

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***In addition, the project leader is licensed to practice as a Registered Nurse in the states of California and Texas, with Advanced Cardiac Life Support (ACLS) certification by the American Heart Association.**

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Bob Serrato, *Dalton Hotshot Superintendent,*
Dalton Station, Mt. Baldy Ranger District, Angeles National Forest

Mark Glos, *Assistant Fire Management Officer,*
Mt. Baldy Ranger District, Angeles National Forest.

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Introduction

Population dynamics of the work force have changed dramatically over the past 30 years and more change is guaranteed for the future. The Forest Service work force reflects these changes, yet many of the tools used in fireline construction remain unchanged. Questions arise about standard hand tools meeting the needs of contemporary firefighters.

These tools must meet rigid requirements and high quality manufacturing specifications. Professional firefighters at the local level have modified fire tools for efficiency and effectiveness in a search to meet the new needs. At the national level there is a desire to evaluate the modifications with applied scientific methods to learn if technology might help in the tool selection process.

This report compares commonly used grubbing tools—the hoe blade end of a standard Pulaski, a Super Pulaski, a Mini-Pulaski, and a Pulaski with a fiberglass handle.

Ratings defined as the weight of material moved per unit time were recorded for three body height/weight ranges. Test subjects were asked to subjectively rate and rank each tool after use in this test.

Scope

San Dimas Technology and Development Center (SDTDC) was asked to evaluate the most commonly used fire tools, shovel, axe, Pulaski, combi-tool, McLeod, and others to determine if their design is still satisfactory to maximize worker efficiency while minimizing the risks of ergonomically induced injuries, such as repetitive motion injury and carpel tunnel syndrome.

The project goal is to determine tool configurations which best balance physiological characteristics with optimum production of fireline. This report discusses a first attempt at quantifying these factors.

Purpose

The purpose of this test was to: 1) develop a procedure for hand tool evaluation; 2) rate selected hand tools based on heart rate (input) and material moved per unit time (output) indexes; and 3) report on opinions of the workers immediately after using the tools being tested.

Background

Fire Tool Survey

A survey was generated to assist in problem identification and to determine features, likes and dislikes regarding the standard and specialty tools in fire service.

The survey was sent to the Interagency Hotshot Crew network and to the Region 5 Fire Equipment Chairperson for further distribution to field personnel. See Appendix A.

Survey responses indicate that professional fire-fighters have modified standard tools in an attempt to make them more effective. Some tool modifications, such as the Super Pulaski and fiberglass handles, have been in use for more than 15 years.

There are several tool modifications that have wide field acceptance. The most common involved the Pulaski (Super Pulaski), shovel (Bosley, Reinhart) and fiberglass handles. There were modifications reported for all standard tools. In some Hotshot Crews, all tools were modified.

Volume of Tools Procured

As shown in Table 1, the volume of the standard tools purchased each year is large. The top four, in order, are the shovel, Pulaski, McLeod, and the combi-tool.

Table 1.—*Volume of fire tools procured*

Tool	1989	1990	1991	1992	1993	1994	1995	Average
Shovel	11,686	10,796	8666	13,324	6076	25,590	5685	11,689
Pulaski	27,078	32,096	8331	13,051	10,815	30,283	9663	18,760
McLeod	5937	7169	2863	5408	3288	8612	3606	5269
Combi-Tool	1857	6639	1539	2294	1483	6237	2930	3283
Axe, Single	2699	1416	1664	1179	1196	1561	1347	1580
Brush Hook	N/A	1262	1327	838	454	513	N/A	879
Axe, Western	773	710	360	245	246	179	105	374
Rake, Council	265	224	387	288	23	257	300	249
Axe, Cruiser	158	160	122	97	65	39	30	96

Previous Fire Tool Studies

Fire tool testing by the Missoula Technology and Development Center (MTDC), as described in *An Improved Wild Land Firefighting Hand Tool*, 8851 2802, of 1988, consisted of 3-minute trials with different tools. These initial tests were followed by a field evaluation. Efficiency was defined as the amount of fireline (feet) versus the amount of energy expended to produce the line. Energy expenditure was measured in liters of oxygen consumed to accomplish the work.

In that previous tool test, after two minutes of steady work, data were collected for one minute. In this test procedure the time was extended and data were collected at two different simulated grub rates, indirect attack and hotline (direct attack). Indirect is a grub rate when building a line a short distance away from the fire edge and hotline is close to the fire edge.

The old study found significant differences in production between fire tools with the greatest difference between the Pulaski and the Super Pulaski. The Pulaski was the lowest in productivity (ft/min) and the Super Pulaski the highest. It was noted that one reason the Pulaski performed so poorly may have been due to the smaller blade hanging up in moderate and difficult digging conditions. The blade often penetrated deeply into the soil and required considerable effort to remove it.

Testing was conducted in various fuel types and digging conditions. Moderate conditions included bear grass, pine grass, huckleberry, and nine bark. The site rated as difficult had a heavier bear grass cover and the soil contained more rock.

It was further noted that the Pulaski hoe blade had been sharpened for digging rather than scraping and that this may be the reason the hoe blade was hard to retrieve. The 1988 fire tool report noted that these aspects of tool design deserved more study.

A 1982 MTDC publication noted a high energy cost with the Super Pulaski, probably due to difficult digging conditions. There also was a safety concern. Persons with a poor grip and decreased physical strength in the forearms could be injured more frequently.

Survey results revealed that the Pulaski was the most common fire tool in use and previous testing indicated it was the least productive; therefore, it was determined that the tool should be tested with various sizes of hoe blades and handles.

Previous publications, *Fit to Work?* by the National Wildfire Coordinating Group (NWCG), NFES 1595, 1985; and *Fatigue and the Firefighter,* NFES 2072, linked upper body strength and physical fitness to work performance.

Another study compared fiberglass handle performance to wooden handles, in the publication *Evaluation of Fiberglass Handles,* SDTDC 1404.1, 1967. Handling and balance characteristics, user reaction, strength and physical properties were evaluated. In addition, static load and temperature tests were conducted. Conclusive results could not be drawn from these tests. It was noted that fiberglass handles showed a trend toward increased strength over wood based on the simple static tests that were conducted. Recommendations were made for future testing, including balancing, impact testing, and crew testing for extensive controlled use under field conditions.

