FINAL REPORT

Effect Of Squeegee Design On Carpal Tunnel Pressure

Submitted by
William H. Musser, Principal Investigator
Squeegee Plus®! Co.
P.O. Box 5556, Eugene, OR 97405

Consultant: David Rempel, M.D.
University of California-San Francisco Ergonomics Laboratory
Richmond Field Station
1301 S 46th St., Building 112
Richmond, California 94804

Project Director: Cathy Coulson

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16. Abstract (Limit: 200 words)

A multitask study was conducted in an effort to examine the relationship between squeegee handle designs and their potential impact on carpal tunnel syndrome and other cumulative trauma disorders (CTDs). The study group was composed of screen print workers. Two important factors in determining perceived comfort and exertion during the hands on evaluation were handle shape and width. The best performing handle made full contact with the fingers and the palmar surface of the hand with the hand in a somewhat open and relaxed position. The grip was also wider than the industry standard handle. There were 42 participants who had used padded handles; 60% indicated a marked decrease in hand fatigue and 55% indicated a marked decrease in hand pain. A mean carpal tunnel pressure value was calculated for each subject using each squeegee handle. There was a trend for the ergonomic handle designs to reduce carpal tunnel pressure relative to the industry standard design. The authors conclude that an ergonomically shaped squeegee handle with a relatively wide grip may increase comfort and decrease CTDs.

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LIST OF ABBREVIATIONS

American National Standards Institute (ANSI)

Carpal Tunnel Pressure (CTP)

Cumulative Trauma Disorders (CTDs)

Carpal Tunnel Syndrome (CTS)

Occupational Safety and Health Administration (OSHA)

Repeated Measures Analysis of Variance (RANOVA)

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SIGNIFICANT FINDINGS

• Handle shape was found to be the most significant factor effecting comfort among the manual screen print workers that served as participants in the study. The shape that performed best made full contact with the fingers and the palmer surface of the hand when the hand was positioned in a somewhat relaxed and open position.

• Grip diameter was also a significant factor in determining comfort. A narrow grip which required a pinching action was perceived to be less comfortable than wider grips which better conformed to the hand in a relaxed, open position.

• Familiarity with the standard industry handle appeared to contribute to its relative success in terms of perceived comfort.

• Padding handles with a compressible surface did not seem to have a substantial effect of perceived comfort in the hands-on evaluation portion of the study. However, respondents to the informal survey who had used padded handles indicated significant reductions of hand pain and fatigue through their continued use.

• Ergonomic handle designs tended to produce lower carpal tunnel pressures in screen print workers in a laboratory setting relative to the standard industry handle, although these differences were not statistically significant.

• Screen print workers maintained static postures, relying primarily on the muscles of the upper extremities to perform the task of printing.

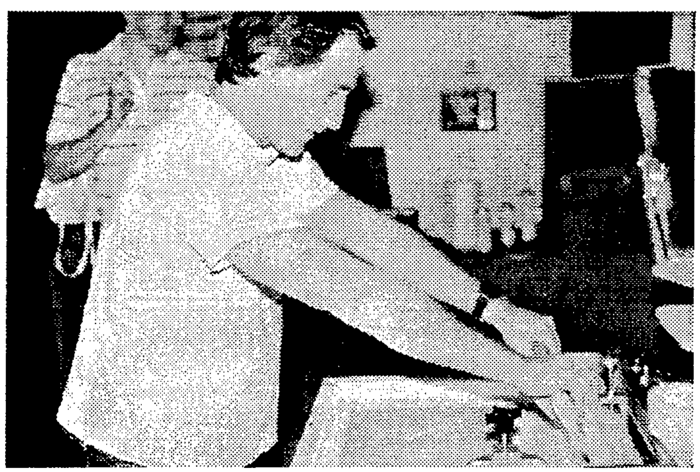

Figure 1.. Screen Printer at Work Using Standard Handle. Static posture with muscles of upper extremities performing task. Note hands in extension.

USEFULNESS OF FINDINGS

• Squeegee handles for manual screen print workers should be designed to conform to the shape of the hand when it is held in a somewhat relaxed, open position. The handle surface should make full contact with the fingers and the palmer surface of the hand. This shape will provide support for the phalanx of the fingers and prevent hyperextension of the fingers.

• The diameter of the squeegee handle grip should be at least 18% wider than the grip diameter of the industry standard handle. Less effort will be required to grip the handle when compared with the narrow pinch grip dictated by the industry standard handle.

• Padding squeegee handles with a compressible surface may be indicated in reducing the incidence of Carpal Tunnel Syndrome (CTS) and Cumulative Trauma Disorders (CTD). Screen print workers reported significant reductions in hand pain and fatigue after using padded handles over time. Padded, ergonomically shaped handles yielded slightly lower carpal tunnel pressures in the laboratory setting.

• Involving the whole body in the task of screen printing may reduce the incidence of upper extremity CTDs by relieving stress on the relatively smaller and weaker muscles in these regions.

ABSTRACT

A multi-task study was conducted to evaluate the relationships between various squeegee handle designs and their potential impact on CTS (CTS) and other cumulative trauma disorders (CTDs) among manual screen print workers at several sites in Eugene, OR and at the UCSF Ergonomics Laboratory in Richmond, CA. A hands-on evaluation of seven commercially-available and two experimental squeegee handle designs was conducted with ten professional screen print workers, an informal survey was mailed/faxed to selected screen print shops across the United States, and a laboratory study was conducted using four screen print workers as subjects to measure the effect of five handles designed (one standard, one over-sized, one padded standard, and two ergonomic designs). Handle shape and width emerged as two important factors in determining perceived comfort and exertion during the hands-on evaluation. The handle that performed best made full contact with the fingers and the palmar surface of the hand with the hand in a somewhat open and relaxed position. The grip of this handle was also wider than the industry standard handle (1.3 inches vs. 1.1 inches); other handles with increased grip diameters (but not necessarily ergonomic shapes) out-performed their narrower counterparts as well. The composition of the handles (compressible vs. non-compressible) did not appear to be an important factor during the hands-on evaluation. but the relationship between compressibility and the reduction of CTDs was indicated in the informal survey. Of the forty-two survey participants who had used padded handles, 60% indicated a marked decrease in hand fatigue and 55% indicated a marked decrease in hand pain. In the laboratory portion of the study, carpal tunnel pressure (CTP) was measured via a saline-filled catheter inserted into the carpal tunnel, and attached at its proximal end to an in-line pressure transducer. A mean CTP value was calculated for each subject using each squeegee handle. Although not statistically significant (due in large part to the small sample size), there was a trend for the ergonomic handle designs to reduce CTP relative to the industry standard design. The authors conclude that an ergonomically-shaped squeegee handle with a relatively wide grip (≥1.3 inches) may increase comfort and decrease CTDs. Recommendations include further study of the effect of the padding of handles with a compressible material on injuries among screen print workers when used on a long-term basis. Other future considerations include developing more effective biomechanical techniques for the performance of manual screen printing, experimenting with varying platen heights (the work surface), and educating subjects in the proper use of experimental handle designs prior to their testing.

INTRODUCTION

In a large number of industrial and agricultural occupations (Lewis and Taih, 1982), hand tools are the primary tools. A major concern of these industries is the high percentages of injuries that occur annually (Putz-Anderson, 1988). Mital (1986) has noted that between 9 percent and 10 percent of all compensatable injuries in the United States occur while using hand tools. "The fastest rising category of worker health problems in America are repetitive motion problems, and the expense imposed on the economy is enormous. About one out of every three worker's compensation dollars, or $20 billion, is attributable to injuries of repetitive motion," said Joe Dear, Assistant Secretary of Labor for OSHA.[1] He estimates that the severity and monetary cost of hand tool injuries in recent years is $10 billion annually. The Bureau of Labor calls cumulative trauma disorders (CTDs) the nation's fastest growing, most widespread occupational hazard. In 1990, more than 185,400 workers sustained such injuries—a 900 percent increase over 1982. CTDs accounted for more than half the nation's worker's compensation costs in 1991.

The screen printing industry is not exempt from this problem. According to a survey conducted by the Screenprinting & Graphic Imaging Association International, seventeen percent of the responding print shops claimed to have employees who had missed work due to CTS or some other CTD. Twenty one percent stated that they had employees with CTS or CTDs; the average number of days lost per year/per injury was 9.8.

The industry standard squeegee handle, which is used by over ninety percent of commercial manual screen printers, (estimated by three major distributors [2]) is made of wood, is one inch in width, and acts as a holder for a flexible blade that is used to force the ink through a screen and into a substrate. (See Figure 1.)

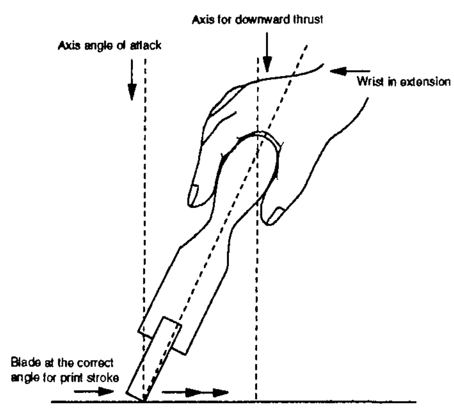

Figure 2 Industry Standard Handle

The grip of this handle is used repetitively by screen printers, and it's narrow grip dictates a high degree of contraction for the muscles involved. This results in greater stress on the tendons that pass through the carpal tunnel, with increased probability of compression on the median nerve. This problem is further complicated by upper body and arm fatigue associated with downward pressures exerted by the muscles of the upper arm in these regions. The work required by these motions detracts from the amount of energy available to perform the pinching action of the hand, and vice versa. The muscles used in contracting the hand include the forearm flexors. which act as wrist stabilizers when the hand is performing the "pinching" action..

[1]Interview on National Public Radio, Morning Edition, April 4, 1996.
[2]Full Line Distributors, Atlanta, GA.; Irish Graphics International, Grants Pass, Or; Midwest Sign & Screen Printing Supply Co., Kansas City, Mo.

It is our belief that handle shapes should make full contact with the fingers and the palmar surface of the hand, and the hand should be postured in a relaxed, somewhat open position, which will require less exertion of the flexor muscles of the forearms and hands. The most powerful wrist action, and least stressful, should occur only when the fingers are relaxed. (See Figures 2, 3, 4)

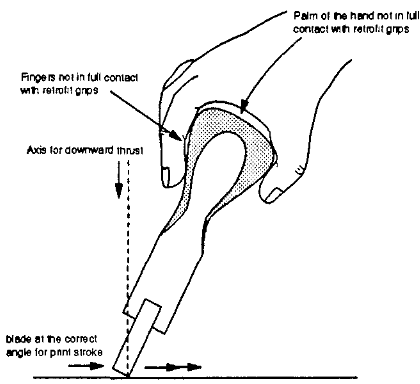

Figure 3.
Padded Retrofit of
a Standard Handle

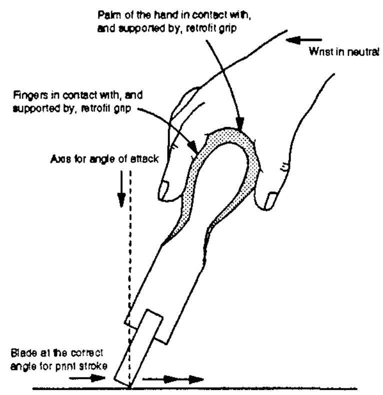

Figure 4.
Padded Ergo Retrofit of
a Standard Handle

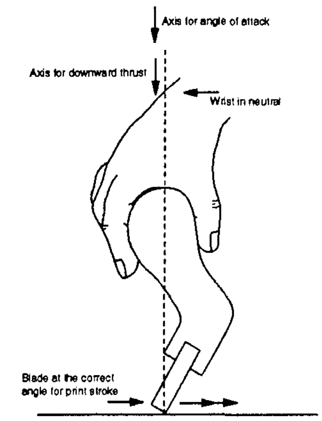

Figure 5.
Ergonomically
Designed Handle

Tichauer and Gage (1977) determined that three areas of the hand are extremely pressure-sensitive; the palmar arch, the ulnar nerve in the heel of the hand, and the mid-palmar area. The narrow grip of the standard squeegee handle (and other commercially available handles) as well as the amount of downward pressure required to print place significant pressures on the mid-palmar areas of the hands of manual printers. (See Fig. 6.) According to Tichauer and Gage and the Draft ANSI Z365 (1993) report, compressibility may help mitigate this pressure. Padding squeegee handles with a compressible material should result in decreased numbness, tingling and pain in the handles.

The position of the wrist is also important when considering potential injuries. Rempel and Horie (1994) found a direct relationship between wrist position and carpal tunnel pressure (CTP); as extension or flexion increased, CTP also increased. They found that the lowest levels of CTP occurred between the neutral position (0 degrees of flexion and extension) and 15 degrees of extension. Their conclusions draw further support from other researchers (Yoshioka, et al [1993], Bech-Foehn [1992], and Tichauer [1966]). Manual screen printers exhibit extension at the beginning of the stroke, and flexion at the end of the stroke. By redesigning a handle that eliminates either significant extension and any flexion, the incidence of CTS and other CTDs among screen print workers should decline. (See Figure 5,)

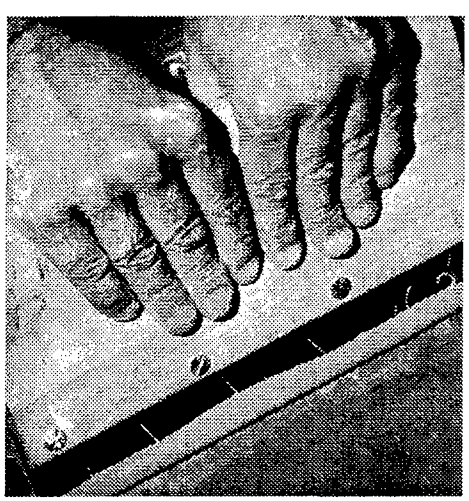

Figure 6.. Industry Standard Handle in Use. Beginning stroke, wrist in extension, fingers in hyperextension

TASK II

Purpose

The objective of this task was twofold:

• To do a task analysis in functioning screen print shops. The purpose of this analysis was to evaluate work environments, documenting job demands and task requirements of essential functions.

• To evaluate nine commercially-available and experimental squeegee handle designs. The purpose of this evaluation was to formulate design criteria for the development of an ergonomically sound squeegee handle that will enhance usability and safety, and reduce the potential for CTS and CTDs. Design considerations included handle shape and width, surface compressibility and texture, and wrist posture. A secondary consideration was weight of the handle.

Methods

The Task analysis was performed at two manual screen print shops in Eugene, Or. Two ergonomists videotaped four subjects performing their regular screen printing tasks. These tasks included not only the repetitive 'push-pull' of the screen printing stroke, but also the lifting , dropping and rotation of screens, the rotation of platens, re-inking, loading the garment onto the platen, removing the garment from the platen surface, and placing the garment onto the dryer. The following anthropometric measurements were taken and recorded: The range of heights of work surfaces, the area squeegeed, horizontal reaches while squeegeeing, and mean wrist postures.

The handle evaluation portion of the study was conducted at the *First Impression Screenprinting* shop in Eugene, Or. Ten volunteers (ages 20±43, four female, six male), who were all experienced commercial screen printers, participated in the ergonomic evaluation and assessment of nine squeegee handles. The following anthropometric measurements were taken with each participant: Floor to platen, elbow to platen, shoulder to knuckle, floor to elbow, and hand length (wrist crease to tip of middle finger).

A workstation was set up using one station of a 10 station commercial carrousel screen press. The screen was positioned, at an off-contact distance from the platen of 1/8th inch (.3125 cm). (See Fig. 6.)

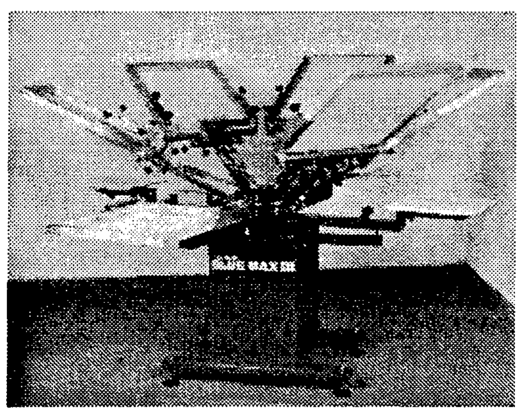

Figure 7. An industry 6-station screen press (table), with screen frames attached.

The screen frame used was 1.50 inches thick (3.8 cm), and 1.50 inches wide (3.8 cm), with an outside diameter of 23 inches (58.4 cm) X 21 inches (53.3 cm), and an inside diameter of 20 inches (50.8 cm) X 18 inches (45.7 cm). The pre-coated mesh tension was measured on four screens using a Newton meter (tensiometer). Measurements were taken in an "S" pattern with seven points measured. Measurements were taken from side to side.

Of the nine squeegee handles that were evaluated, seven handles are commercially available, and two were experimental. One of the commercially available handles, the industry standard handle was Handle W. Two more of the standard handles were used and retrofitted with compressible rubber grips, Handles U and H. Handles N and O, were made of metal. Handle F was molded in plastic, and G was made of wood. Handles Q and S were experimental. Each handle was measured for the following physical characteristics: Length, handle height (including blade), exposed blade height, handle diameter, composition and weight. Figures of each handle and handle measurements can be found in Appendix B.