Test Procedure

Testing consisted of grubbing a 4-foot-wide line for 92 feet, with different tools. The work output, defined as the weight of material moved per unit of time, was quantified by weighting the amount of ground cover and soil grubbed at a collection point and recording the time. Heart rates were used as physiological indicators of energy expenditure. The production rate (lbs/min) of grubbed material was compared to the heart rate, strength and fitness scores, and the perceived exertion rating.

The old test procedure was modified by SDTDC to incorporate a longer test period, wider fireline, heart rate rather than amount of oxygen consumed, three height/weight body classes rather than body weight, and weight of material grubbed rather than length of fireline. Data were collected as workers grubbed with a standard Pulaski and three modifications. Seventeen workers, varying in height and weight, were grouped into three height/weight ranges and instructed to dig with the three different digging heads and two different handles. See Figure 1.

An attempt was made to control heart rate at 140 to 150 beats/min during indirect line construction and at 170 to 180 beats/min for hotline (direct attack) by coaching the worker to speed up or slow down grubbing in relation to the desired heart rate. The heart rate was continuously monitored. Heart monitoring apparatus consisted of a transmitter positioned over the lower chest and a receiver taped to the hard hat. See Figure 2.

Figure 1.—*Fire tool testing with a worker grubbing at a collection point, a data collector, and test assistant.*

After completing the 92-foot line, workers were asked specific exertion questions (Borg Perceived Exertion Rating). These questions were designed by physiologists in order to predict heart rate without actually monitoring subjects, so that in future tests, subjects would not need to be instrumented. A minimum rest break of 20 minutes was required between tools.

The recovery heart rate was monitored until it was below 110 beats per minute to tell if the break was long enough. Returning to work with a heart rate above 110 hastens the onset of fatigue, as described in *Fatigue and the Firefighter.*

Some workers took only the minimum rest time and others took up to an hour. Workers were encouraged to drink water and an electrolyte replacement drink during rest breaks.

The tests were conducted over a 20-day period in September of 1995. The test site was a grassy, south facing, gentle slope off the Old Morgan truck trail on the San Dimas Experimental Forest. A test plan was approved prior to gathering data and can be found in Appendix B.

As testing progressed, data were collected and recorded. Parameters measured were ambient and body temperatures, weight of material grubbed, time increments, heart rate, an opinion ranking and Borg rating of perceived exertion. See data forms in Appendix C. Data can be found in Appendix D. Photos and video were taken for analysis and documentation.

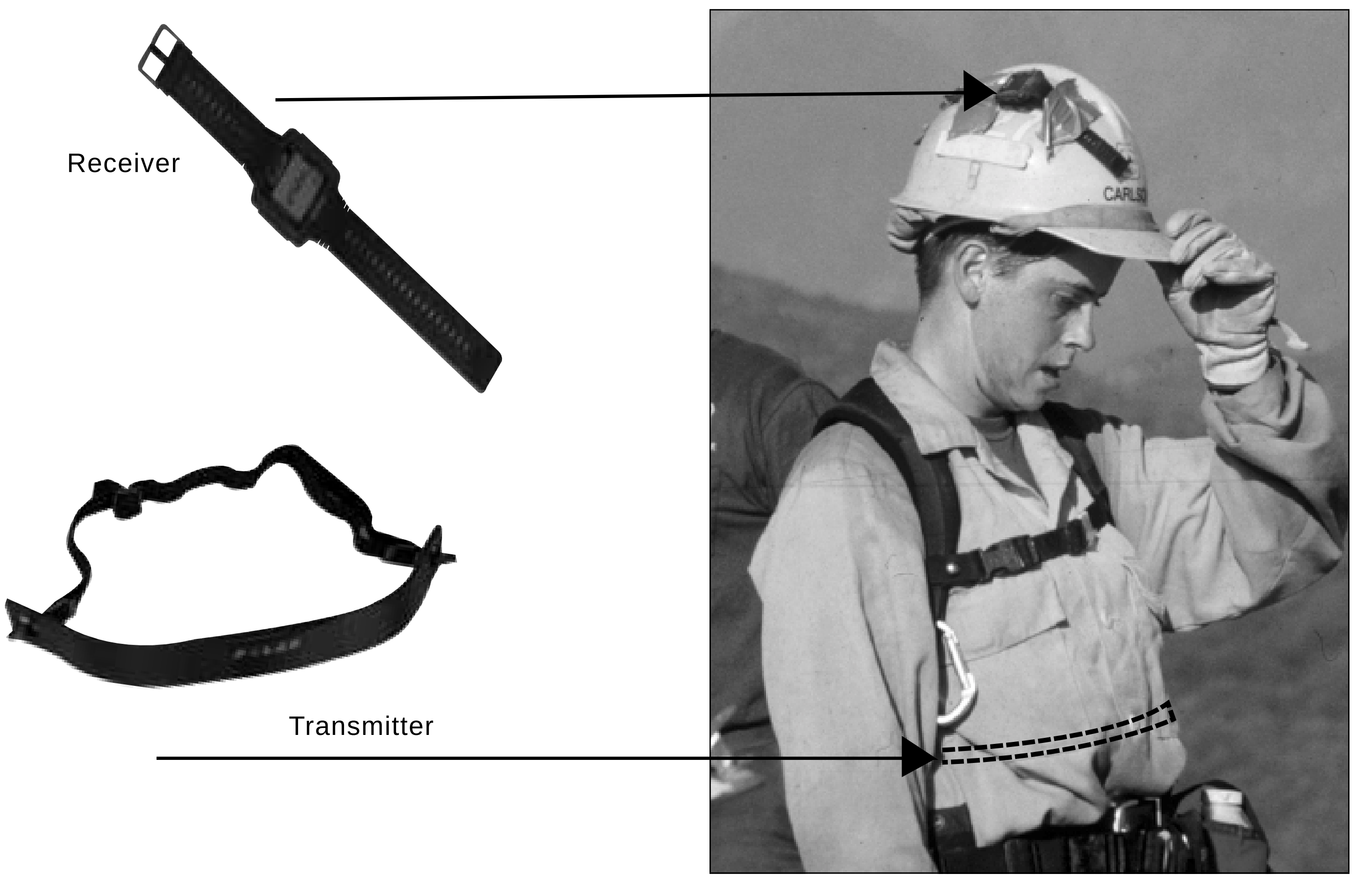

Figure 2.—*Heart rate monitor apparatus.*

The Tools

Variations in the Pulaski hoe blade and handle were field tested to evaluate weight of light fuel and dirt moved versus heart rate. The configurations tested were a standard Pulaski, Super Pulaski, Mini Pulaski, and the standard Pulaski with a fiberglass handle. See Figure 3 and Table 2.