The nine squeegee blades were measured using a Reb-Co durometer. All blades were approximately 14 inches in length, and three measurements were taken at the following intervals from right to left: 3.5 inches, 7 inches and 10.5 inches. Durometer is the measure of hardness or softness of the blade. It is measured on the "Shore A" scale and is expressed as degrees.

The ink used was Maxopake White, PADM-1020C, batch #66805, made by Union Ink Co., Ridgefield, NJ. The undiluted, high viscosity ink was printed on black T-shirt material, and produced the need for maximum force while printing.

Each subject arrived separately. The test procedure was explained and anthropometric measurements were taken. The handles were tested in random order for each subject. Each handle was used for a duration of five minutes. The rate of pulls was determined by a recorded voice marking five second intervals. A recovery interval of three minutes was given each subject between the use of each handle , during which she or he completed an evaluation of the handle. After each subject had used all nine handles they were asked to rank each handle for familiarity, comfort, exertion and slipperiness.

Results

Task Analysis

- Subjects spent an average of ten percent of their time using the squeegee handle.

- Ninety percent of the subjects' time was spent applying ink, spraying garment adhesive to the platen surface, retrieving the unprinted garment, loading the garment onto the platen, removing the garment from the platen surface and placing the garment onto the dryer conveyer belt.

- Work surface heights ranged from 37 1/8 inches (94.3 cm) to 38 1/4 inches (97.6cm).

- Areas squeegeed in the two shops were 20 inches (50.8 cm) by 14 inches (35.6cm) and 12 5/8 inches (32.1 cm) by 15 inches (38.1 cm).

- The range of horizontal reach distance was 26 inches (66.0 cm) by 27 1/8 inches (68.9 cm).

- Mean wrist flexion was 20 degrees; mean wrist extension was 45 degrees; radial deviation was 5 degrees.

- The factors that affect posture are: Standing surface to platen level and shoulder level to platen level.

- The anthropometric measurements and mesh tension data can be found in Appendix B.

Handle Evaluation

Mean Scores

Mean scores were calculated for subjects' responses to the comfort, exertion, and slipperiness scales for each handle.

Comfort

Handle G had the highest mean score for comfort, 4.5 (on a 7-point scale); this handle is similar to the industry standard squeegee smooth wood handle (Handle W), but has a larger grip diameter (1.80 inches vs. 1.10 inches at the widest point). Handle W had the next highest mean comfort score (4.4). Handle H ranked third with a mean of 4.3. The remaining handles and their mean scores for comfort were: Handle O (4.2), Handle U (3.7), Handle N (3.3), Handle Q (3.1), Handle F (3.0), Handle S (2.9).

Exertion

Handle O and Handle N had the lowest mean scores for exertion (2.5). Handle W had the third lowest mean exertion score (3.2). The remaining handles, ranked from lower exertion to greater exertion: Handle G (3.3), Handle H (3.7), Handle U (3.8), Handle Q (4.2), Handle F (4.5), Handle S (4.8)

Slipperiness

Handle H had the lowest mean score for slipperiness (1.1). It was followed by Handle Q (1.5) and Handle O (2.0). From less slippery to more slippery, the remaining handles and their mean scores for this variable are: Handle N (2.3), Handle G (2.4),
Handle U (2.5), Handle W (2.8), Handle S (3.1), Handle F (3.3)

Comfort Rankings

After using all nine handles, each subject placed the handles in order from most comfortable to least comfortable. Scores from one (least comfortable) to ten (most comfortable) were assigned to the handles based on these rankings. The scores for each handle were then totaled.

Handle O scored the highest with a total score of 78 (mean=7.8); of the ten participants, five chose this handle as the most comfortable of the nine handles and it was the second choice for three of the subjects.

The remaining handles (from most comfortable to least comfortable):

Handle U (63), Handle G (59), Handle H (57), Handle W (49), Handle F (44), Handle N (37), Handle Q (31), Handle S (26)

Statistical analyses

Evaluation Tools

A significant positive relationship existed between responses to the comfort scale on the questionnaires and the way the subjects ranked the handles for comfort as a group (r = 0.746). When responses to the comfort rankings and the comfort scale on the questionnaires were compared with responses to the exertion scale on the questionnaires, inverse relationships were found although these relationships were not significant (r = - 0.59 and - 0.56, respectively). In other words, if a subject perceived a particular handle to be relatively more comfortable they tended to perceive that it took less effort to print with the handle. No relationship was found between the two comfort measures and 'slipperiness' (r = -0.25 and -0.35).

Hand size, handle weight, handle diameter, blade durometer, handle height, exposed blade height with comfort rankings, comfort scale responses and exertion scale responses. (Please refer to evaluation rankings for more information.)

Two significant relationships were found:

- Hand size and comfort (from the bipolar scale on the questionnaires) were inversely related during use of the Handle Q (r = -0.780, significant at the .01 level), i.e., when hand size increased, perceived comfort decreased.
- An inverse relationship also existed between hand size and exertion when employing the standard handle (r = -0.656, significant at the .05 level), i.e., when hand size increased, perceived exertion deceased.

No other significant relationships existed among the other variables, however, there were some tendencies.

- Hand size and comfort (as determined by the comfort rankings) were somewhat directly related for Handle G and Handle W (r = 0.521 and 0.578, respectively).
- There were tendencies toward relationships (strong, but not statistically significant) between hand size and exertion. This relationship was positive for Handle W (r =0.569) and inverse for Handle N (r = - 0.592).
- There appeared to be an inverse relationship between handle weight and exertion, but it was not significant (r = - 0.494).
- If significant, this relationship might have indicated that any increase in the perception of exertion that may have been caused by having to lift a heavier squeegee handle would have been mitigated by decreased effort in exerting downward pressure.
- There was a tendency toward a direct relationship between handle diameter and perceived exertion (r = 0.596), and toward an inverse relationship between handle diameter and comfort as assessed by the bipolar scales (R = -0.527).
- There was a relatively strong but not significant relationship between blade durometer and perceived exertion (r = 0.567).

DISCUSSION

The most sensitive comfort measure was the ranking of handles done by each study participant after using all of the handles.

Handle O ranked first with a raw score of 78, followed by Handle U (63). Handle G (59) and Handle H (57) were virtually tied for third.

The apparent reason for Handle O's success on this variable was the shape of the handle; the handle shape made full contact with the fingers and the palmar surface of the hand in the relaxed position. Participant's comments and observations by the ergonomists and the principal investigator supported this conclusion. This handle grip is 18% wider than Handle W, the industry standard handle (1.3 inches vs. 1.1 inches), which may also account for its perceived comfort. Although this handle is constructed out of aluminum, compressibility, slipperiness, and temperature conductivity did not appear to be issues, contrary to what our ergonomics team had predicted. With use over extended time these variables may, however, become issues.

Handle U performed well, most likely due to its increased grip diameter, its shape, and its compressibility. Subjects' comments focused on the support provided to the fingers and knuckles. Handle G was given a negative evaluation by the ergonomics team, however, the subjects in the study rated it positively. Although this handle is constructed of wood, it did have a significantly wider grip than the industry standard handle, Handle W, (1.8 inches vs. 1.1 inches), which may have contributed to its perceived comfort.

Handle H most likely performed well on this variable for the same reasons as the other retrofitted handle, Handle U, but no illustrative comments were provided by the subjects.

The comfort evaluations for each handle from the questionnaires were clustered in a fairly narrow range and did not give as sensitive an indication as the comfort rankings done by each participant after using all of the handles.

- The top four were Handle G, Handle W, Handle H, and the Handle O. The merits of all of these handles, except for the standard handle, were discussed in the prior section. Once again, the industry standard handles, Handle W, performance was contrary to the predictions of the ergonomics team, who gave it no merits in their analysis.
- Familiarity may have been the most likely reason for its perceived comfort; eight of the ten subjects in the study use this handle in their workplace. According to one subject, "Like home - normal, comfortable, light, easy to use".

The most favorable handles on the exertion scale were Handles N, O, W, and G. All but Handle N were discussed in prior sections. According to the ergonomists, one merit of Handle N's design is that it made full contact with the palm and first phalanx of digits two through five. One of the participants commented that it was heavy to lift, but that its weight made it easier to apply the downward force needed for printing. Almost all the subjects complained that it was too heavy, but the problem of weight associated with lifting may have been mitigated by the decrease in downward pressure needed to apply ink to the substrate. In our statistical analysis we did find some support for this, although it was not statistically significant.

The least slippery handles were:

Handles H, Q, O and N. On first glance it appears that the relatively high friction provided by padding is responsible for the performance of the two handles, H and Q. Handle U, another rubber retrofit, placed sixth on this variable, however, after Handle G. Although inconclusive, grip width, shape, and surface composition all seem to enter into the perception of 'slipperiness'.

New Ergonomic Handle Design:

Handle Q (See Fig.4) has been designed with a wider grip to better fit the shape of the hand, to allow for greater downward force by placing the palm of the hand over the blade, and to reduce the amount of wrist extension (0-15 degrees optimal).

Handle Q is a new concept in squeegee handle shape (See figure 4). the blade has been moved back under the palm of the hand and has been angled at 29 degrees to allow for an appropriate angle of attack. Its design will potentially alleviate two perceived problems associated with the standard industry handle.

The first issue involves the optimal generation of downward force. When using the standard handle the blade is beyond the hand and as a result more force is required to generate downward pressure on the screen mesh. By moving the blade under the palm of the hand the line of downward force is centered directly over the point of application.

The second perceived problem associated with the standard handle is excessive extension at the beginning of the pulling stroke. Placing the blade directly under the palm at an angle of twenty nine degrees eliminates the need for this extension.

The FAXBAK survey (See Appendix C) indicated that there is a significant injury problem in terms of incidence of pain, fatigue, numbness and tingling in their hands, wrists, and arms. It also indicated that workers with symptoms who used padded handles for at least a week experienced a reduction in symptoms. It further showed that the injuries that are most often effected by the addition of padding are injuries involving the hands and to a lesser extent, the wrists and the arms.

In response to the 'hands-on' evaluation and for use in Task IV, we re-designed the shape of the retrofit materials to create a grip which appears to lie somewhere between the pinch grip and the power grip. This grip allows full contact of the palm and fingers with the handle while the fingers and hand are in a relaxed, somewhat open position. The pinch or 'precision' grip was found to be biomechanically unsound because the fingers cannot curl; as a result this grip can only exert about 25% as much force as the power grip (Eastman Kodak, 1986). It was also noted in our hands-on study that the traditional standard handle, as well as other models that did not conform well to the shape of the hand, resulted in hyperextension of the fingers and as a result, pain. Napier (1956) found that the power grip (which occurs when the hand makes a fist with four fingers on one side of a tool and the thumb reaching around the other side to 'lock' on the first finger) was superior in terms of force; he did not, however consider its influence on potential injury. Performing the pinch grip requires significant contractions of the muscles of the forearm and wrist which can lead to fatigue and pain in these areas. It also puts stress on the tendons which extend from these muscles across the wrist and to the fingers. By exerting force on the bones of the wrist and hand (essentially decreasing the space between these structures, e.g., the carpal tunnel), this grip may contribute to an increase in CTP and other injuries to the nerves, tendons, tendon sheaths, ligaments and other tissues in the fingers, hands, and wrists.

Although the data seemed to indicate that the shape of the handle and an increased width in the grip were keys to increased comfort and decreased exertion, each handle was used for a period of only five minutes. It is predicted that over time, compressibility (or a lack thereof) may become an additional important factor. This hypothesis is supported by the FAXBAK survey, which showed that symptoms tended to respond favorably to neoprene padding in the absence of an optimal handle shape (although the retrofitted squeegee handles did have a wider grip than the traditional standard handle). Also, the laboratory study performed by Dr. Rempel and his associates in Task IV suggested that by padding the squeegee handles with a compressible surface there was a trend toward lower CTP.

Two additional issues emerged during the course of Phase I, Task II.

The first resulted from our observations of the biomechanics of the screen print workers in the task analysis and during the handle evaluations . These workers hold their bodies in a static position while they worked and used, almost exclusively, the arms, wrists, and hands to perform the task of screen printing. A majority of the force for exerting downward force on the platen and for pulling the squeegee handle across the surface came from the hands and arms. As a result undue stress was placed on the relatively small and weak muscles that act as movers of the upper extremities. This stress may be responsible for the high incidence of CTS and CTDs observed in screen print workers. Correct biomechanics, with an emphasis on full-body force that involves the use of the relatively larger and stronger muscles of the legs and trunk, could, cost effectively, we believe, contribute to the decrease in the incidence CTS and other forms of arm, wrist, and hand fatigue, pain, numbness and tingling associated with screen printing. According to the draft *Ergonomic Standards for the Screen Printing Industry*, "Work methods should be designed to reduce static, extreme, and awkward postures; repetitive motion, and excessive force." By bringing the larger and stronger muscles of the trunk and the lower extremities into play, manual screen printers may realize a decrease in upper extremity repetitive motion injuries by reducing the amount of force generated in the hands and arms and eliminate the static postures (which essentially are continuous isometric contractions) of the upper back, neck, lower back and legs. (See Fig. 1.)

The second issue involved meeting the needs of workers with varying hand sizes. The participants in the handle evaluation portion of Task II ranged from 17.5cm. to 20.8cm. in hand length. The most significant relationships found existed between hand size and comfort, and hand size and exertion. Retrofitted padding of varying sizes may help increase comfort, decrease exertion, and as a result decrease injury. According to Lewis and Narayan (1993), varying hand sizes might be accommodated by three handle sizes.

TASK IV

Purpose

The purpose of this task was to conduct a repeated measures design laboratory experiment to investigate the relationship of carpal tunnel pressure (CTP) to different screen printing handle designs. These tests were conducted at the UCSF Ergonomics Laboratory in Richmond, California.

Methods

Four volunteers (age 25.5 ± 1.3 years) who demonstrated no evidence of CTS based on history, examination, and nerve conduction testing participated in this study. All were experienced screen printers.

Carpal tunnel pressure was measured via a saline-filled catheter inserted into the carpal tunnel, and attached at its proximal end to an in-line pressure transducer. Output from the transducer was amplified and stored on a digital computer.

Ulnar/radial deviation and flexion/extension of the subject's wrist were monitored using a 2-channel electrogoniometer. The neutral wrist position was determined using a calibration fixture which aligned the long finger, the wrist, and the elbow.

Subjects performed screen printing tasks on a board mounted on a pair of six-degree-of-freedom force platforms. Vertical and horizontal forces were amplified and stored on a digital computer. All systems were calibrated prior to use.

Five different squeegee handle designs were tested. One handle was the industry standard design (Standard) used in the majority of screen printing shops. A second handle was an oversized variation on this first design (Oversized). The third design consisted of the industry standard handle which had large rubber grips retrofitted to it (Retrofitted). The fourth design consisted of an oversized wooden handle which had the squeegee blade offset by an angle of 29 degrees from the axis of the handle (Ergo Plain). The final design was identical to the fourth with the exception that the gripping surface was covered with 1/8" thick foam rubber (Ergo Padded).

The order of the handle presentation was randomized. Each subject was instructed in the proper use of each handle and was allowed to practice as necessary. Subjects performed a series of 10 successive pulls with each handle.

A mean CTP value was calculated for each subject using each squeegee handle. This value represents the average CTP from the start of the first pull through the end of the tenth. The average was calculated to give a realistic CTP value for a typical screen printing task. The data were subjected to a Repeated Measures Analysis of Variance (RANOVA) procedure with one factor (handle, 5 levels).

Results

A typical plot of CTP and platen force versus time can be seen in Figure 8. It evident from this graph that there is a small delay between the development of platen force and a corresponding change in CTP.

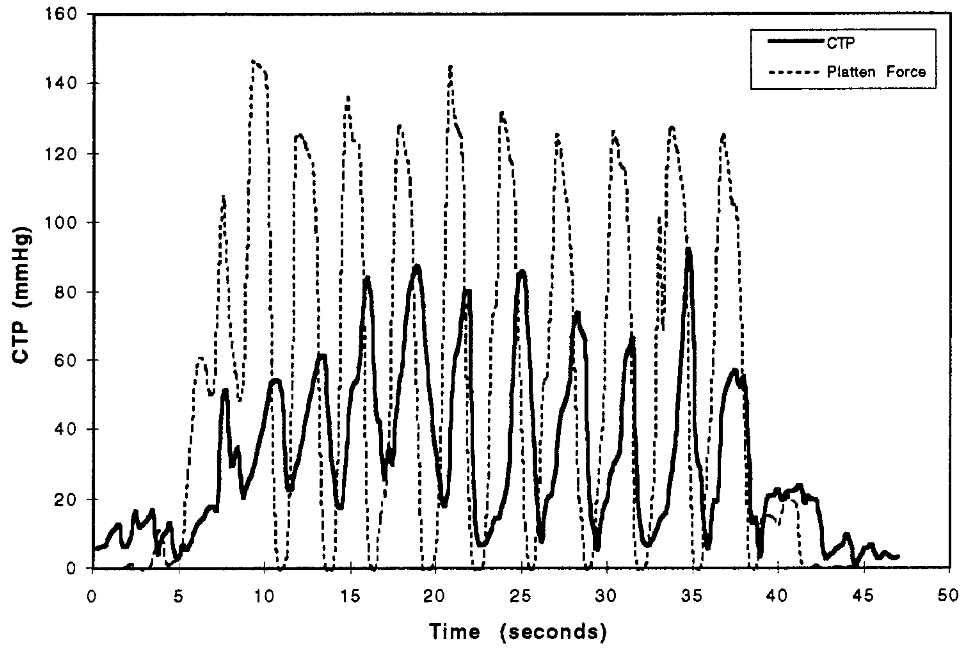

Figure 8 - Typical CTP vs. time graph.