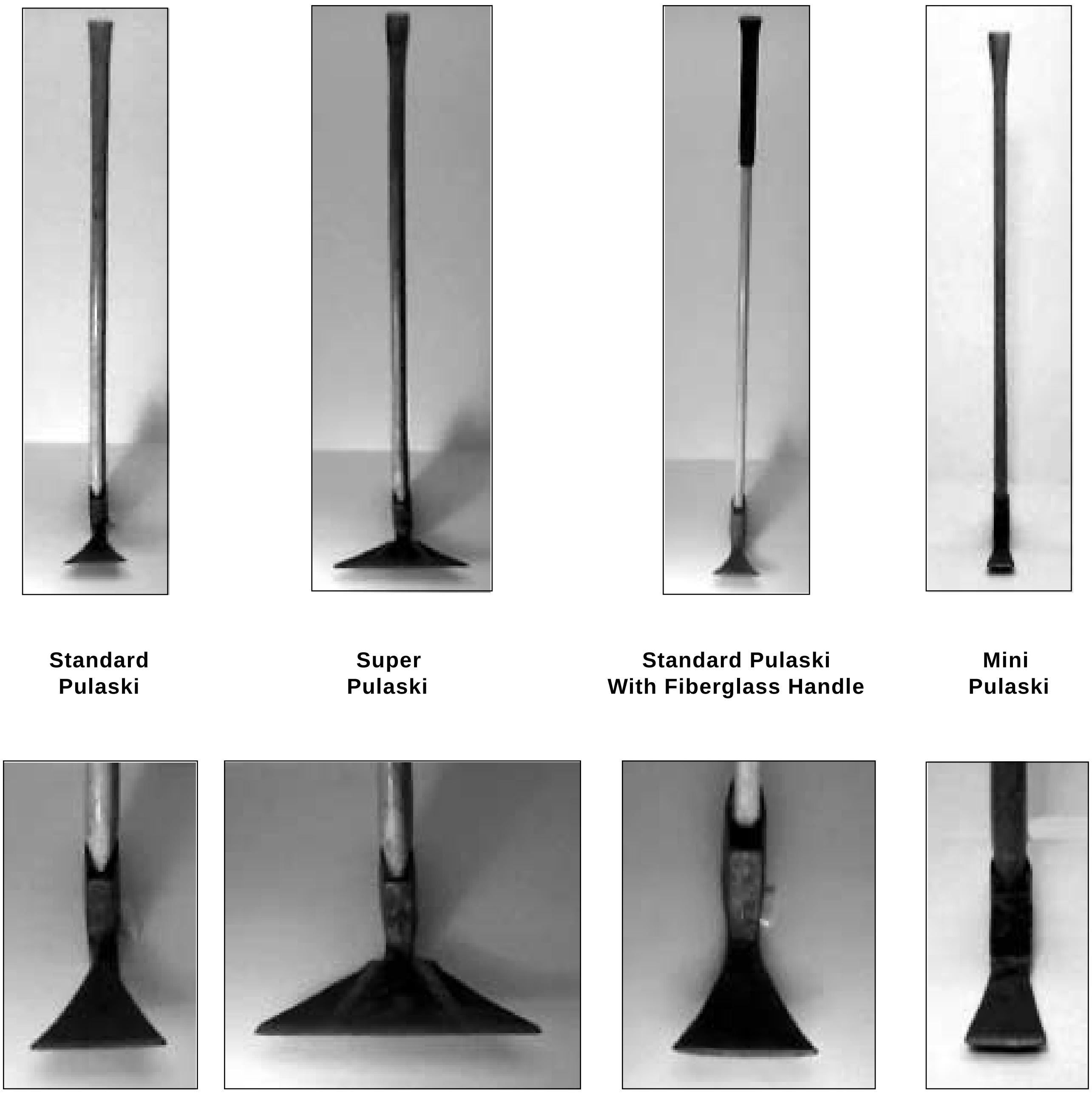

Figure 3.—*Test Tools.*

Table 2.—*Tool specifications*

Tool	Blade Width inches	Weight pounds	Weight/Width pounds/inches	Overall Length inches
Pulaski	3.3	5.4	1.6	34.5
Super Pulaski	6.8	6.9	1.0	34.5
Fiberglass Pulaski	3.3	6.4	1.9	36.1
Mini Pulaski	2.0	4.3	2.2	28.5

Results

Tool Test Results

Table 3.—*Production rate in pounds per minute averaged for indirect and hotline*

Category [1]	Production Rate (lbs/min) Average Line Rate			
	Pulaski	Super P	Fiberglass	Mini P
Class I Average	32	38	32	21
Class II Average	62	64	38	29
Class III Average	59	78	51	53
Female Average	41	42	32	22
Male Average	60	72	45	43

[1] Class I = less than 5 feet 5 inches or 135 lbs
Class II = between 5 feet 5 inches to 5 feet 9 inches and 135 to 160 lbs
Class III = greater than 5 feet 9 inches and 160 lbs
If the worker is between frame types, height will take precedent.

Table 3 summarizes production rates and is averaged for three body sizes and for gender. For example, the Class II production average using the Pulaski was obtained by averaging the weight of material grubbed by each of the six workers in that size range, divided by the average time it took for each of the workers to grub the material at four collection points.

Workers in the test were assigned a number to be used in the published report. Data gathered for Class II workers using a Pulaski included test workers identified with numbers 15a, 16a, 17a, 18a, 19a, and 20a. The production calculations were made for collection points 1 and 2 at the indirect line rate and collection points 3 and 4 at the hotline rate and then averaged.

For example, for test number 15a, the material weight for collection points 1 and 2, for the indirect line, were 125 and 150 pounds, for an average of 137.5 pounds. Subtracting 10 pounds for the weight of the bucket and cables (hardware used in weighing) the weight for collection points 1 and 2 equals 127.5 pounds. The time for collection points 1 and 2, for the indirect line, were 3.30 and 3.38 minutes, for an average of 3.34 minutes. The average production over collection points 1 and 2 equals 127.5/3.34, which equals 38 lbs/min.

The material weight for collection points 3 and 4, for hotline, were 185 and 165 pounds, for an average of 175 pounds—subtracting 10 pounds for hardware, equals 165 pounds.

Time for collection points 3 and 4, were 2.02 and 1.53 minutes, for an average of 1.76 minutes. The average production over collection points 3 and 4 equals 165/1.76, of 94 lbs/min.