The summary data for the four subjects is displayed graphically in Figure 9. Although there are differences in the mean pressures for each handle, the RANOVA did not find these differences to be statistically significant. A sample size estimate was performed to determine the number of subjects necessary to detect a CTP difference between handles of 10 mmHg. Using a=0.05 and b=0.10 the predicted sample size is 13 subjects. Reducing the detectable difference to 5 mmHg increases the necessary sample size to 51.

Since it was beyond the scope of the current study to test more than five subjects, the data was also analyzed nonparametrically in an attempt to determine if there were any statistically significant differences between the five handles. The five handles were ranked from 1 (lowest CTP) to 5 (highest CTP) for each subject (Table 1). A Friedman F_r test was performed on the ranked data. The differences between handles were again not statistically significant at the a=0.05 level.

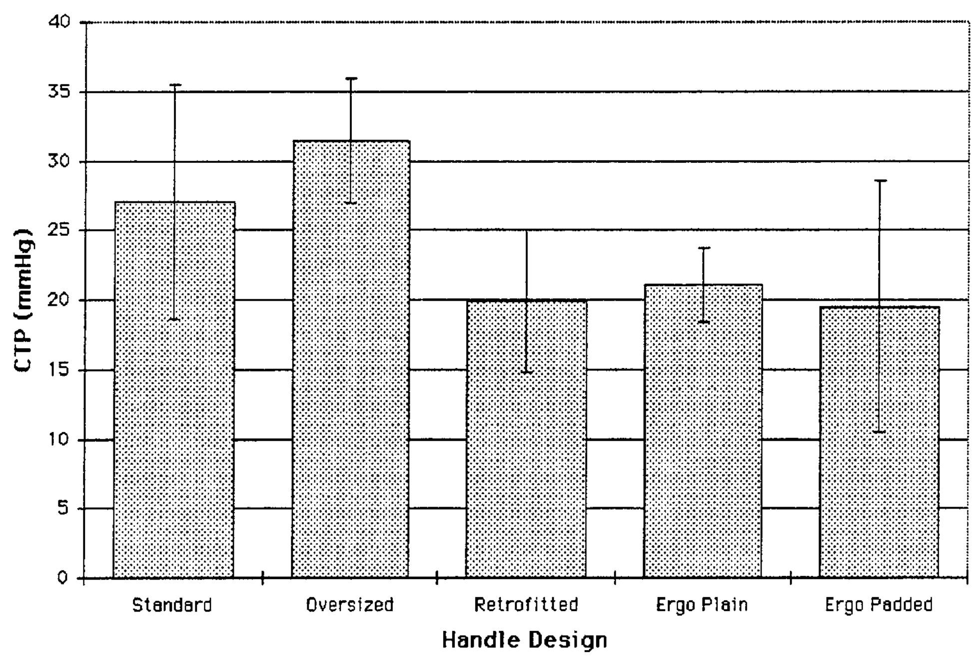

Figure 9. CTP vs. handle design. Values represent means, error bars represent standard errors (n=4).

Subject Handle	120	122	123	124
Standard	5	3	3	3
Oversized	4	2	5	5
Retrofitted	3	1	4	1
Ergo Plain	2	4	1	2
Ergo Padded	1	5	2	4

Table 1 - Relative rankings of handles by subject.

DISCUSSION

Given the small sample size, there was no statistical significance between handles. However, there was a trend for the ergonomic handle designs to reduce CTP relative to the industry standard design. The Retrofitted, Ergo Padded, and Ergo Plain designs resulted in similarly low CTP relative to the Oversized and Standard designs. An estimated thirteen subjects would have been required to obtain a significant result.

Several shortcomings in the experimental design may have been responsible for the lack of statistical significance. The subjects were only given a few minutes to practice with each handle design. All subjects had used the Standard design handle exclusively in their previous screen printing work. Thus the biomechanics of this handle design were familiar to the subjects. The Oversized handle, and to a lesser extent the Retrofitted handle, would require similar biomechanics and thus be fairly familiar to the subjects. The Ergo Plain and Ergo Padded designs on the other hand required biomechanics that were initially awkward for the subjects. These handles altered the wrist flexion angle and point of load application relative to the Standard design. These changes most likely caused the subjects to use higher grip forces and stabilizing moments than they would have had they been given more time to get used to these designs. These elevated forces would be expected to lead to increased CTP.

A second shortcoming involved the way that the data were analyzed. The mean CTP for each handle was calculated by averaging the CTP from the beginning of the first pull through the end of the last. Thus during this time there were significant intervals were there was no load being applied through the squeegee to the platen and therefore the CTP was low (near baseline levels). If we had averaged the pressures only while there was force being applied to the platen then the mean pressures would have been higher. Unfortunately CTP did not follow platen force exactly with elevated CTP persisting after the force on the platen had been removed (Figure 1). Thus eliminating the no-load portions of the data would have removed some of the corresponding elevated CTP data from the analysis.

A third shortcoming involved platen height which was constant for all subjects. Adjusting the platen height according to each subjects anthropometry might have lead to larger CTP differences between the ergonomic and non-ergonomic handle designs by affecting the loads that the subject could apply and by altering wrist postures.

Each of these shortcomings could be eliminated, or compensated for, in future studies. The most obvious area of improvement would involve training subjects more thoroughly in the use of the ergonomic handle designs and to allowing them to practice longer. All four subjects stated that they felt the ergonomic design handles were "awkward" to use compared to the more traditional designs. Subsequent interviews with screen printers who have used the new designs for a longer period of time indicate that they adjust to the modified biomechanics and eventually feel comfortable with the new handles. In phase two of this research (if funded) we intend to allow screen printers to use the handles for up to six months before evaluating them.

The issue of platen height is one of the main items to be investigated in the phase two research. Subjects will perform screen printing tasks with the platen adjusted according to the individuals anthropometry as well as at the industry standard height. It is expected that platen height will have an effect on wrist posture which has been shown to affect CTP.

The final potential area for improvement involves the analysis of the data. Further analysis is being performed but the results will not be available before this report is due. Eliminating the data for those periods of time that there is no load on the platen should result in higher mean CTP and potentially larger differences between the handles. An analysis will also be performed on the peak CTP values. It is anticipated that these analyses will indicate significant differences between the handle designs.

In conclusion, there was a trend for ergonomic handle designs to lower carpal tunnel pressures during screen printing. By reducing CTP these handles have the potential to reduce the incidence of CTS in the screen printing industry. More work is needed to refine the ergonomic designs and better evaluate their ability to significantly reduce CTP.

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IN KIND DONATIONS

•Irish Graphics Products Int'l 250 Tech Way Grants Pass, Or. 97526	4 Textile 21"x 23"Screens	$125
•CALCOM Inc. 1822 NE Grand Ave	1 Gallon Union Ink	$44
•American Thieme Corp. 900 C Paramount Pkwy. Batavia, Il 60510	Squeegee Handle 14"	$48
•EUROSCREEN P.O.Box 42641 Cincinnati, Ohio 45242	14" Blades, 14" Handles	$153
•Shoals Trading & Recycling 813 Missouri St. Tuscumbia, Al 35674	T-Shirt Tubes	$115
•First Impression Screenprinting 4087 W. 11th Eugene, Or. 97402	Use of a Commercial Screen Shop/3 days	$600
	Creation of Screen Design For Test T-Shirts	$40
•Full Line Distb. 2375 Button Gwinnett Dr #800 Atlanta, Ga. 30340 & •Union Ink Co. 453 Broad Ave. Ridgefield, NJ 07657	Ink Mixing System Prize for FAXBAK Survey	$239
•Pat Schaeffer	Analysis of FAXBAK Survey	$300
•Squeegee Plus!® P.O.Box 5556 Eugene, Oregon 97405	Ergo/Eval. Tests Worker (Loaded/unloaded shirts on screen press)	$100
	2 Gallons Union Ink	$98
	2 Platens for UCSF	$25
	Screen Cleaner/UCSF	$30
	Trip to UCSF :Flt. & Car	$250
	Shipping & Off. Supls	$220
	FAXBAK Survey Form	$75
	Fax Phone Charges Sent to 600Print Shops	$150

APPENDIX A

Ergonomic Handle Evaluation Test

Pages 22-49

EVALUATION DATA

# of subjects:	10
Duration of work:	5 minutes (11 pulls of squeegee every 5 seconds with a 10 second interval to re-load substrates x 5)
Recovery Interval:	3 minutes (included time to respond to written questionnaire)
# of handles	9
Evaluation dates:	December 13 and 16, 1995
Evaluation location:	First Impressions, Eugene, OR

SCREEN FRAME DIMENSION

Thickness	3.75 centimeters
Outside dimensions	
Length:	57.5 centimeters
Width:	52.5 centimeters
Inside dimensions	
Length:	50 centimeters
Width:	45 centimeters

MESH TENSION (PRE-COATED)

Measurement tool: Newton Meter (Tensiometer)

Note: Measurements were taken in an "S" pattern with seven points measured. ("S" positioned from side to side)

1	2	3	4	5	6	7	Average
17	19	21.5	21	21	20.5	15.5	19.35

OFF CONTACT DISTANCE

Measurement tools:	Aluminum stock and calipers
Off Contact Distance:	.3175 centimeters (1/8" stock)

SQUEEGEE DUROMETER

Measurement tool:	Reb-Co Durometer
Length of blade:	35 centimeters (Handle F= 33.75 cm.)
# of measurements taken:	3 from right to left at 8.75, 24.5 and 36.75 centimeters

	Density #1	Density #2	Density #3	Average
S	62	62	60	61.33
H	62	60	62	61.33
Q	65	64	64	64.33
W	58	58	58	58
G	68	68	69	68.33
F	68	68	66	67.33
O	54	56	56	55.33
N	58	59	56	57.67
U	69.5	69	68	68.83

Note: Handle O has an aluminum backing behind the blade; durometer may not be an accurate measure of its "stiffness".

INK

Maxopake White, PADM-1020C, Batch 66805, Union Ink Company.

ROOM TEMPERATURE = 67 DEGREES FAHRENHEIT

INSTRUCTIONS READ TO EACH PARTICIPANT

SUBJECT NUMBER ______

Thank you for agreeing to take part in this study.

How many years have you been screen printing? _____

Are you having any pain, numbness or tingling in your upper arms, forearms, wrists or hands at this time? Where?

____

Please read and sign these statements (hand them the confidentiality and nonaffiliatedness statements; be sure to get them back)

(MOVE TO WORK STATION)

Please make any adjustments in the work station to assist you as you work.

The ergonomists will make the following measurements:

Hand size
Floor to platen
Elbow to platen
Shoulder to middle of grip
Floor to elbow

(Read the following instructions)

You will be working with nine different squeegee handles.

You will be using each handle for a total of five minutes.

Your rate of pulls will be determined by the voice on the

tape recorder which will ask you to pull at five second intervals.

Please try to stay in time with the pace of the voice on the tape. If you do miss a pull or two, just wait for the next command to 'pull' and begin again. The focus of this study is not on your ability to keep up with the pace we have established, but rather on your evaluation of each of the handles; try not to become flustered if you fall behind at any time. Also - try to perform the task of screen printing similarly to the way you normally would while still attempting to maintain the pace we have established for you. The tape will also instruct you when it is time to lift the screen and to rest.
We will load the substrates for you as they need to be replaced. As you use each handle please do not discuss your impressions of it, and please try to reserve judgment until you have finished using the handle.

After using each handle you will be given three minutes to answer this questionnaire. Please read along quietly as I read the questionnaire out loud.

1. Do you regularly use this handle design or one like it?

Yes_____ No_____

2. How comfortable to use was this handle?

Very Uncomfortable ____ Very Comfortable

3. How did using this handle effect your level of exertion?

No Exertion ____ Extreme Exertion

4. How slippery was this handle?

Not Slippery ____ Very Slippery

5. Additional comments about this handle (use back of this sheet if needed).

After completing the questionnaire you may rest, get a drink of water, or use the restroom during the remainder of the three-minute interval. Please do not discuss your impressions of the squeegee handles at this time.

After using all of the handles you will be asked to arrange the handles in order of perceived comfort.

Do you have any questions?

We will begin the study. Please hold each handle with the letter facing away from you.
(Start the tape)

Observations re: this subject

____

(AT END OF STUDY)

To the best of your ability please arrange the handles in order of comfort of use.

Order of Placement (Best to worst) ______________________________

Thank you for participating.

QUESTIONNAIRE FOR EACH SQUEEGEE HANDLE

Subject __________ Letter on squeegee handle ________

1. Do you regularly use this handle design or one like it?

   Yes_____ No_____

2. How comfortable to use was this handle?

Very ____ Very
Uncomfortable Comfortable

3. How did using this handle effect your level of exertion?

No ____ Extreme
Exertion Exertion

4. How slippery was this handle?

Not ____ Very
Slippery Slippery

5. Additional comments about this handle (use back of this sheet if needed).

KEY TO RESEARCH HANDLES

S - Unpatented handle (plastic)

H - Squeegee Plus! (wood/rubber)

Q - Squeegee Plus! II(wood/rubber)

W - "Standard handle" (wood)

G - Printer's Edge "Big Boy"

F - Flexible Products (plastic)

O - RKS Thieme (metal)

N - Printer's Edge "Tech Mark" (metal)

U - Squeegee Plus! Assymetrical (wood/rubber)

KEYS TO UNDERSTANDING RAW DATA TABLES

The first column lists the handles as they were coded with the letters above.

The second column lists the subject's responses to the question, "Do you reguarly use this handle design or one like it?"

The third column lists scores on a 1 - 7 bipolar scale for 'comfort', with a score of 7 being 'very comfortable' and 1 being 'very uncomfortable'.

The fourth column lists scores on a 1 - 7 bipolar scale for 'exertion', with a score of 7 being 'extreme exertion' and 1 being 'no exertion'.

The fifth column lists scores on a 1 - 7 bipolar scale for 'slipperiness', with a score of 7 being 'very slippery' and 1 being 'not slippery'.

Column six contains the subjects' comments re: each handle.

RAW DATA

Subject One	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing=8	Pain or parasthesi a
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	radial wrist tendinitis in past;
	S	no	3	4	3	Awkward grip	none now
	H	no	6	3	1		
	Q	no	6	5	1	awkward reach/angle	
	W	yes	4	4	5	feel add'l. pressure	
	G	no	5	3	1	uncomfortable thumb-width	
	F	no	6	5	1		
	O	no	5	5	3		
	N	no	6	6	5	heavy to lift;easy for printing	
	U	no	6	5	1	like finger ridges	

ORDER OF PREFERENCE:
F U H N O G Q S W

Subject Two	Squeeeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 15	Pain or parasthesi a
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	Tendinitis in right index
	S	no	7	7	6	too flexible. crippler	about ten years ago -
	H	no	5	4	1	too large for small hands	none now
	Q	no	2	7	2	foam loose;hard to push.crippler	
	W	no	4	3	3	fingers roll up when extended	
	G	no	2	5	4	uncomfortable for s-m hands	
	F	no	1	7	7	crippled of no other choice	
	O	no	4	3	2	web bet. thumb & finger irritated	
	N	no	4	5	3	too heavy; fingers rolled up	
	U	no	3	5	1	fingers turned up; unequal rubber thickness	

ORDER OF PREFERENCE:

O G W N H U Q S F

Subject Three	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 5	Pain or parasthesia
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	No
	S	no	3	3	4	flex & outside grip>uneven strokes	
	H	no	2	3	1		
	Q	no	1	5	1	difficult to push	
	W	yes	4	4	4		
	G	no	6	4	5		
	F	no	1	3	5		
	O	no	1	2	2		
	N	no	4	4	3	a little heavy	
	U	yes	6	2	3		

ORDER OF PREFERENCE:

O F U H W S N G Q

Subject Four	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing=1	Pain or parasthesia
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	no
	S	no	1	7	2		
	H	no	5	6	1		
	Q	no	5	3	1		
	W	yes	7	2	4		
	G	no	6	3	2		
	F	no	5	3	2		
	O	no	6	2	1		
	N	no	3	5	1		
	U	no	2	6	1	too big; grip too wide	

ORDER OF PREFERENCE:

W O G Q F U H N S

Subject Five	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 13	Pain or parasthesia
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	Left elbow (7 on 1 - 10 scale)
	S	yes	2	5	4	Too small for my hand	
	H	no	2	2	2	Nice	
	Q	no	3	4	4	Easy if used to it; different	
	W	yes	5	4	4		
	G	yes	2	3	2		
	F	no	3	5	6		
	O	no	2	1	4		
	N	no	3	3	4	heavy	
	U	no	3	3	4		

ORDER OF PREFERENCE:

H O G U N F W Q S

Subject Six	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= <1	Pain or parasthesia
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	numbness in lateral aspect of
	S	no	5	4	3	a little light but comfortable	right thumb
	H	no	5	5	1		about 4 months
	Q	no	5	2	1	very nice,little awkward to flood	ago - no problem now
	W	yes	3	4	2		
	G	no	2	5	1		
	F	no	4	4	5	a little less pain in the fingers	
	O	no	5	2	3	nicely shaped to palm of hand	
	N	no	4	4	2	nice weight	
	U	no	5	5	1	nicely shaped to hand	

ORDER OF PREFERENCE:

O U S Q N H F W G

Subject Seven	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 13	Pain or parasthesi a
			7=very comfort-able	7=extrem e exertion	7=very slippery	Comments	1984-85: neck and shoulders
	S	no	1	4	6	too sharp @ thumb grip; poor finger grip	to ulnar area.
	H	no	4	3	1	needs wider grip	1990-91: medial
	Q	no	1	4	2	blade angle too severe; uneven durometer: harder	extensors and middle fingers of
	W	no	3	4	3	no support under fingers; knuckles hyperextend; pinch grip too pronounced	left hand.
	G	no	3	4	2	width toward blade too scooped; forced hyerextended knuckles	
	F	no	2	5	4	extreme hyperextension of fingertips; nice weight, shape uncomfortable	
	O	no	6	2	2	support great for fingertips and knuckle regions; too narrow for thumb grip	
	N	no	1	5	2	heavy and cumbersome; s-hyperextended knuckles.	
	U	no	4	3	2	wider grips needed; not supported under fingertips - knuckles hyperextended	

ORDER OF PREFERENCE

O U G H W N F Q S

Subject Eight	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 11	Pain or parasthesia
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	recent left ulnar pain with
	S	no	4	4	1	comfortable;not too much pressure	numbness/ tingling at night. No
	H	no	5	5	1	not too heavy; nice wide finger grip	pain today. Don't
	Q	no	1	7	1	From Mars. Too weird. needed to hold at sides to get good print	print much
	W	yes	7	2	1	like home - normal, comfortable , light, easy to use	
	G	no	7	1	1	awesome, the best so	
	F	no	2	6	1	'ridge' effect not liked-no good place to rest fingers	
	O	no	7	2	1	very good; light wrists @diff. angle-very flat so if pressure needed to clear screen, angle must be changed (no big deal)	
	N	no	1	7	1	too heavy	
	U	no	4	4	1	grip very wide; too heavy takes getting used to - I noticed I printed better	

ORDER OF PREFERENCE:
O G W S H U F Q N

Subject Nine	Squeege Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 5.5	Pain or parasthesi a
			7=very comfort-able	7=extreme exertion	7=very slippery	Comments	none
	S	no	1	5	1	unnatural, uncomfortable, dug into area bet. thumb and finger	
	H	no	6	2	1	rubber pads need to be moved out to edges; thicker & bigger on finger side to keep them straighter; felt pretty good	
	Q	no	5	2	1	messy; couldn't scoop ink; rubber padding loose. had to move hands away from me to print. felt like I was pushing instead of pulling	
	W	yes	6	2	1	easier to grip; fits hands well	
	G	no	6	2	5	light; felt pretty good; don;'t care for big round top	
	F	no	2	2	1	fingers didn't fit in back groove	
	O	no	3	3	1	didn't hold ink on drag back; dripped a lot	
	N	no	5	2	1	metal on side away from me bothered fingertips	
	U	no	3	3	1	little uncomfortable bet. thumb and forefinger; maybe a little big and square	

ORDER OF PREFERENCE:
W H U G O F N Q S

Subject Ten	Squeegee Handle	Handle you use?	Comfort Rating	Exertion Rating	Slippery Rating	Years printing= 1	Pain or parasthesi a
			7=very comfort-able	7=extrem e exertion	7=very slippery	Comments	No
	S	no	2	5	1	hurt my thumbs	
	H	yes	3	3	1		
	Q	no	2	3	1		
	W	yes	1	3	1	too thin; hurt my knuckles	
	G	yes	6	3	1		
	F	no	4	5	1		
	O	no	3	3	1		
	N	no	2	4	1	too heavy	
	U	yes	1	2	1		

ORDER OF PREFERENCE:

G O U Q H F W N S

The participants in the study were asked to arrange the squeegee handles in order of comfort. The handles were then signed scores ranging from nine (9) to one (1), with nine being the most favorable and one being the least favorable. The results of the rankings were as follows:

HANDLE	***SCORE***
O	78
U	63
G	59
H	57
W	49
F	44
N	37
Q	31
S	26

The subjects were asked to evaluate each handle for comfort, exertion, and 'slipperiness'. They were asked to rank the handles on a 1-7 bipolar scale.

The mean scores for comfort (with 7 being 'very comfortable' and 1 being 'very uncomfortable) for each handle are as follows:

HANDLE	***MEAN COMFORT SCORES***
G	4.5
W	4.4
H	4.3
O	4.2
U	3.7
N	3.3
Q	3.1
F	3.0
S	2.9

The mean scores for exertion (with 7 being 'extreme exertion' and 1 being 'no exertion') for each handle are as follows:

HANDLE	***MEAN EXERTION SCORES***
S	4.8
F	4.5
Q	4.2
U	3.8
H	3.7
G	3.3
W	3.2
O	2.5
N	2.5

The mean scores for 'slipperiness' (with 7 being 'very slippery' and 1 being 'not slippery') for each handle are as follows:

HANDLE	***MEAN 'SLIPPERINESS' SCORE***
F	3.3
S	3.1
W	2.8
U	2.5
G	2.4
N	2.3
O	2.0
Q	1.5
H	1.1

The participants in the study were asked to arrange the squeegee handles in order of comfort. The handles were then assigned scores ranging from nine (9) to one (1), with nine being the most comfortable and one being the least comfortable. The results of the rankings are listed in the second column in the table below.

The subjects were also asked to evaluate each handle for comfort, exertion, and 'slipperiness' on a 1-7 bipolar scales. The mean scores for comfort (with 7 being 'very comfortable' and 1 being 'very uncomfortable), mean scores for exertion (with 7 being 'extreme exertion' and 1 being 'no exertion'), and mean scores for 'slipperiness' (with 7 being 'very slippery' and 1 being 'not slippery') for each handle are listed in the third through the fifth columns in the table below

SQUEEGEE HANDLE	Comfort rating scores	Mean scores for 'comfort'	Mean score for 'exertion'	Mean score for 'slipperiness'
Thieme RKS 'O'	**78**	**4.2**	**2.5**	**2.0**
Squeegee Plus! Assymetrical 'U'	**63**	**3.7**	**3.8**	**2.5**
Printer's Edge "Big Boy" 'G'	**59**	**4.5**	**3.3**	**2.4**
Squeegee Plus! 'H'	**57**	**4.3**	**3.7**	**1.1**
"Standard Handle" 'W'	**49**	**4.4**	**3.2**	**2.8**
Flexible Products 'F'	**44**	**3.0**	**4.5**	**3.3**
Printer's Edge "Tech Mark" 'N'	**37**	**3.3**	**2.5**	**2.3**
Squeegee Plus! "II" 'Q'	**31**	**3.1**	**4.2**	**1.5**
Unpatented Handle 'S'	**26**	**2.9**	**4.8**	**3.1**

Comparison of rankings: Individual rankings, comfort means, and exertion means(from lowest exertion to highest) :

Ranked in descending order.

Subjects' Comfort Rankings	Mean Scores for 'Comfort'	Mean Scores for 'Exertion'
Thieme "RKS"	Printer's Edge "Big Boy"	Printer's Edge "Tech Mark"
Squeegee Plus! Assymetrical	"Standard Handle"	Thieme "RKS"
Printer's Edge "Big Boy"	Squeegee Plus!	"Standard Handle"
Squeegee Plus!	Thieme "RKS"	Printer's Edge "Big Boy"
"Standard Handle"	Squeegee Plus! Asymmetrical	Squeegee Plus!
Flexible Products	Printer's Edge "Tech Mark"	Squeegee Plus! Asymmetrical
Printer's Edge "Tech Mark"	Squeegee Plus! II	Squeegee Plus! II
Squeegee Plus! II	Flexible Products	Flexible Products
Unpatented Handle	Unpatented Handle	Unpatented Handle

An examination of the tools of evaluation (the questionnaire and the ordered rankings by the participants) yielded the following:

A significant positive relationship existed between responses to the comfort scale on the questionnaire and the way the subjects ranked the handles for comfort (r = 0.746). When responses to the comfort rankings and the comfort scale on the questionnaire were compared to responses to the exertion scale on the questionnaire, inverse relationships were found, although these relationships were not significant (r = -0.59 and -0.56, respectively). No relationship was found between the two comfort measures and 'slipperiness' (r = -0.25 and -0.35).

Sample correlation coefficients were computed for the relationships between the following variables:

Hand size and comfort rankings

Hand size and responses to the comfort scale

Hand size and responses to the exertion scale

Handle weight and comfort rankings

Handle weight and responses to the comfort scale

Handle weight and responses to the exertion scale

Handle diameter and comfort rankings

Handle diameter and responses to the comfort scale

Handle diameter and and responses to the exertion scale

Blade durometer and comfort rankings

Blade durometer and responses to the comfort scale

Blade durometer and responses to the exertion scale

Handle height and comfort rankings

Handle height and responses to the comfort scale

Handle height and responses to the exertion scale

Exposed blade height and comfort rankings

Exposed blade height and responses to the comfort scale

Exposed blade height and responses to the exertion scale

The values for r for these computations will be listed at the end of the following discussion.

DISCUSSION

Two significant relationships were found. Hand size and comfort (from the bipolar scale on the questionnaire) were inversely related during use of the Squeegee Plus! II handle (r = -0.780, significant at the .01 level), i.e, when hand size increased, perceived comfort decreased. An inverse relationship also existed between hand size and exertion when employing the standard squeegee handle (r = -0.656 ,significant at the .or level), i.e., when hand size increased, the perceived exertion level decreased. No other significnat relationships existed among the other varialbles, however, there were some tendencies.

Hand size and comfort (as determined by the comfort rankings) appeared to be somewhat associated directly for the Printer's Edge "Big Boy" and the standard handle, and inversely for the Flexible Products handle. There were tendencies toward relationships between hand size and exertion while using the "Tech Mark" by Printer's Edge and the unpatented handle (r = -0.592 and r = 0.569, respectively), however, these relationships were not significant. There appeared to be an inverse relationship between handle weight and exertion but it was not significant (r = - 0.494). If significant, this relationship might have indicated that any increase in the perception of exertion that may have been caused by having to lift a heavier squeegee handle would have been mitigated by decreased effort in exerting downward pressure.

There was a tendency toward a direct relationship between handle diameter and perceived exertion (r = 0.596), and toward an inverse relationship between handle and comfort as assessed by the questionnaire (r = - 0.527). There was a relatively strong, but not significant, relationship between squeegee blade durometer and perceived exertion (r = 0.567).

Values of r

Comfort rankings with:	r
Comfort (from bipolar scale)	0.746
Exertion (from bipolar scale)	- 0.560
Slipperiness (from bipolar scale)	- 0.247
Hand size:	
Unpatented handle	- 0.384
Squeegee Plus!	0.123
Squeegee Plus! II	0.159
Standard handle	0.578
Printer's Edge "Big Boy"	0.521
Flexible Products	- 0.536
RKS Thieme	- 0.206
Printer's Edge "Tech Mark"	- 0.292
Squeegee Plus! Assymmetrical	- 0.334
Handle weight	0.049
Handle diameter	- 0.348
Blade durometer	- 0.064
Handle height	- 0.082
Exposed blade height	0.028
Handle length	- 0.212

Values of r (continued)

Comfort from (bipolar scale) with:	r
Exertion (from bipolar scale)	- 0.593
Slipperiness (from bipolar scale)	- 0.350
Hand size:	
Unpatented handle	- 0.167
Squeegee Plus!	0.110
Squeegee Plus! II	0.077
Standard handle	0.182
Printer's Edge "Big Boy"	0.102
Flexible Products	- 0.241
RKS Thieme	- 0.221
Printer's Edge "Tech Mark"	- 0.043
Squeegee Plus! Asymmetrical	- 0.780
Handle weight	0.037
Handle diameter	- 0.527
Blade durometer	- 0.169
Handle height	0.133
Exposed blade height	0.166
Handle length	- 0.011

Values of r (continued)

Exertion (from bipolar scale) with:	r
Hand size:	
Unpatented handle	0.569
Squeegee Plus!	- 0.169
Squeegee Plus! II	- 0.333
Standard handle	- 0.656
Printer's Edge "Big Boy"	- 0.267
Flexible Products	- 0.213
RKS Thieme	- 0.163
Printer's Edge "Tech Mark"	- 0.592
Squeegee Plus! Asymmetrical	- 0.155
Handle weight	- 0.494
Handle diameter	0.596
Blade durometer	0.567
Handle height	- 0.443
Exposed blade height	0.151
Handle length	- 0.088

APPENDIX B

Ergonomic Evaluation of Squeegee Handle Design

Pages 50-76

ERGONOMIC EVALUATION OF SQUEEGEE HANDLE DESIGN

NIH Grant # IR430H03357-01

Phase 1 1995-96

Annette Blake-Swindler, C.I.E.

Baron Rathe Le Gurche, C.I.E.

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Abstract

Manual screen printers are affected by cumulative trauma disorders (CTDs), particularly carpal tunnel syndrome and tendinitis. Statistics from a 1990 study by the Bureau of Labor indicate that 60 percent of all CTDs involve hand/wrist injuries and that CTDs now account for 52 percent of all workplace injuries. It is also estimated that hand tools are involved in approximately nine percent of all disabling injuries (Ayoub, Purswell & Hoag; 1975).

This evaluation studied the ergonomic merits and weaknesses of nine squeegee handle designs to formulate design decisions in the next generation of handles. The criteria used to evaluate the merits and weaknesses of these nine handles were physical properties (weight, size, shape, texture, conductivity, sharp edges and corners) and grasping (a motor response).

Based on the findings under "Merits and Weaknesses", design considerations were identified to enhance usability and safety to reduce the potential for cumulative trauma disorders. Design considerations included material composition, surface compressibility, texture, weight, physical shape and force.

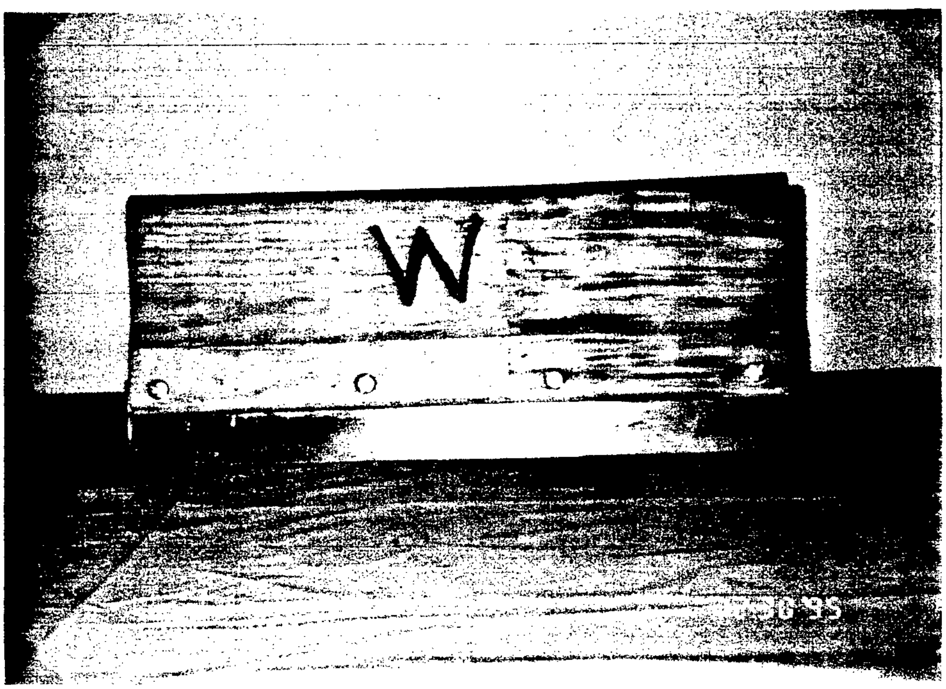
However, work-related injuries suffered by screen printers, particularly carpal tunnel syndrome and tendinitis, are not solely attributable to handle design. The task of screen printing is repetitive and screen printers spend long periods of time in static postures. Workstation height and the angle at which the blade is used, have a direct effect on the amount of wrist deviation. The squeegee durometer, off-contact distance and length of the blade are directly correlated to the amount of force needed to push the ink through the screen to the garment.

Figure 1.