Averaging the production for indirect and hotline for collection points 1, 2 and 3, 4 equals an average production rate of 66 lbs/min.

Using the same method, the average production for test workers 16a, 17a, 18a, 19a, and 20a were 81, 62, 85, 45, and 33 lbs/min. Including 15a with 66 lbs/min, the Class II average for the Pulaski is 62 lbs/min.

Table 4.—Production rate in feet per minute

	Rate of Construction (ft/min)			
	Pulaski	**Super P**	**Fiberglass**	**Mini P**
Class I Average	1.48	1.51	1.44	1.37
Class II Average	2.00	2.36	1.46	1.80
Class III Average	2.24	2.71	1.84	2.00
Female Average	1.44	1.59	1.30	1.33
Male Average	2.30	2.56	1.74	2.04

Table 4 summarizes the rate at which the 4-foot-wide line was constructed in the tool test and is averaged similar to the previous example for each body size class and gender.

Table 5.—Borg Exertion Rating and heart rate data for hotline rate

	Borg Exertion Rating				Heart Rate (beats/min)			
	Pulaski	Super P	Fiberglass	Mini P	Pulaski	Super P	Fiberglass	Mini P
Class I Average	17	14	15	18	178	159	172	171
Class II Average	14	13	17	15	179	173	170	164
Class III Average	14	13	15	16	166	160	159	153
Female Average	15	14	15	16	174	163	166	166
Male Average	14	13	16	16	174	165	164	160

Table 5 summarizes the workers' response to exertion questions posed after the use of all tools. The numbers shown in the Borg Exertion column is an indication of the workers' perceived effort to operate each tool. Workers were asked to consider their responses for the more difficult portion of work, where their heart rate was around 170 to 180 beats per minute. If this process were to be used, the number in the Borg Exertion rating could be multiplied by 10 to obtain the heart rate.

Table 6.—Participant ranking of three modifications to a standard Pulaski

Participant Ranking of Three Modifications to a Standard Pulaski

	Super P	Fiberglass	Mini P
Quantity of Line	3.1	-0.8	-3.9
Effectiveness	2.1	-0.6	-4.4
Versatility	-0.5	-0.7	-3.7
Fatigue - Hand and Arm	-0.6	-1.3	-1.7
Fatigue - Lower Back	0.3	-0.3	-2.9
Safety - Control	-0.4	-0.5	-1.8
Shock - Handle	-0.8	-1.9	-0.1
Grip	0.0	-0.8	-2.2

Key for Ranking
Most Negative = -5
No Difference = 0
Most Positive = +5

Note: The baseline is the standard Pulaski

After using all four tools, the workers were asked to rank them for eight different features. Table 6 averages everyone's comparison of the tool with a standard Pulaski, on a scale from a negative to positive 5.

Table 7.—*Strength and fitness scores*

	Arm (pounds) Push	Pull	Lift	Pack Test (min)	1.5 Mile (min)	Push Ups	Sit Ups	Chin Ups	Step Score Before
Class I Average	60	74	69	37.67	10.6	56	85	4	52
Class II Average	N/A	N/A	N/A	38.7	9.78	82	84	8	50
Class III Average	51	103	144	33.42	9.67	78	108	15	53
Female Average	64	66	69	41.25	11.28	37	77	2	50
Male Average	53	98	119	37.71	9.60	83	102	13	53

Table 7 summarizes strength and fitness scores for all classes. N/A = Not Available

Survey Results

Table 8.—*Super Pulaski improvements and features extracted from respondents*

Super Pulaski Improvements and Features Extracted From Over 600 Test and Survey Respondents
* Desire longer handle
* Desire stronger handle
* Like wider grub hoe
* Needs steeper angle for dragging
* Can move more dirt
* Scrapes, stirs, and drags better
* Smokejumpers cannot tolerate weight increase
* Preferred tool
* Might be more effective if lighter
* Needs to be balanced

In the survey, respondents were asked to comment on modifications to the standard Pulaski. Their comments for the Super Pulaski are summarized in Table 8.

Table 9.—*Scraping and digging/throwing dirt tools in use*

Scraping and Digging Tools In Use Today	
Scraping	Digging/Throwing Dirt
* Shovel	* Shovel
* Combi-Tool	* Combi-Tool
* Bosley	* Bosley
* Reinhart	* Reinhart
* McLeod	

In the survey, respondents were asked to list their preferred tool. Their responses for scraping and digging tools are summarized in Table 9.

Table 10.—*Summary of comments about fiberglass handles for fire tools.*

Summary of Comments About Fiberglass Handles for Fire Tools From Over 600 Test and Survey Respondents
* **Stronger than wood**
* **More reliable than wood**
* **Greater crew productivity, especially in project work**
* **Does not absorb enough shock**
* **Good for tools requiring long handles**
* **Can't let it sit in the heat**
* **Need smaller diameter fiberglass handles**
* **Need handle with vibram grip**
* **Need less expensive fiberglass handles under contract**
* **Needs to be balanced**

In the survey, respondents were asked to comment on fiberglass handles. Their comments are summarized in Table 10.

Discussion

A. Attitude affects test values. Several workers were highly motivated and appeared to perform at levels significantly above the average for their fitness level and height/weight class. Some of the workers had used some of the modified tools extensively before testing and had high expectations. Others had minimal experience, and, after testing, indicated that tool performance differed from their expectations.

B. The worker heart rate was held constant and production was expected to vary. In addition, it was anticipated that the Borg rating would relate to the heart rate by a factor of 10. For example, workers were coached to work at an indirect rate with a heart rate in the 140's for half the test and a hotline rate with a heart rate in the 170's for the other half of the test, for all the tools. So when a worker was coached to work to a heart rate in the 170's during the hotline portion, the worker should have rated the exertion at 17, for all the tools. The production rates did vary, but the Borg rating also varied, from 13 to 18, rather than remain constant at 17. This reflects human behavioral factors such as attitude, field acceptance, and expectations.

For example, if the worker assumes that a tool was designed to "fit" their physical characteristics or if the worker perceives that it's "macho" to use this tool well, they will try to adapt to it, whether or not they are work effective.

Therefore, due to the influence of behavioral factors, it may be more appropriate to measure worker efficiency using work in[2] and work out[3], rather than measure production versus heart rate. In his review, Art Jukkala noted that, *"The dependence on heart rate as a measure of work, physical fitness, environmental conditions, and many other factors can confound this data. This is why oxygen consumption measurements provide the most reliable and accurate measure of energy cost."*

Fire tool use can be approached as a mechanical system in terms of a human/tool system. This system is made of many different components. Components such as swing rate, work position, tool balance, weight, grasp, handle length, pack weight distribution, and swing mechanics can be identified, studied, and optimized.

C. All height/weight classes liked the Super Pulaski better than the other tool heads. The Super Pulaski performed best in the light fuel and soft soil conditions encountered in this test, but this may change with more severe conditions.

D. Differences in grubbing technique were noted. One type grubbing technique, methodical, appeared to be more productive than others.

E. There was a trend noted that the more experienced workers had a higher production rate than workers with less than one season.

F. The project goal, as taken from the project proposal, is to develop optimal fire tool configurations. There are some who believe that greater good can come from work with a biomechanics "expert" on how best to use the existing tools to reduce fatigue, soreness, and overuse injuries.

G. All the physical measurements taken to create Table 7 illustrate how upper body strength has an effect on productivity. Previous publications, *Fit to Work?,* by the National Wildfire Coordinating Group (NWCG), NFES 1595, 1985; and *Fatigue and the Firefighter,* NFES 2072, also linked upper body strength and physical fitness to work performance.

H. The majority of workers completed testing in one day. Some workers required a second day to complete all four tools. There was no trend noted that the production rates varied between these workers. However, this is not a good practice to follow. There was not enough data collected to draw a conclusion.

In his review, Art Jukkala noted that:

"Strength decrement studies conducted by the University of Montana exercise physiologists for MTDC in the early 1960's, showed that the best performances by people came after a warm-up of about 15-30 minutes of work/exercise. Performance then declined with fatigue after several hours of work. Thus in this study, the second tool tested could be expected to perform well and the last tool to perform poorly. That's what happened.

Unfortunately, the tool most likely to perform the best of the four configurations tested, based upon MTDC's findings, was tested second by everyone. Furthermore, the tool, due to its size, that was most likely to perform the poorest, was tested last. Thus, an order effect that may be showing up in the results, is harder to see. It's unfortunate, because if you had randomized the order of tool testing, I believe the Super Pulaski would still have come out the best and the Mini Pulaski last.

I find it very hard to believe that the production rate of a standard Pulaski with a fiberglass handle could be 37 percent less than that for a standard Pulaski. It seems that order effect or other experimental error occurred."

I. Workers sharpened the test tools to their preference for tool sharpness and angle for digging. There was no set test standard for sharpness and angle. The welds on the Super Pulaski hoe blade made the tool harder to sharpen and get a good straight edge for maximum contact with the ground.

[2] Calories burned per minute

[3] Weight of the material moved per minute times the mean distance moved

J. The workers grubbed without being constrained by data collection. The heart rate transmitter was strapped around the chest, snugly without affecting normal upper body movement. The heart rate receiver was taped to the top of the hard hat in a position readily visible to the test engineer, when the worker was in a grubbing position. Workers were encouraged to drink water and stretch, etc., as they would normally on the fireline.

K. Test conditions varied as follows:

1. Relative humidity varied during testing which varied grass and soil moisture. This should be insignificant. Grass or the soil moisture were not measured. The relative humidity was noticeably increased on only 2 out of 15 test days. Site consisted of decomposed granite, which would vary little in resistance with minor changes in moisture content.

2. The fireline quality of grubbing to bare mineral soil was monitored and enforced.

3. The temperature usually varied from 82 °F to 95 °F. There was a day of testing at 78 °F and another at 54 °F. Production tended to increase on these days, but there was not enough data collected to draw a conclusion.

4. Roots, such as rye grass and thistle, were removed from the test course, prior to testing, in order to maintain a uniform light fuel. Removal was minimal.

5. Performance or production data were not shared with the test subjects, in order to prevent competition between test subjects and between tools for each test subject.

6. All test subjects were in full gear with backpack and full water canteens. The weight of the backpacks varied between crew members. Some of the test subjects were from engine crews and had a lighter backpack than the hotshots. The crew members were instructed to carry the weight normally carried during fireline construction. There was not enough data collected to detect the effects of these differences.

L. The survey may not have been sufficiently national and interagency in scope, therefore, the findings may be biased. Hotshot crews and smokejumpers are interagency and national resources, but they are unique. They usually carry their own tools to a fire, so they can customize them to their likes or needs. They are classified as Type I crews, higher in training and experience and above average in fitness. Type II crews were not surveyed outside of Region 5 and their unique fuel/soil types, especially in southern California, are very different from the Pacific Northwest, Rocky Mountain, and eastern hardwood areas.

M. This test measured production for various modifications to the grubbing end of a Pulaski. One must remember that the Pulaski is also used extensively for chopping with the other blade. Changing the mass of the tool head may create chopping limitations and a compromise in safety.

If the center of gravity and center of percussion are moved, the angular acceleration also changes to the detriment of the user, i.e., stinging hands, fatigue, impact rotation. See Figure 4.

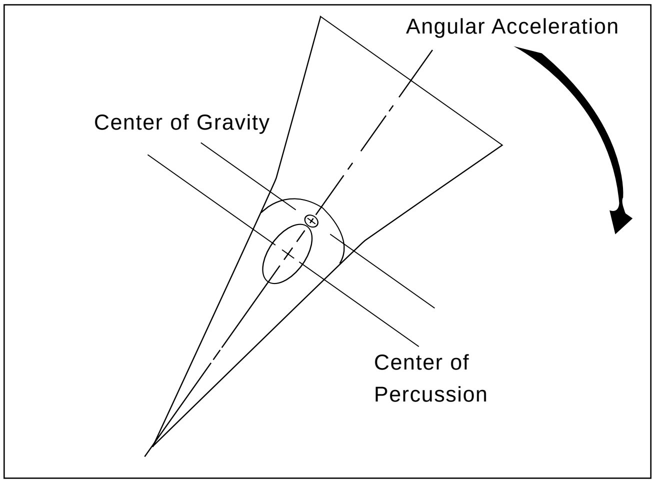

Figure 4.—*The center of percussion will move with a change in the mass of the tool head.*

N. Publication of this report is planned for January 1996. Due to this requirement, analysis has been limited and further work in that area is merited. For example, Dr. Brian Sharkey saw a possible correlation of tool performance to aerobic fitness (step test or 1.5 mile run), or muscular fitness data. He noted that the results might be interesting, especially if performance time is used as the independent variable. In his review, Dr. Sharkey recommended that:

> *"Time may be a better measure of performance. It could provide more insight, especially if fitness scores are correlated to performance. Obtain the production rate in lbs/min and time, and the results may be the same or different."*

Dr. Sharkey further recommended that *"Statistical analysis should include:*

1. *Descriptive data for subjects*
2. *Treatment (tool) effects for pounds and time*
3. *Group and gender comparisons*
4. *Correlations between BMI[4] or LBW[5] and performance; aerobic fitness and performance; muscular fitness and performance; and working heart rate and aerobic fitness*
5. *Multiple regression analysis using several variables to predict performance on each tool, always measured with lbs/min, as well as time*

    If criteria for fireline quality are set and monitored, the time to complete the task becomes a relevant measure of performance

    Time is a less complicated measure than volume of material for field personnel to use in tool evaluations."