Handle W

FACTS

Handle length = 13 7/8 inches (35.2 cm)
Handle height = 5.80 inches (14.7 cm)
Exposed blade height = 1 1/8 inches (2.9 cm)
Handle diameter = 1.10 inches at its widest point (2.8 cm)
Handle makeup = smooth wood
Weight = 1 lb., 4 oz. (2.76 kg)
Squeegee durometer = 58 degrees



SIDE VIEW

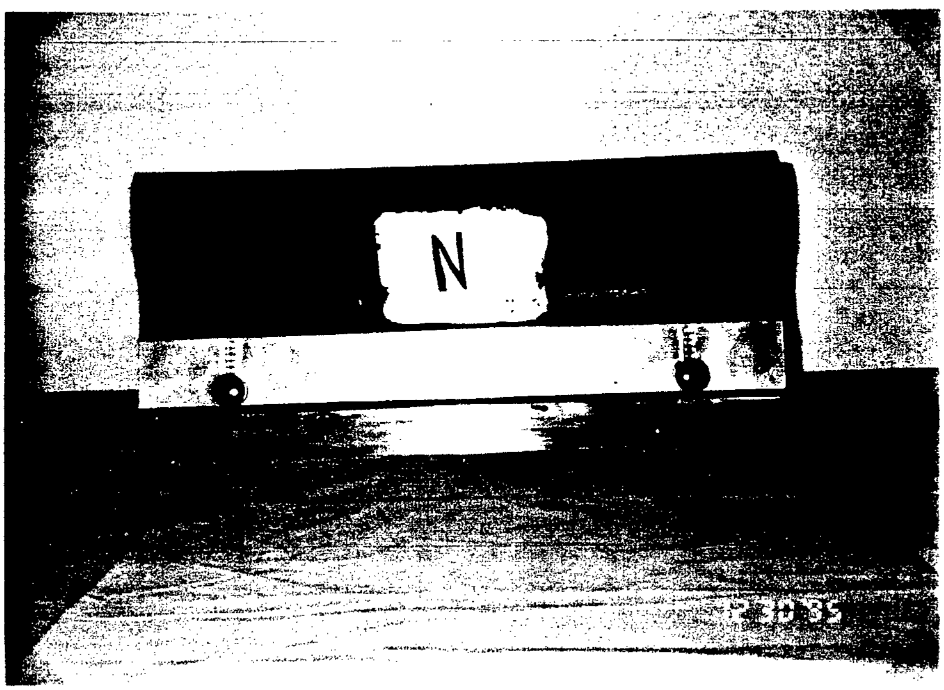
ACTUAL SIZE

Figure 2.

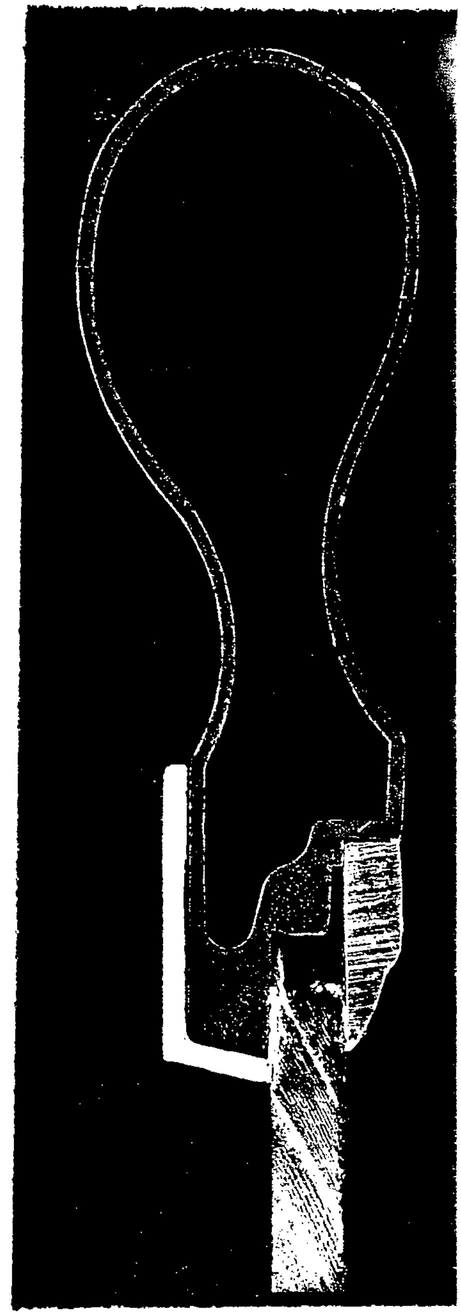
Handle N

FACTS

Handle length = 14 inches (35.6 cm)
Handle height = 6.40 inches (16.3 cm)
Exposed blade height = 1 inch (2.5 cm)
Handle diameter = 1.80 inches at its widest point (4.6 cm)
Handle makeup = aluminum texture w/a .10 inch (.26 cm) material thickness
Weight = 2 lb., 15 oz (6.48 kg)
Squeegee durometer = 57.66 degrees



SIDE VIEW



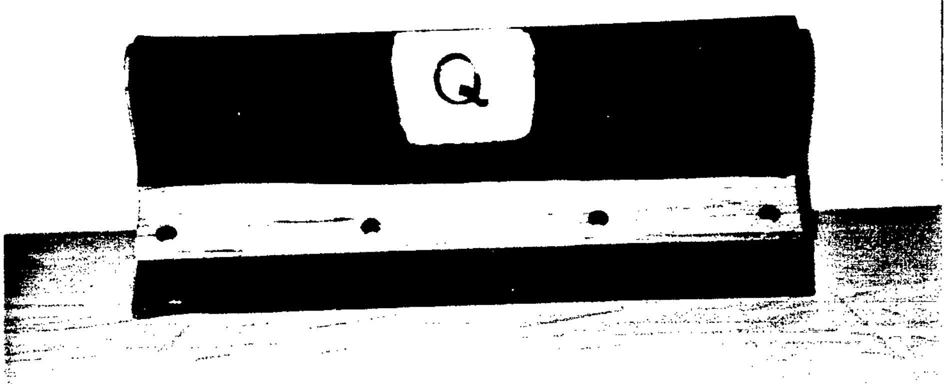
ACTUAL SIZE

Figure 3.

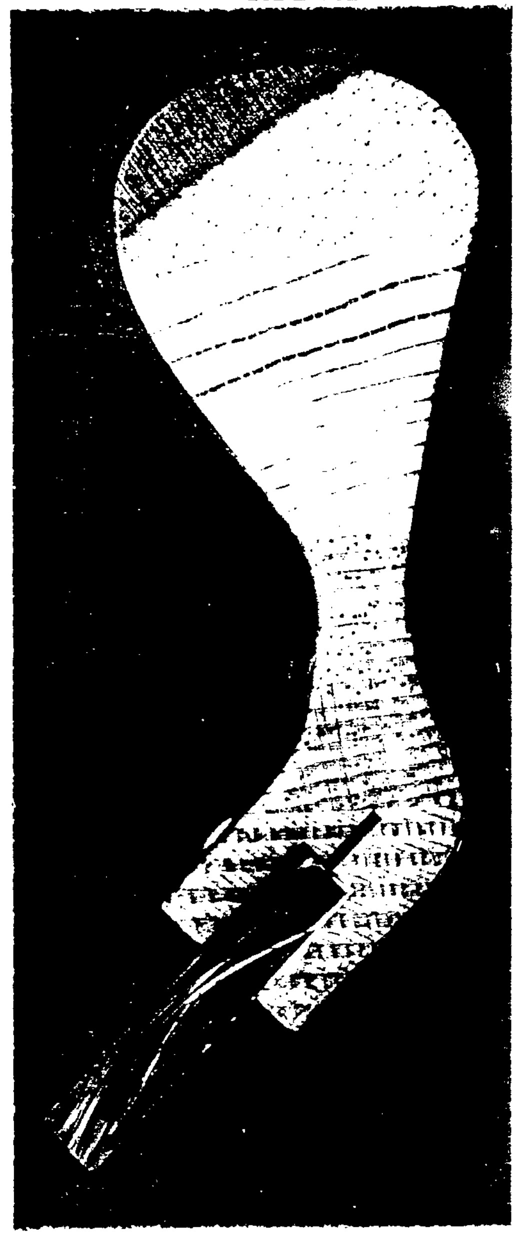
Handle Q

FACTS

Handle length = 14 inches (35.6 cm)
Handle height = 5.80 inches (14.7 cm)
Exposed blade height = 1.25 inches (3.2 cm)
Handle diameter = 2.10 inches at its widest point (5.3 cm)
Handle makeup = wood w/ compressible foam rubber
Weight = 1 lb., 12 oz. (3.86 kg)
Squeegee durometer = 64.33 degrees



SIDE VIEW



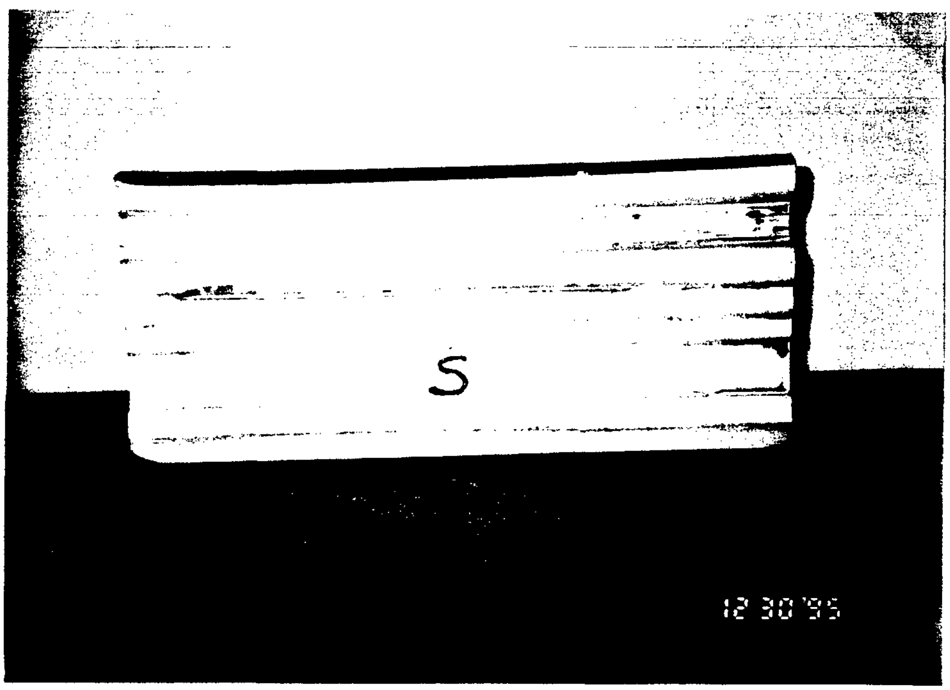
ACTUAL SIZE

Figure 4.

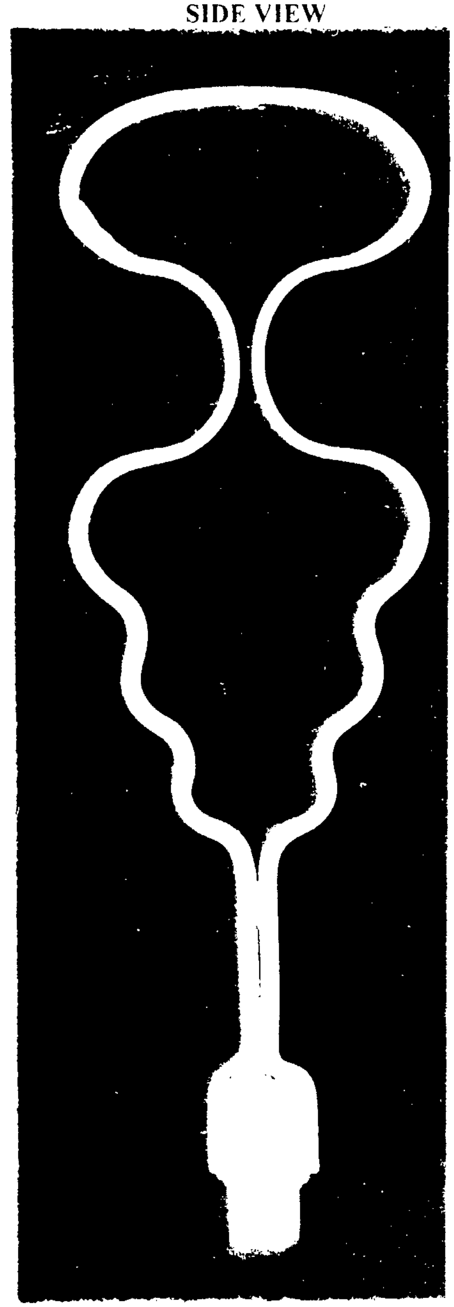
Handle S

FACTS

Handle length = 14 1/8 inches (35.9 cm)
Handle height = 6.20 inches (15.7 cm)
Exposed blade height = .50 inches (1.3 cm)
Handle diameter = 1.90 inches at its widest point (4.8 cm)
Handle makeup = PVC smooth plastic w/a .10 inch (.26 cm) material thickness
Weight = 1 lb., 3 oz. (2.62 kg)
Squeegee durometer = 61.33 degrees



SIDE VIEW



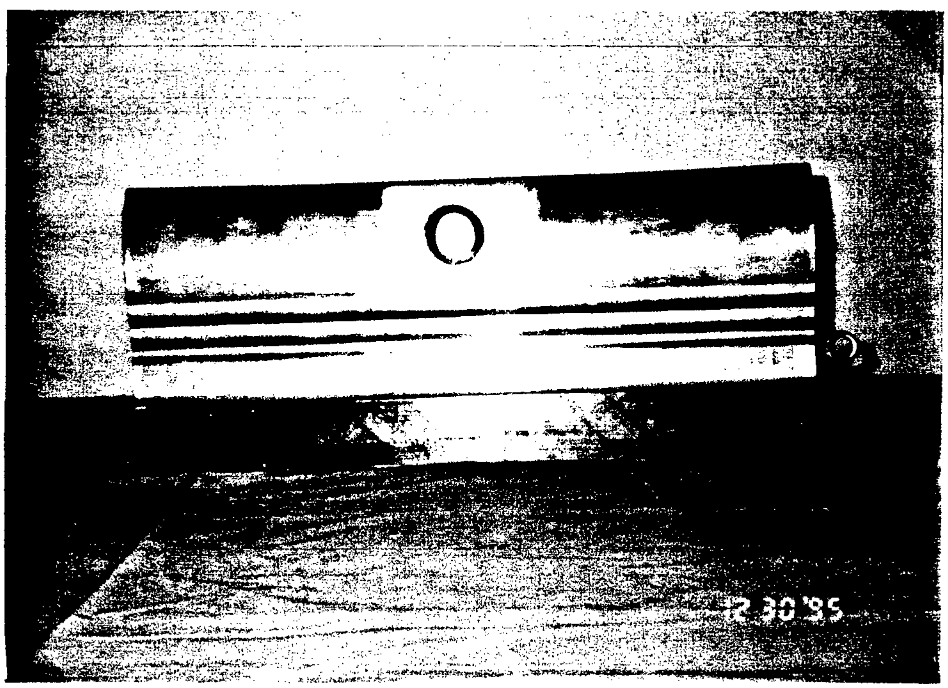
ACTUAL SIZE

Figure 5.

Handle O

FACTS

Handle length = 14 inches (35.6 cm)
Handle height = 5.95 inches (15.1 cm)
Exposed blade height = .60 inches (1.5 cm)
Handle diameter = 1.30 inches at its widest point (3.3 cm)
Handle makeup = smooth aluminum w/a .10 inch (.26 cm) material thickness
Weight = 1 lb., 8 oz. (3.31 kg)
Squeegee durometer = 55.33 degrees



SIDE VIEW

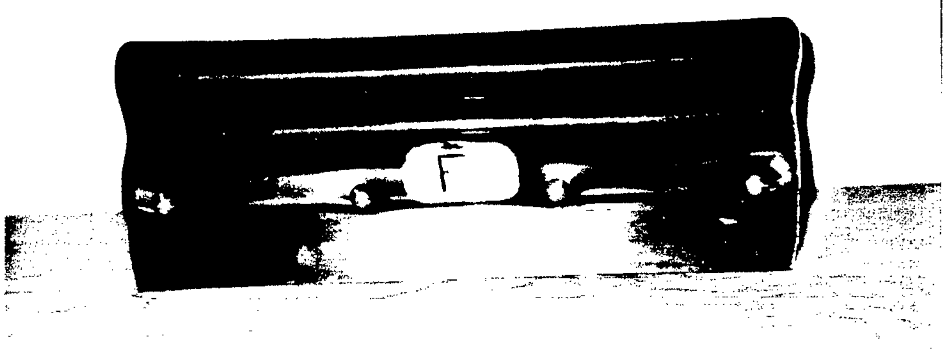
ACTUAL SIZE

Figure 6.