[4] Body Mass Index

[5] Lean Body Weight

Tool Test Conclusions

A. From this test, one can conclude that the weight, size, and shape of the tool head influences the quantity of light fuel and dirt that can be moved per unit time.

One can further conclude that workers, no matter their size, sex, upper body strength, level of experience, or response to Borg inquiries will consistently move more light fuel and dirt, (construct more fireline), when using a Super Pulaski hoe blade, than would be possible with other configurations in common use. See Tables 3 and 4. In addition, the perception is that less energy is required. See Table 5 for various averages.

Responses from interviews at the end of each test cycle ranked the Super Pulaski high. See Table 6. There are a wide array of Super Pulaski configurations in use, as noted in the survey, which indicates that although the tool is well received, it merits refinement. See Table 8.

B. From the results in Table 5, one can conclude that workers response to the Borg exertion questions are a better indicator of human factors/opinions about the tool, than it is a predictor of heart rate or energy required, or any parameter that may be used to quantify tool efficiency.

C. The tables of results are shown for three body sizes and both genders. The sample size is inadequate to perform statistical analysis in many categories. The results reflect only production rates that are in light fuels and soft soils.

D. Production rates in Table 3 show that larger workers using a fiberglass handle move less light fuel and dirt than with tools equipped with a wooden handle. Survey comments, see Table 8, indicate that many users prefer a fiberglass handle for strength and reliability. Therefore, it can be concluded that further study to more clearly delineate the reasons for these discrepancies is warranted.

E. The test procedure needs to be modified to include a randomized tool order, standard tool edge and angle, statistical analysis, measurement of oxygen consumed, and narrower line width.

Survey Conclusions

A. The survey revealed that there are a wide range of digging and scraping tools preferred today. See Table 9.

B. Over 75 percent of the Interagency Hotshot Crews responded to the survey. In addition numerous responses were received from other field personnel. From this positive response, one can conclude that there is considerable interest in hand tools, their design and use.

Recommendations

Based on the findings of this test it is recommended:

A. That work on new designs, based on firefighter input and impact to cutting ability and safety, be continued. A hypothesis needs to be clearly identified. Development should include further testing in heavier fuels and a technical investigation, in the laboratory, for static and dynamic balance (including shock, bending, center of gravity, grasp, contour, and the establishment of the optimum blade dimensions and weight) based on production as measured in this test. Design goals should closely conform with the user comments in Table 8. See Figure 5 for proposed experimental design matrix.

Project work could include working with biomechanics experts from Lawrence Laboratory of the University of California at Berkeley or the National Institute of Standards and Technology (or organizations with similar capabilities) and field personnel to conduct studies of optimal designs, tool mixes, posture, and use techniques.

B. That the existing procedure be modified to include methods for measuring digging and scraping tool production rates; to include changes mentioned in the conclusions; and, subsequently test the tools listed in Table 9. Top priority should be given to implementing the use of the combi-tool based on Jukkala's studies which have found that a 20-person crew can benefit greatly by including this tool in their lineup.

C. That testing be expanded to strengthen the results by varying the fuel type and soil hardness.

D. That the past development work of Sirois, et al., be continued to make available a "state of the art" composite that closely resembles the feel of wood and the durability of modern materials, since plastic reinforced handles exhibit superior strength.[6]

E. The survey be further analyzed and published in a report for field distribution.

[6] Jukkala recommends that "first conduct a life-cycle cost analysis between wood and fiberglass handles for both fire caches and ranger districts. My instincts tell me that while fiberglass handles might be cost effective for district fire and work crews, they are unlikely to be for fire caches."

Pulaski Design Variables, Independent versus Dependent:

	Dependent Variable(s)				
	Performance			Muscular Fatigue	Ergonomics
	Production Of Line	Heart Rate	O_2 Debt	Posture - Back/Arm/Shoulder EMG - Fatigue	Pain/Discomfort/Strain
Independent Variable(s)					
Accident Rates					
Age					
Sex/Gender					
Ethnicity					
Anthropometric Data					
Height					
Weight					
Arm Length/Reach					
Arm Circumference					
Physiological Data					
Body Mass Index/Body Fat					
Hand/Grip Strength					
Arm Strength					
Lung Capacity/Tidal Volume					
Heart Rate					
Endurance					
Smoking					
Health					
Accident History/Disability					
Field Experience					
Tool Training					
Rest Period Intervals/Durations					
Environmental Factors					
Temperature					
Humidity					
Wind Velocity/Chill					
Terrain					
Vegetation					
Soil Type					
Soil Compaction					
Clothing					
Gloves					
Personal Protection Equipment					
Attire					
Footwear					
Gear/Pack Weight					
Psychological Factors					
Motivation					
Fear					
Competitiveness					
Attitude					
Team Effort					
Individual Effort					
Tool Design					
Tool Weight					
Tool Handle Length					
Hoe/Blade Width					
Hoe/Blade Sharpness					
Hoe/Blade Angle					
Tool Aesthetics/Appearance					
Test Duration (Time)					
Other(s) ____________________					

Select and run correlation, inferential statistical analysis such asT-test, Chi-square, or Nonparametric tests, etc.

Figure 5.—Proposed Experimental Design Matrix

Appendix A

Survey for Superintendent, Captain or Crew Boss,
and the Individual Crew Member Survey

United States Department of Agriculture | **Forest Service** | **SDTDC**

File Code: 4E41P15 Date: July 11, 1995

Route To: Type I and Type II crews, and Regional Equipment Committee Chairs

Subject: Fire Tool Ergonomics Questionnaire

To: Hot Shot Superintendents, Engine Captains, Helitack/Helishot/Rappel, and Hand Crew Captain and FPT's.

The San Dimas Technology and Development Center has been assigned a project to take a closer look at the fire tools we use in all phases of firefighting. The field has modified fire tools in order to become more effective and efficient to meet the needs of an ever changing work force.

This mailing includes two surveys, one for the crew boss, superintendent or captain, and another to be completed by each crew member. The purpose of these surveys is to collect information on standard, modified, and specialty fire tools in service. This information will be used to determine the most commonly used fire tools and to assist in determining which tools will be studied further to determine if their design is satisfactory to maximize worker efficiency while minimizing the risks of ergonomically induced injuries.

Mail the survey back by August 3, if possible. If August 3rd isn't possible, then when you're able to. Your input is valuable.

Please mail the completed survey to:

San Dimas Technology and Development Center
Attn: Lois Sicking, Mechanical Engineer
444 East Bonita, San Dimas, CA 91773-3198.
Telephone: 909/599/1267, extension 294

Fire Tool Superintendent, Captain or Crew Boss Field Survey

The changing work force has necessitated taking a closer look at the fire tools we use. The field has modified fire tools in order to become more effective and efficient in meeting the needs of an ever changing work force. The purpose of this survey is to collect information on standard, modified, and specialty fire tools in service.

If you are the Superintendent, Captain or Crew Boss, please print this survey and complete by writing in your comments. Mail the completed survey to the San Dimas Technology and Development Center, Attn: Lois Sicking, 444 East Bonita, San Dimas, CA 91773-3198. Please mail the survey back by August 3, if possible. If August 3rd isn't possible, then when you're able to. Your input is valuable.

Crew Name: Your Name: (Optional)

Number of Crew by Months Experience: ____1-3 months, ____4-6 months, ____7-9 months, ____more

Number of Crew: (Optional) ______Male, ______Female

What is your standard tool order for line construction?

What is your standard tool order for mop-up?

What is your standard tool complement, if you fly?

What percentage of your tool complement is specialty tools?

Describe your complement of specialty tools.

When the crew changes fuel types, how do you typically change the tool complement? i.e., timber vs brush vs grass?

What is the typical fuel type that represents most of the fires the crew works in?

In making a tool assignment, do you consider body frame? i.e., McLeod for a large frame or a Pulaski for a smaller frame? Explain.

Does the crew use any tools with fiberglass handles? If yes, on which tools?

If yes, why do you use fiberglass handles on these tools?

Does the crew use any other standard hand tool(s) not mentioned already in this survey? ____yes, ____ no; If yes, please name these hand tool(s):

If yes, what does the crew like about these hand tools?

Does the crew use any other modified hand tool(s) not mentioned already in this survey? ___ yes, ___ no; If yes, please name these hand tool(s):

If yes, what does the crew like about these modified hand tools?

Does the crew use any other specialty hand tool(s) not mentioned already in this survey? ___ yes, ___ no; If yes, please name these hand tool(s):

If yes, what does the crew like about these specialty hand tools?

What percentage of your crew uses the following tools:

___% Pulaski, ___% Shovel, ___% Combi-Tool, ___% McLeod, ___% Modified Pulaski, ___% Modified Shovel,
___% Modified Combi-Tool, ___% Modified McLeod,
___% Brush Hook, ___% Double Bit Axe, ___% Falling Axe, ___% Council,
___% Fire Leaf Rake, ___% Other (Name:______), ___% Other (Name:______)

General Comments: (Use the back of this page if you need more space.)

Your input is valuable. Thank you for your assistance and time. If you have any additional input or questions, please contact Lois Sicking, Mechanical Engineer at the San Dimas Technology and Development Center, 444 East Bonita, San Dimas, CA 91773-3198; Telephone: 909-599-1267, X294; Fax: 909-592-2309; or L.Sicking:W07A.

Fire Tool Crew Individual Field Survey

The changing work force has necessitated taking a closer look at the fire tools we use. The field has modified fire tools in order to become more effective and efficient in meeting the needs of an ever changing work force. The purpose of this survey is to collect information on standard, modified, and specialty fire tools in service.

Please mail the completed survey to the San Dimas Technology and Development Center, Attn: Lois Sicking, 444 East Bonita, San Dimas, CA 91773-3198. Mail the survey back by August 3, if possible. If August 3rd isn't possible, then when you're able to. Your input is valuable.

Crew Name: Your Name: (Optional)

Total Months Experience: ____ 1-3 months ____ 4-6 months ____7-9 months ______ more

Total Months Experience in Each Area: ______ Engine ______ Hand Crew _______ Trail

_________Height ________Weight ________ Age_______,Gender: ________Male ________ Female

---

Pulaski - Do you use a modified Pulaski? ______ yes, _______no; If yes, please describe the modification(s) in detail. In addition, please send sketches, drawings, photos, or hardware:

What do you like about the modified Pulaski?

Is the modified Pulaski:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the modified Pulaski: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

What do you like about the standard Pulaski?:

Is the standard Pulaski:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the standard Pulaski: { } Foot, { } Ankle,{ } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

Shovel - Have you used a modified shovel? _____yes, _____no; If yes, please describe the modification. In addition, please send sketches, drawings, photos or hardware:

If yes, What do you like about the modified Shovel?

Is the Modified Shovel:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the Modified Shovel: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

What do you like about the standard Shovel?:

Is the standard Shovel:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the standard Shovel: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

Combi-Tool - Do you use a modified Combi? ____ yes, ____ no; If yes, please describe the modification(s) in detail. In addition, please send sketches, drawings, photos or hardware:

What do you like about the modified Combi?

Is the modified Combi:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the modified Combi: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

What do you like about the standard Combi?:

Is the standard Combi:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the standard Combi: { } Foot, { } Ankle, { } Knee, {} Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

McLeod - Do you use a modified McLeod? ____yes,_____no; If yes, please describe the modification(s) in detail. In addition, please send sketches, drawings, photos or hardware:

What do you like about the modified McLeod?

Is the modified McLeod:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the modified McLeod: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

What do you like about the standard McLeod?:

Is the standard McLeod:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of the standard McLeod: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

General:

What is your preferred tool for line construction? __________________, Why?

What is your preferred tool for mop-up? ______________________, Why?

What percentage of work do you do with the following tools:

_____% Pulaski, _____% Shovel, _____% Combi-Tool, _____% McLeod, _____% Modified Pulaski, _____% Modified Shovel, _____% Modified Combi-Tool, _____% Modified McLeod, _____% Brush Hook, _____% Double Bit Axe, _____% Falling Axe, _____% Council, _____% Fire Leaf Rake, _____% Other (Name:___________________________), ______% Other (Name:____________________________)

What is the typical fuel type that represents most of the fires you work in?