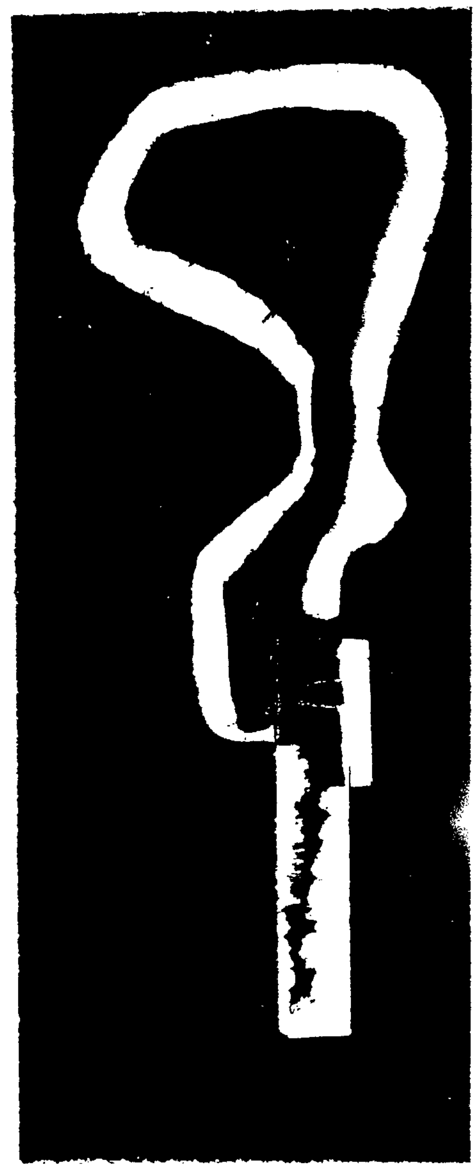
Handle F

FACTS

Handle length = 13.75 inches (34.9 cm)
Handle height = 5.10 inches (13.0 cm)
Exposed blade height = 1.50 inches (3.8 cm)
Handle diameter = 2.10 inches at its widest point (5.3 cm)
Handle makeup = smooth molded plastic
Weight = 1 lb., 2 oz. (2.48 kg)
Squeegee durometer = 67.33 degrees



SIDE VIEW



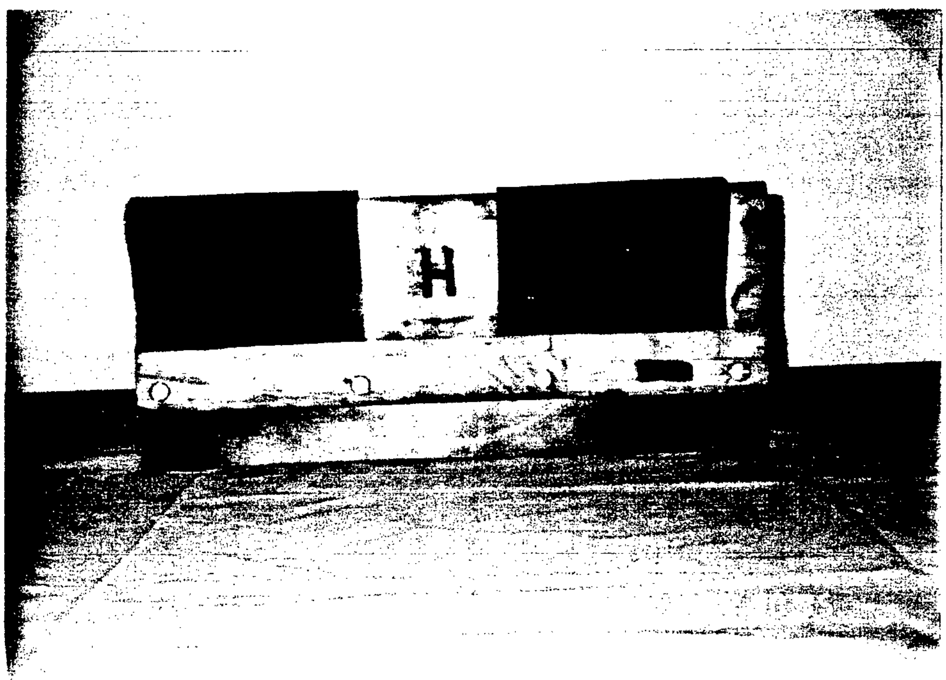
ACTUAL SIZE

Figure 7.

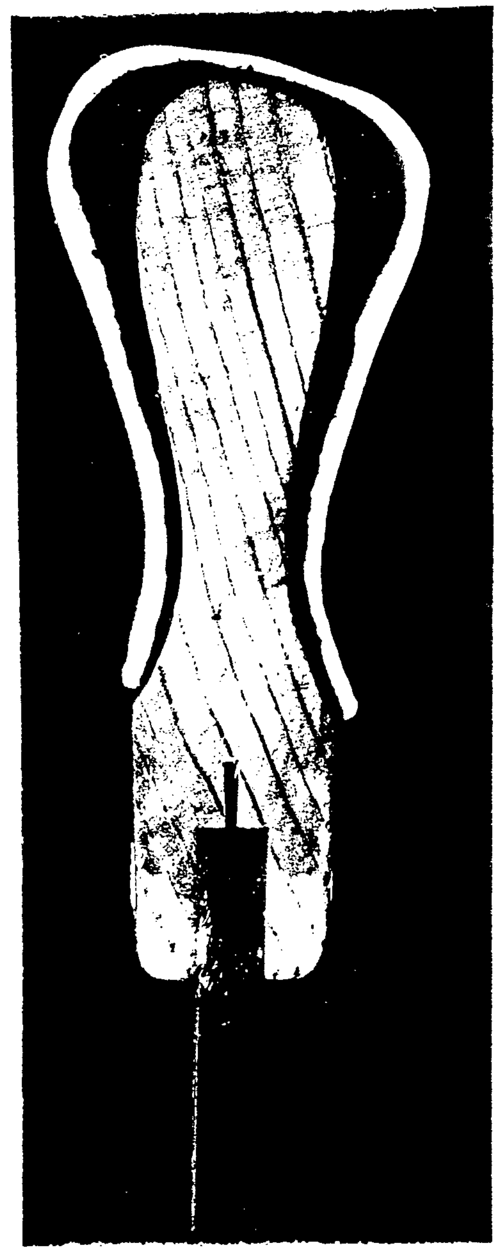
Handle H

FACTS

Handle length = 14 inches (35.6 cm)
Handle height = 6 inches (15.2 cm)
Exposed blade height = 1 1/4 inches (3.2 cm)
Handle diameter = 2 inches at its widest point (5.1 cm)
Handle makeup = wood w/ribbed rubber padding
Weight = 2 lb., 2 oz. (4.69 kg)
Squeegee durometer = 61.33 degrees



SIDE VIEW



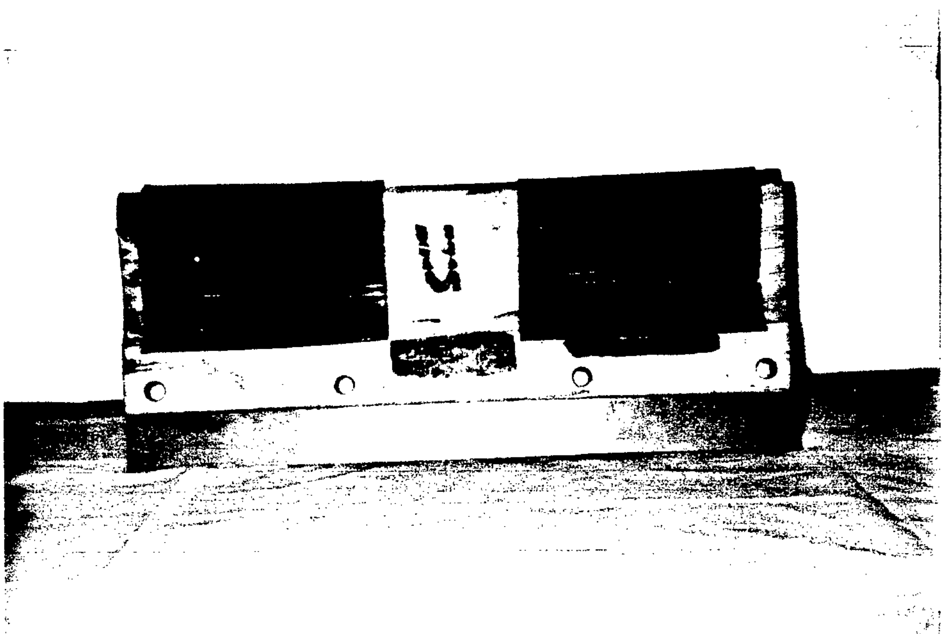
ACTUAL SIZE

Figure 8.

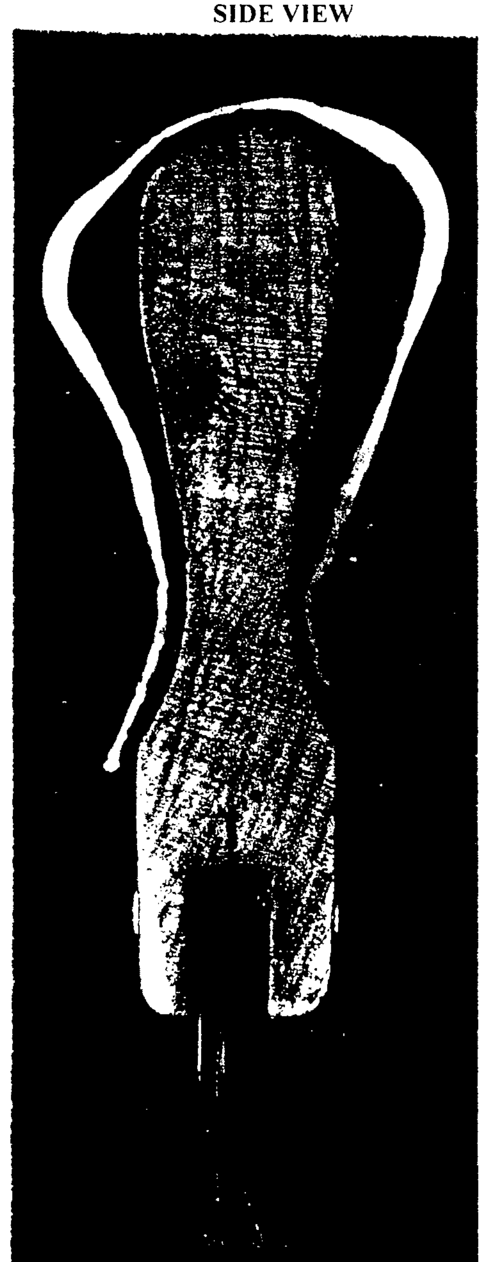
Handle U

FACTS

Handle length = 13.78 inches (35.2 cm)
Handle height = 5.90 inches (15.0 cm)
Exposed blade height = 1 3/16 inches (3.0 cm)
Handle diameter = 2.10 inches at its widest point (5.3 cm)
Handle makeup = wood w/ribbed rubber padding
Weight = 2 lb., 4 oz. (4.96 kg)
Squeegee durometer = 68.83 degrees



SIDE VIEW



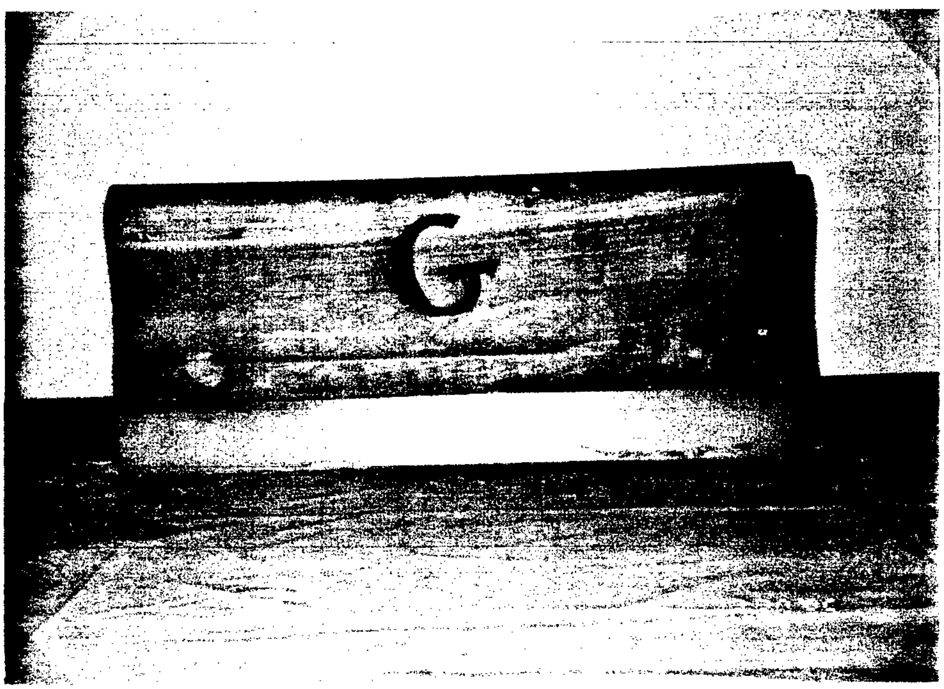
ACTUAL SIZE

Figure 9.

Handle G

FACTS

Handle length = 14 inches (35.6 cm)
Handle height = 6 inches (15.2 cm)
Exposed blade height = 1 7/16 inches (3.7 cm)
Handle diameter = 1.80 inches at its widest point (4.8 cm)
Handle makeup = smooth wood
Weight = 1 lb., 11 oz. (3.72 kg)
Squeegee durometer = 68.33



SIDE VIEW

ACTUAL SIZE

Table 1. Pre-coated Mesh Tension

(Measured in Newton-meter)

	1	2	3	4	5	6	7	Average
#1	17	19	21.5	21	21	20.5	15.5	19.35 nt-m
#2	21	20.5	21	20.75	20	17.75	15.25	19.46 nt-m
#3	19	19	20	21.5	18.75	19	17.25	19.14 nt-m
#4	17.5	17	19	23	23	21	17.25	19.67 nt-m

Table 2. Squeegee Durometer

(Measured in degrees, "Shore A" scale)

Handle	Density #1	Density #2	Density #3	Average
U	69.5	69	68	68.83 degrees
N	58	59	56	57.66 degrees
G	68	68	69	68.33 degrees
O	54	56	56	55.33 degrees
F	68	68	66	67.33 degrees
W	58	58	58	58 degrees
S	62	62	60	61.33 degrees
H	62	60	62	61.33 degrees
Q	65	64	64	64.33 degrees

Note: * Handle O blade is reinforced with a plastic back, this tends to not allow the blade to flex.

Table 3. Anthropometric Data

Name	Subject #	Floor to Platen	Elbow to Platen	Shoulder to Knuckle	Floor to Elbow	Hand Length
D. Scott	1	37 1/8" (94.3 cm)	3 5/8" (9.2 cm)	21 3/4" (55.2 cm)	40 1/4" (102.2 cm)	6.900" (17.5 cm)
B. Cook	2	37 1/8" (94.3 cm)	7 3/4" (19.7 cm)	28 3/8" (72.1 cm)	45" (114.3 cm)	7.700" (19.6 cm)
J. Haworth	3	37 1/8" (94.3 cm)	4 7/8" (12.4 cm)	24" (61.0 cm)	41 1/8" (104.5 cm)	7.100" (18.0 cm)
R. Perez	4	37 1/8" (94.3 cm)	4 ½" (11.4 cm)	23 1/4" (58.7 cm)	42 1/8" (107.0 cm)	7.600" (19.3 cm)
D. Scott	5	37 1/8" (94.3 cm)	6" (15.2 cm)	23" (58.4 cm)	43 1/8" (109.5 cm)	7.600" (19.3 cm)
J. Polk	6	37 1/8" (94.3 cm)	12 1/8" (30.8 cm)	26 ½" (67.3 cm)	48 1/8" (122.2 cm)	7.3" (18.5 cm)
S. Cowan	7	37 1/8" (94.3 cm)	5 ½" (14.0 cm)	25 1/4" (63.8 cm)	42 5/8" (108.3 cm)	7.2" (18.3 cm)
S. Truax	8	37 1/8" (94.3 cm)	6 3/8" (16.2 cm)	25" (63.5 cm)	42 7/8" (108.9 cm)	7.4" (18.8 cm)
P. Hill	9	37 1/8" (94.3 cm)	8 3/4" (22.2 cm)	25 7/8" (65.7 cm)	46" (116.8 cm)	8.2" (20.8 cm)
C. McKinney	10	37 1/8" (94.3 cm)	8 7/8" (22.5 cm)	26 3/4" (67.9 cm)	45 ½" (115.6 cm)	7.8" (19.8 cm)

Table 4. Squeegee Handle Data

Handle	Handle Length	Handle Height (includes blade)	Exposed Blade Height	Handle Diameter	Handle Makeup	Weight	Squeegee Durometer
W	13 7/8" (35.2 cm)	5.80" (14.7 cm)	1 1/8" (2.9 cm)	1.10" (2.8 cm)	smooth wood	1 lb., 4 oz. (2.7 kg)	58 degrees
N	14" (35.6 cm)	6.40" (16.3 cm)	1" (2.5 cm)	1.80" (4.6 cm)	alum. textured	2 lb., 15 oz. (6.48 kg)	57.66 degrees
Q	14" (35.6 cm)	5.80" (14.7 cm)	1.25" (3.2 cm)	2.10" (5.3 cm)	wood w/ foam rubber	1 lb., 12 oz. (3.86 kg)	64.33 degrees
S	14 1/8" (35.9 cm)	6.20" (15.7 cm)	.50" (1.3 cm)	1.90" (4.8 cm)	PVC smooth plastic	1 lb., 3 oz. (2.62 kg)	61.33 degrees
O	14" (35.6 cm)	5.95" (15.1 cm)	.60" (1.5 cm)	1.30" (3.3 cm)	smooth alum.	1 lb., 8 oz. (3.31 kg)	55.33 degrees
F	13.75" (34.9 cm)	5.10" (13.0 cm)	1.50" (3.8 cm)	2.10" (5.3 cm)	smooth molded plastic	1 lb., 2 oz. (2.48 kg)	67.33 degrees
H	14" (35.6 cm)	6" (15.2 cm)	1 1/4" (3.2 cm)	2" (5.1 cm)	wood w/ rubber	2 lb., 2 oz. (4.69 kg)	61.33 degrees
U	13.78" (35.2 cm)	5.90" (15.0 cm)	1 3/16" (3.0 cm)	2.10" (5.3 cm)	wood w/ rubber	2 lb., 4 oz. (4.96 kg)	68.83 degrees
G	14" (35.6 cm)	6" (15.2 cm)	1 7/16" (3.7 cm)	1.80" (4.8 cm)	smooth wood	1 lb., 11 oz. (3.72 kg)	68.33 degrees

Method

Participants

There were ten subjects who participated in the squeegee handle evaluation. All participants were actively employed as screen printers and were recruited from commercial print shops in Eugene, Oregon..

Task

The following task evaluation measurements were taken:

(a) Screen frame dimensions
(b) Mesh tension
(c) Squeegee durometer
(d) Off contact distance
(e) Anthropometric data
(f) Squeegee handle data

(a) Screen frame dimensions: Documented the area on which a screen was printed.

Frame thickness:	1.50 inches (3.8 cm)
Frame width:	1.50 inches (3.8 cm)
Outside diameter:	23 inches (58.4 cm) X 21 inches (53.3 cm)
Inside diameter:	20 inches (50. 8 cm) X 18 inches (45.7 cm)

(b) Mesh tension: The pre-coated mesh tension was measured on four screens using a Newton meter (tensiometer). Measurements were taken in an "S" pattern with seven points measured. Measurements were taken from side to side. **(Table 1. Pre-coated Mesh Tension)**

Mesh tension impacts force requirements. Screen printing mesh has an elastic quality with the capability to stretch, then regain its original shape. The higher the mesh tension, the less force is required to get the ink to transfer through the screen surface to the garment.

(c) Squeegee durometer: Nine squeegee blades were measured using a Reb-Co durometer. All blades were approximately 14 inches in length and three measurements were taken at the following intervals from right to left: 3.5 inches, 7 inches and 10.5 inches. **(Table 2. Squeegee Durometer)**

Durometer is the measure of hardness or softness of the blade. It is measured on the "Shore A" scale and is expressed as degrees. The range in textile printing would be from 50 degrees (extremely soft) to 80 degrees (extremely hard). The most common durometer used in textile printing is 65-75 degrees. If the blade is too soft, it will bend easily; or if too hard, no flexing will occur. The objective is to have slight flexing, with the force centered on the edge of the blade.

(d) Off-contact distance: The off- contact distance was measured with calipers at 1/8 inch (3.125 cm). The measurement was taken at the front of the screen on an eight-color printing press. The off-contact distance is the distance between the screen and the printing surface. The higher the distance, the more squeegee pressure is required to get the ink through the screen mesh to the printed surface.

(e) Anthropometric data: The following measurements were taken with each participant: Floor to workstation platen, elbow to platen, shoulder to knuckle, floor to elbow and hand length (wrist crease to tip of middle finger). **(Table 3. Anthropometric Data)**

(f) Squeegee handle data: Each handle was measured for the following physical characteristics: Length, handle height (including blade), exposed blade height, handle diameter, composition and weight. **(Table 4. Squeegee Handle Data)**

Procedure

Nine squeegee handles were used by the participants **(Figures 1. through 9.)**, for a duration of five minutes per handle, at a rate of one pull/push or squeegee stroke every five seconds. A recovery interval of three minutes was given between each handle usage. At each three-minute recovery interval, all subjects completed a written evaluation on the last handle used.

Merits & Weaknesses

The following observations are based on physical examination of the squeegee handles and video analysis of handles in use by 10 professional screen printers. The following **physical properties** (weight, size, shape, texture, temperature conductivity, sharp edges and corners) and **motor response** (grasping) were used as criteria for the evaluation of each handle.

	MERITS	WEAKNESSES
HANDLE *W*		* The hard wooden handle is slippery in texture. * Handle only makes contact with the palm, tips of digits two through five and digit one (thumb). * Wrist flexion occurs throughout and is greatest at the completion of the stroke. * Subject 3, who used the technique of pushing, demonstrated greater wrist deviation than subjects who pulled. * Subject 9's fingers (largest hand length of all participants) extended beyond the base of the handle.
HANDLE *N*	* The crown of the handle made full contact with the palm and first phalanx of digits two through five.	* Heaviest of all handles (2 lb. 15 oz./ 6.48 kg). * Aluminum alloy is temperature conductive. * The frontal curvature of the handle precludes the ability of the subjects to make full contact with the fingers (second & third phalanx). * Subject 9's fingers (largest hand length of all participants) made contact with blade attachment. * Wrist flexion occurs throughout and is most extreme at the beginning of the stroke. * The aluminum alloy is hard & slippery in texture.

HANDLE *Q*	* The foam padding provides a good gripping surface. * Even contact distribution throughout the hand and fingers.	* The task of pushing or pulling resulted in the blade skipping from the mesh surface. * Wrist flexion occurs throughout stroke. *Note:* **80 percent of the participants did not use this handle at the angle for which it was designed.**
HANDLE *S*	* Light weight (1 lb. 3 oz./2.62 kg).	* PVC plastic is hard & slippery in texture. * The corrugated shape of the front & back prohibits contact of the first and second phalanges of digits two through five and first phalanx of digit one (thumb) when used with a straight finger grasp. * Wrist flexion occurs throughout stroke with greatest deviation occurring while picking the squeegee up from the back of the screen.
HANDLE *O*	* Light weight (1 lb. 8 oz./3.31 kg). * The handle shape made full contact with the fingers.	* Aluminum is temperature conductive. * The aluminum is hard & slippery in texture. * Wrist flexion occurs throughout stroke.
HANDLE *F*	* Light weight (1 lb. 2 oz./2.48 kg). * The crown of the handle made full contact with the palm.	* Molded plastic is hard & slippery in texture. * Seam from mold may tend to abrade the skin. * The contour of the handle resulted in various grasps, causing an uneven contact distribution throughout the fingers. * Wrist flexion occurs throughout stroke.
HANDLE *H*	* The rubber padding provides a good gripping surface. * Ridges located at the base of rubber padding provide a good gripping surface for the fingers.	* The crown of the rubber padding resulted in uneven contact distribution for Subject 1, who had the smallest hand length. (6.9 in/17.5 cm). * Wrist flexion occurs throughout stroke. * Rubber padding did not run the full hand breadth.

HANDLE *U*	* The rubber padding provides a good gripping surface. * Ridges located at the base of rubber padding provides a good gripping surface for the thumb. * The crown of the rubber padding made full contact with the subject's palm and first phalanx of all fingers.	* Wrist flexion occurs throughout and is more extreme at the beginning of the stroke. * Rubber padding did not run the full hand breadth.
HANDLE *G*		* Wrist flexion occurs throughout stroke. * The hard wooden surface is slippery in texture. * Subject 9's fingers (largest hand length of all participants) had uneven contact distribution throughout the second and fifth digits.

Note: * Upon completion of the stroke (pull), many printers pushed the ink to the front of the screen resulting in extreme wrist extension.

Design Considerations

Factors such as material composition, physical shape, forces which must be applied in order to use it, surface compressibility, texture and weight affect the design of squeegee handles. The following design considerations are necessary to enhance usability and safety.

Material Composition

Handle material should be nonconductive to temperature and electricity, thus wood and rubber are better than plastic and metal. Wood is good for two reasons: (1) Wood releases heat to the hand more slowly than plastic or metal; (2) wood gains heat more slowly than plastic or metal.

Materials which are conductive to a cooling environment, combined with prolonged exposure of the user to mild localized cooling, significantly impairs the ability to sense small external forces along with an initial reduction in blood flow.

Surface Compressibility

Rubber and compressible plastic are the better than hard plastic or metal.

Compressible materials reduce slipping of the grip. A compressible grip with a high coefficient of friction is good. Resistance to absorption of sweat, oil, and similar materials is a desirable feature.

Texture

The surface texture of a product affects the ease with which it may be held, and its potential for causing injury to the skin. A highly polished or very smooth surface may be slippery in the user's hands especially if they are moist from sweat, thus requiring extra force to hold in the hand. On the other hand, rough grasping surfaces should not be so rough that they are abrasive resulting in discomfort and pressure points in the hand.

Weight

Grasping and control abilities are affected by the weight of a hand tool. The greater the weight, particularly when combined with repetitive motions, the greater the resultant fatigue in the hands and forearms. However, a very light squeegee handle may create the need to apply increased pressure to the screen. A balance must be struck between weight and controllability. The squeegee handle should be designed as light as feasible, while maintaining controllability.

Physical Shape

The shape must promote grip strength. The center of the palm is poorly designed to withstand direct force application. This anatomical limitation is caused by the proximity of the median nerve, arteries and synovium for the flexor finger tendons which lie directly under the skin of the palm.

The product's shape directly affects a person's ability to firmly grasp it. The position of the wrist is influenced by the product's shape, which affects gripping capabilities of the fingers. This is especially true when the wrist is flexed. It is important for the shape to allow the wrist to maintain a neutral orientation.

Forces

Configuration of the squeegee handle should be sufficient to distribute the forces across digits two through five to minimize stress concentration and maximize forces of the user while working at a lower percentage of his or her strength.

Task Analysis.

An ergonomic task analysis is an objective and systematic evaluation of the work environment documenting the job demands and task requirements of essential functions. However, for the purpose of this evaluation, the following task analysis data was observed, measured and recorded as requested by the principal investigator:

(1) What is the percentage time using the squeegee?
A. Participants spent an average of 10 percent of their time using the squeegee handle.

(2) What is the percentage of time performing other sub-tasks (e.g., loading, re-inking, etc.), as well as identification of these tasks?
A. The remaining 90 percent is spent applying ink to the screen, spraying garment adhesive to the platen surface, retrieving the unprinted garment, loading the garment onto the platen, removing the garment from the platen surface and placing the garment onto the dryer conveyor belt.

(3) What is the range of heights for work surfaces?
A. Work surface heights ranged from 37 1/8 inches (94.3 cm) to 38 1/4 inches (97.6 cm).

(4) What is the area printed?
A. Areas squeegeed: (a) 20 inches (50.8 cm) by 14 inches (35.6 cm)
(b) 12 5/8 inches (32.1 cm) by 15 inches (38.1 cm)

(5) What is the horizontal reach distance while printing?
A. The range of horizontal reach distance was 26 inches (66.0 cm) by 27 1/8 inches (68.9 cm).

(6) What are the mean wrist postures while using squeegees?
A. The mean wrist postures while printing: Flexion 20 degrees; extension 45 degrees; radial deviation 5 degrees.

(7) What factors affect posture?
A. The factors that affect posture are: Standing surface to platen level and shoulder level to platen level.

Participants

Video analysis of four subjects performing their regular screen printing tasks.

Task

Manual screen printing follows a series of tasks:

(1) Apply ink to screen.

(2) Spray garment adhesive on platen surface.

(3) Retrieve the unprinted garment.

(4) Load garment onto platen.

(5) Squeegee stencil onto garment surface by pushing or pulling squeegee handle.

(6) Remove garment from platen surface.

(7) Place garment onto dryer conveyor belt.

These seven task steps are for one-color screen printing. If applying more than one color or coat to a garment, step 5 is repeated

Observations

The following risk factors were observed in the screen printing process:

(1) Forceful exertions of the hands, wrists, arms and shoulders.

(2) High repetition

(3) Bending at the waist

(4) Reaching

(5) Twisting at the trunk

(6) Standing on hard surfaces for prolonged periods of time.

(7) Some printers were observed scooping ink onto the blade after each stroke, resulting in more frequent wrist flexion.

Discussion

Findings indicate that handle design is not the only factor which may contribute to injuries involving the hand/wrist. Factors that affect the productivity and health of the screen printer included: Static loading of arm and shoulder muscles, awkward hand position, pressure on the palm and fingers.

Platens that are too high place the shoulders, arms and wrists at risk. Platen surfaces which are too low result in stress to the lower back. Experimentation should be done with the platen angle to research its influence on wrist deviation and upper torso posture.

Incorporating in the handle an adjustable mechanism allowing for changes in the blade height and the angle of the blade would allow for less force requirements along with promoting a more neutral posture at the wrist. To accommodate worker population hand sizes, retrofitting the handle with varying sizes of padding would allow you to meet the premise of one-size-handle-fits-all.

Acknowledgments

At this time, we would like to thank the owners of First Impressions, Steve Hulsey and Jim Tennapel, for generously allowing us to use their facilities; Michael Gannon of Survival Lines for allowing us to perform video analysis of the screen printing process; and a special thanks to Jay McCune for his time, patience and feedback, Cathy Coulson for her never-ending perseverance and enthusiasm and to both our families and friends whose understanding and patience helped us maintain our perspective and sense of humor.

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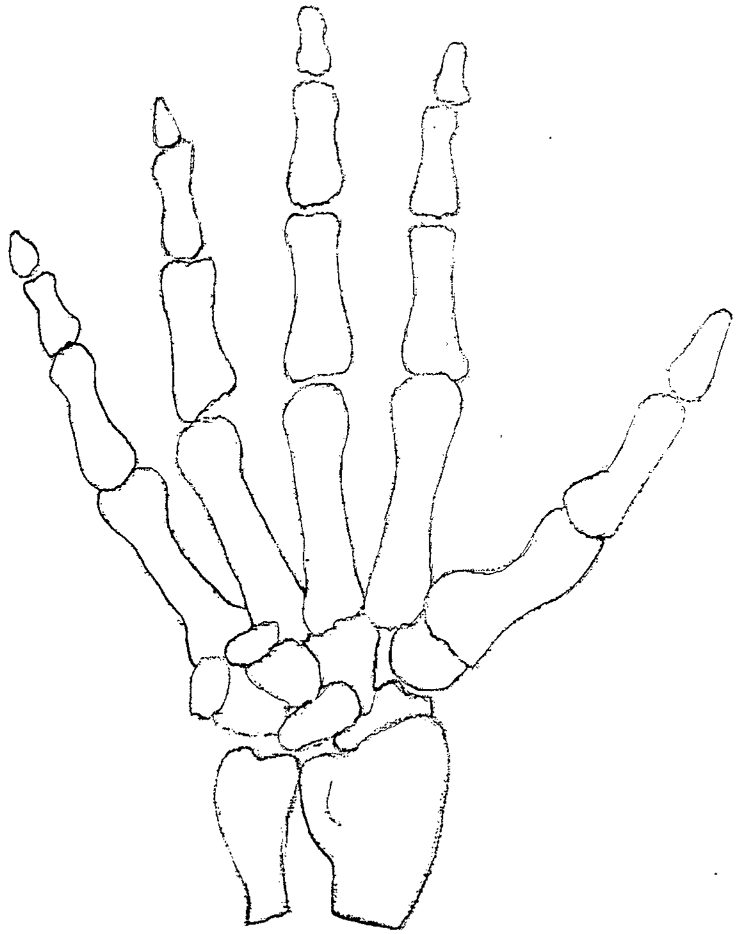
APPENDIX C

Ergonomic FAXBAK Survey
of Commercial Screen Printers

Pages 77-90

Manual Screen Printers Ergonomic



FAXBAK Survey Report

Report:	**Manual Screen Printers Ergonomic FaxBak Survey**
Report Date:	**1 April, 1996**
From:	**Patrick Schaeffer**

Summary:

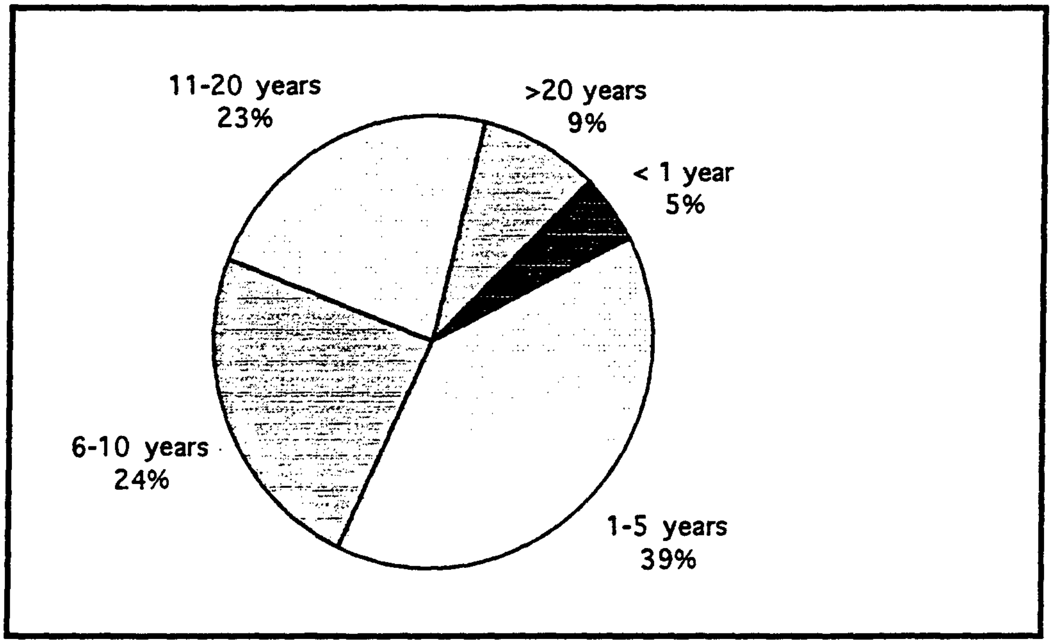
This is a summary of the Manual Screen Printers Ergonomic FaxBak Survey results. The survey sample came from a U.S. nation-wide population of professional screen printers. Eighty responses were received, tabulated, and analyzed for significant observations and trends.