Do you use any other standard hand tool(s) not mentioned here? _______ yes, _______ no
If yes, please name these hand tool(s):

If yes, what do you like about these hand tools?

Do you use any other modified hand tool(s) not mentioned here? _______ yes, _______ no
If yes, please name these hand tool(s):

If yes, what do you like about these modified hand tools?

Do you use any other specialty hand tool(s) not mentioned here? _______ yes, _______ no
If yes, please name these hand tool(s):

If yes, what do you like about these specialty hand tools?

General Comments: (Use the back of this page if you need more space.)

Your input is valuable. Thank you for your assistance and time. If you have any additional input or questions, please contact Lois Sicking, Mechanical Engineer at the San Dimas Technology and Development Center, 444 East Bonita, San Dimas, CA 91773-3198; Telephone: 909-599-1267, X294; Fax: 909-592-2309; or L.Sicking:W07A.

Appendix B

Test Procedure

This test procedure is not reproduced here, but is available from the author upon request.

Appendix C

Data Forms

General Data Sheet

General Data Sheet   Name:

Tool: ___________________________   Fuel Model Type: _____________________________________

Total Months Experience: _____ 1-3 months, _____ 4-6 months, _____7-9 months, _____ more

Total Months Experience in Each Area: _____ Engine _____ Hand Crew _____ Trail

_______Height ________ Weight _______ Age______Gender ______ Male ______ Female

Step Test Score:_______ Time for 1 1/2-mile run:__________No. pushups:___________

Time to perform pack test:________________ No. chin-ups:____________ No. sit-ups:____________

Heart rate before tool use: _________   Temperature - Oral: ______ Temperature Ambient: ________

Testing:

Heart rate at Tarp & every 30 secs

Indirect Rate		Direct Rate	
Tarp #1	Tarp #2	Tarp #3	Tarp #4
Weight: (Tarp #1, #1a, or #1b?)	Weight:	Weight:	Weight:
Indirect Line Rate		Direct Line Rate	
time begin:	time begin:	time begin:	time begin:
HR _______ _______	HR _______ _______	HR _______ _______	HR _______ _______
_______ _______	_______ _______	_______ _______	_______ _______
_______ _______	_______ _______	_______ _______	_______ _______
_______ _______	_______ _______	_______ _______	_______ _______
_______ _______	_______ _______	_______ _______	_______ _______
_______ _______	_______ _______	_______ _______	_______ _______
_______ _______	_______ _______	_______ _______	_______ _______
time end:	time end:	time end:	time end:

Total test time:

Recovery Heart rate

HR at 0 secs:	at 60 secs:	at 120 secs:	at 180 secs:
at 10 secs:	at 70 secs:	at 130 secs:	at 190 secs:
at 20 secs:	at 80 secs:	at 140 secs:	at 200 secs:
at 30 secs:	at 90 secs:	at 150 secs:	at 210 secs:
at 40 secs:	at 100 secs:	at 160 secs:	at 220 secs:
at 50 secs:	at 110 secs:	at 170 secs:	at 230 secs:
			at 240 secs:

Borg RPE Rating: Temperature oral:

Comments:

Borg Rating of Perceived Exertion

The 1960 Borg RPE Scale[1]
-Modified 1985-

Instructions to the scale administrator:

While the respondent looks at the rating scale you say:

"I will not ask you to specify the feeling, but do select the number which most accurately corresponds to your perception of the physical demand of the task from a fatigue perspective.

If you don't feel anything, for example, you answer 6 - no exertion at all.

If you start to feel something, just noticeable, you answer 7 - extremely light.

If you feel the task is very physically demanding in terms of fatigue, you would answer 19 - extremely hard.

The more you feel, the stronger the feeling, the higher the number you choose."

6 - no exertion at all
7 - extremely light
8
9 - very light
10
11 - light
12
13- somewhat hard
14
15 - hard (heavy)
16
17 - very hard
18
19 - extremely hard
20 - maximal exertion

[1]Selan, Joesph L., *The Advanced Ergonomics Manual,* Advanced Ergonomics, Inc., 1994.

For each category, compare the standard Pulaski to the other tools you have used today.

Rate on a scale of -5 to 5
-5 is the least, 0 is the same as, and 5 is the most
Mark only one number per box

	Super Pulaski	Fiberglass	Mini Pulaski
For an equal period of use the standard Pulaski produces: More line than: Same amount of line as: Less line than:			
The standard Pulaski is: A more effective tool: Equally effective as: Less effective as:			
The standard Pulaski is: More versatile than: Equally versatile as: Less versatile as:			
The standard Pulaski produces: Less hand and arm fatigue: Same amount of hand and arm fatigue: More hand and arm fatigue:			
Less lower back fatigue: Same amount of lower back fatigue: More lower back fatigue:			
From an overall safety standpoint, the standard Pulaski is: Easier to control and safer to use than: Comparable to control and equally safe to use than: Harder to control and less safe to use:			
The standard Pulaski produces: Less vibration absorption: Same amount of vibration absorption: More vibration absorption:			
Less handle grip: Same amount of handle grip: More handle grip:			

Tool Performance Evaluation

Standard Pulaski - What do you like and dislike about this standard Pulaski?

Is this standard Pulaski:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of this standard Pulaski: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

Super Pulaski - What do you like and dislike about this super Pulaski?

Is this Super Pulaski:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of this super Pulaski: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

Pulaski with Fiberglass Handle - What do you like and dislike about this Pulaski with a fiberglass handle?

Is this Pulaski with a fiberglass handle:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of this Pulaski with a fiberglass handle: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

Mini Pulaski - What do you like and dislike about this mini Pulaski?

Is this mini Pulaski:

Tool Weight	{ } Too Light	{ } Comfortable	{ } Too Heavy
Handle Diameter	{ } Too Small	{ } Comfortable	{ } Too Large
Handle Length	{ } Too Short	{ } Comfortable	{ } Too Long
Handle Grip	{ } Poor	{ } Moderate	{ } Good
Vibration Absorption	{ } Poor	{ } Moderate	{ } Good

Area(s) fatigued with the use of this Mini Pulaski: { } Foot, { } Ankle, { } Knee, { } Thigh, { } Leg, { } Hip, { } Lower Back, { } Abdomen, { } Upper Back, { } Neck, { } Shoulders, { } Upper Arms, { } Elbow, { } Forearm, { } Wrist, { } Hand.

General Comments:

Appendix D

Test Data

The test data is not reproduced here, but are available from the author upon request.