Conclusions:

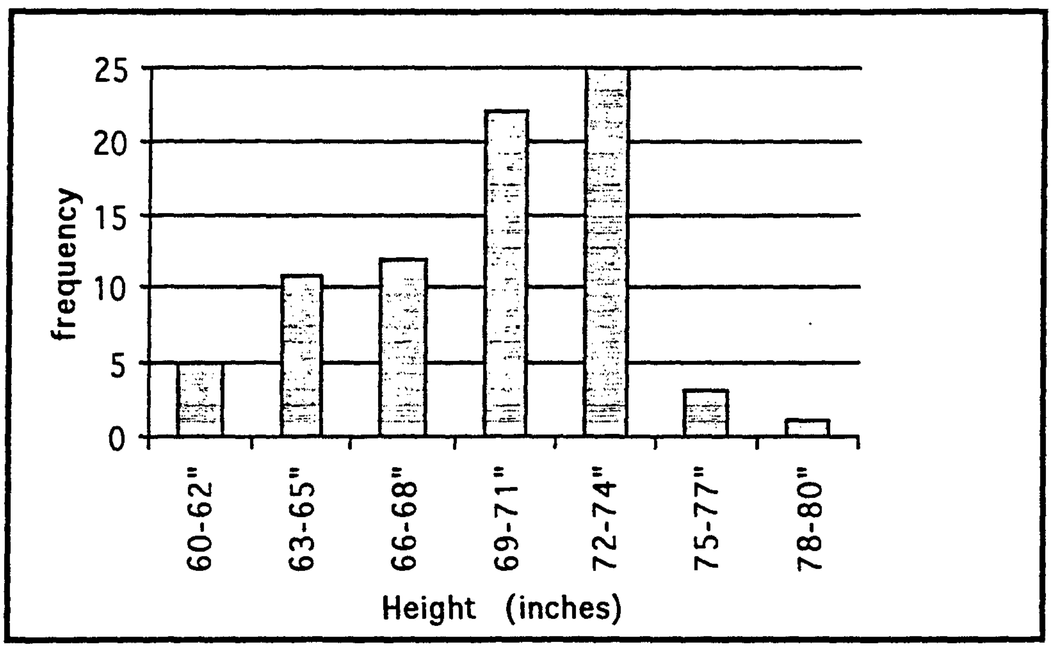
Details for the survey analysis can be found within the body of this report. From the survey results, the following observations and conclusion can be inferred:

- Greater than half (approximately 56%) of the survey participants have been screen printing manually for longer than 5 years.
- Approximately 75% of the manual screen printer professionals are male.
- The average age of those surveyed is 36 years.
- The average height of those surveyed is 5 feet 9.5 inches (69.5 inches).
- Greater than two thirds (69%) of the respondents engage in 20 or more hours per week of manual screen printing.
- 50% of all those surveyed indicated some level of fatigue, pain, or adverse symptom in the arms, wrists, or hands. Of those, 40% categorized this as "severe".
- Greater than half (55%) of the respondents indicated they had changed the way they perform their tasks as a result of pain and/or fatigue.
- Greater than half (53%) of the respondents indicated they had screen printed with a padded handle.
- Of those that had used a padded handle during screen printing, 60% indicated a marked decrease in hand fatigue, and 55% indicated a marked decrease in hand pain.
- There is evidence to infer significant correlation ($r \geq 0.80$, $r \leq -0.80$) between wrist pain and wrist fatigue.
- There is evidence to infer significant correlation ($r \geq 0.80$, $r \leq -0.80$) between hand numbness and hand tingling.
- There is evidence to infer significant correlation ($r \geq 0.80$, $r \leq -0.80$) between wrist and hand fatigue, pain, and numbness/tingling.
- Increased or decreased arm fatigue is a poorer indicator of wrist and hand wellness ($0.75 \leq r \leq 0.87$).
- There appears to be no significant correlation between fatigue/pain and the number of years screen printing, height, age, or the number of hours per week screen printing.

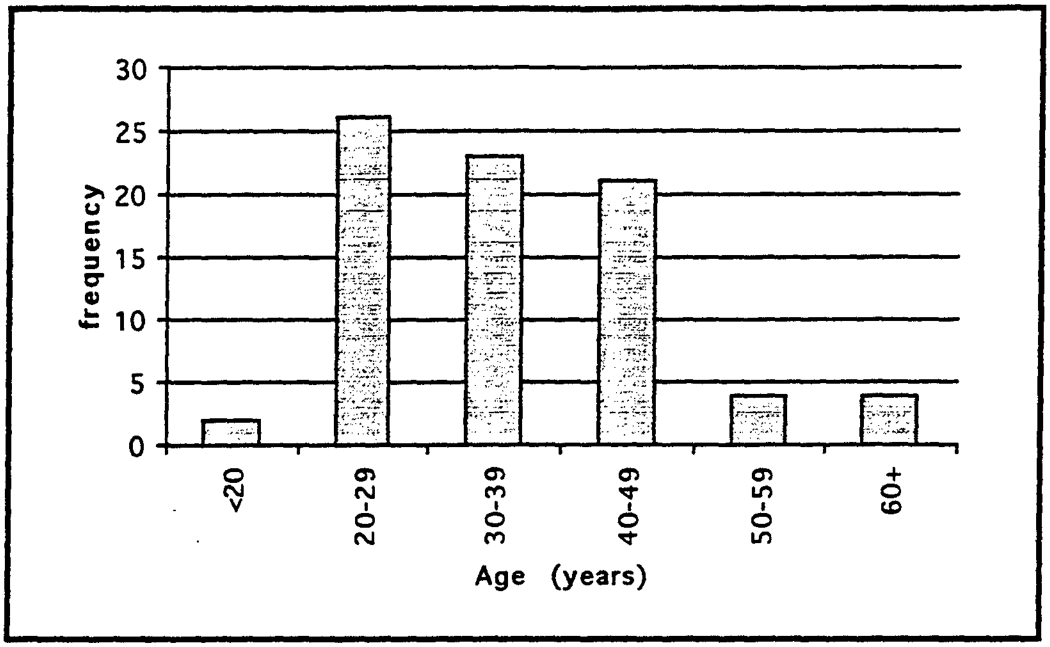
1. ***For how many years have you screen printed manually?*** Eighty survey participant responses are distributed as show below:



2. ***What is your height?*** Survey participant heights are distributed as shown below:



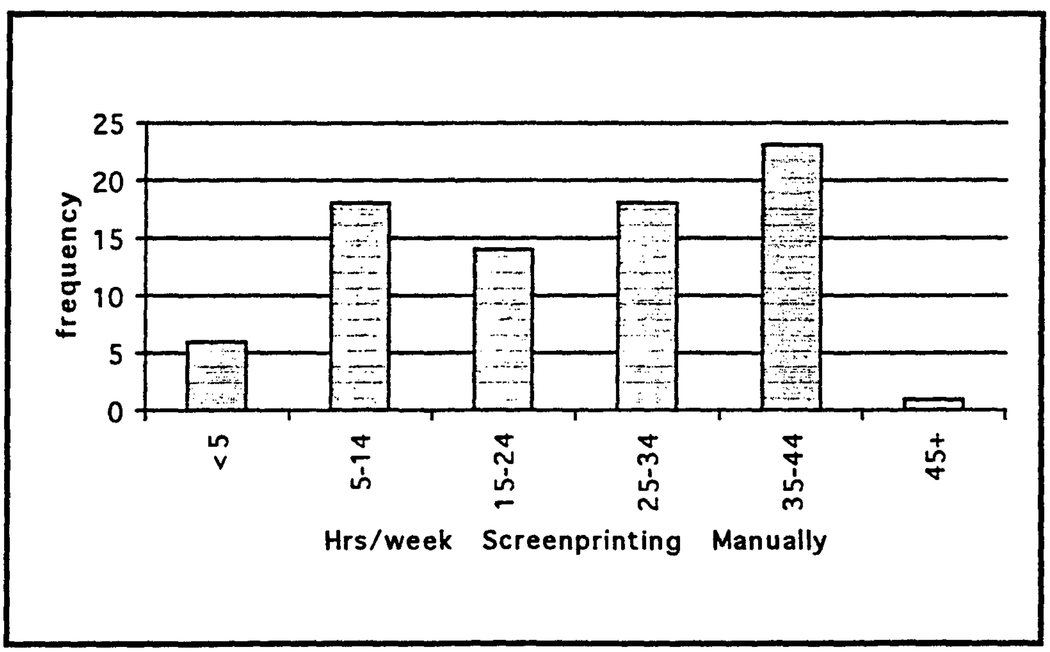
3. ***What is your age?*** Survey participant ages are distributed as follows:



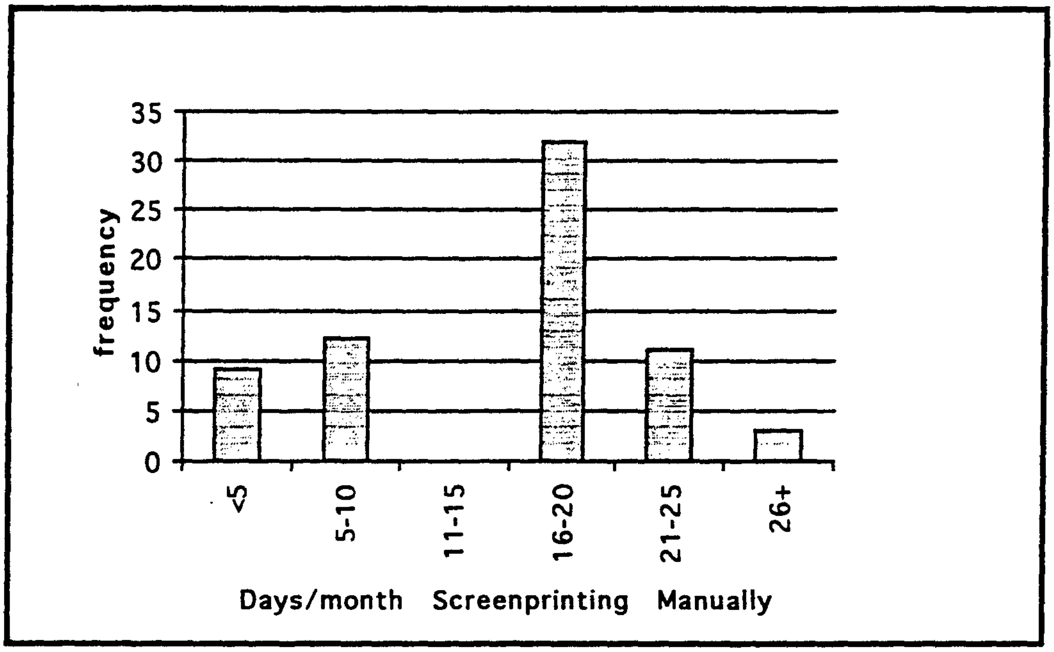
4. ***What is your gender?*** Of the eighty survey responses, male/female breakdown is as follows:

Male = 77.5%	**Female = 22.5%**

5. ***What is the average number of hours per week that you spend screen printing manually?*** Hourly breakdowns for survey participants are as follows:

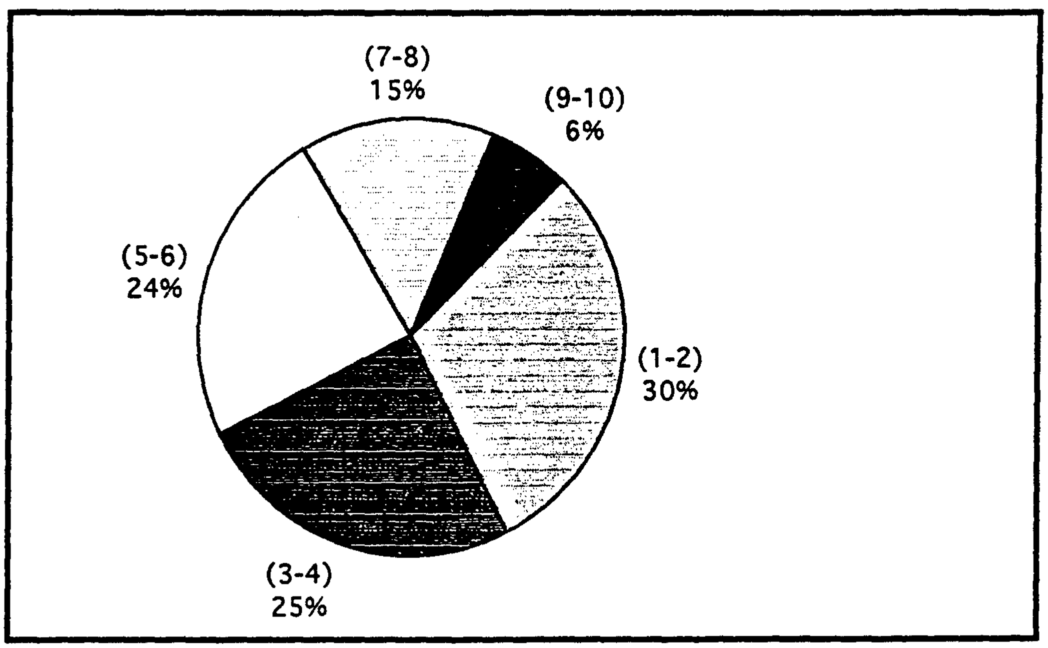


6. ***How many days per month do you screen print manually?*** Survey participant response distribution is shown below:

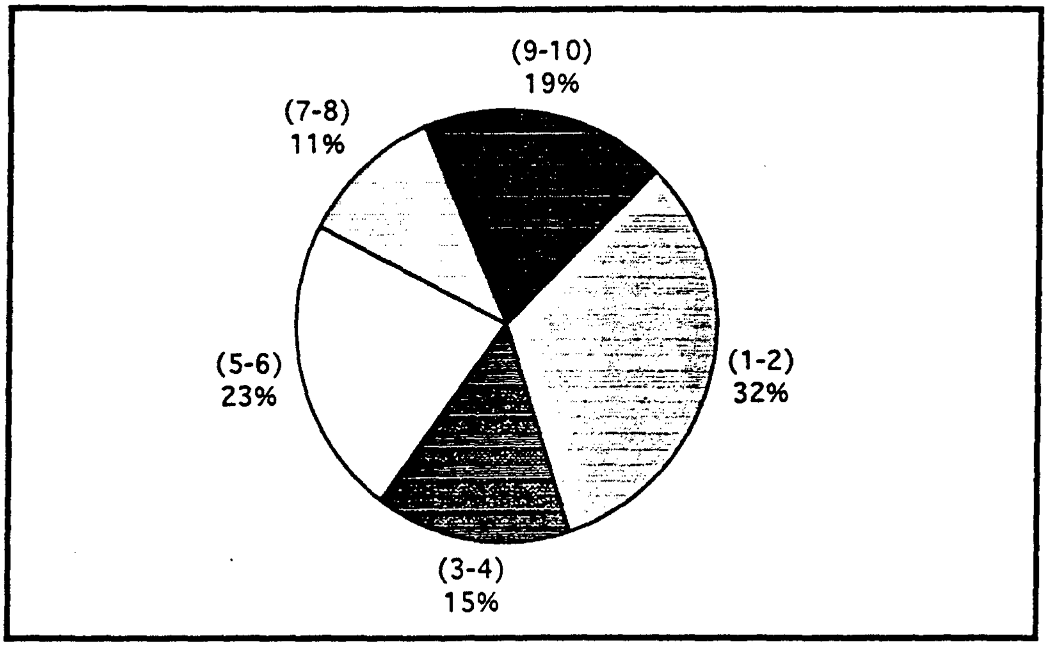


7. Survey participants rated the degree of severity for the following problems:

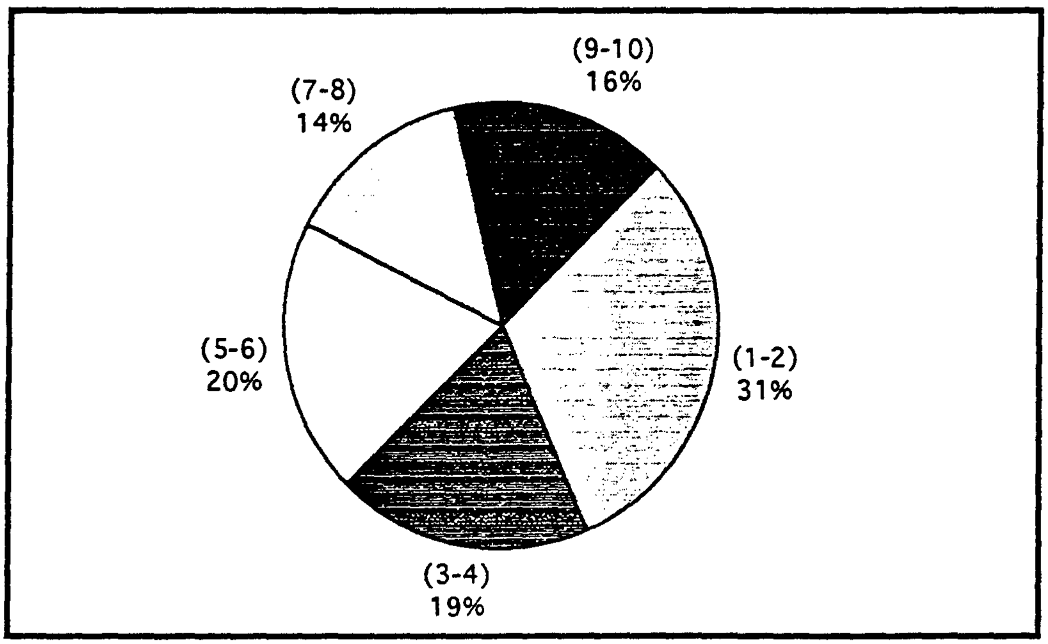
7a. Fatigue in arms (1 = none, 10 = severe):



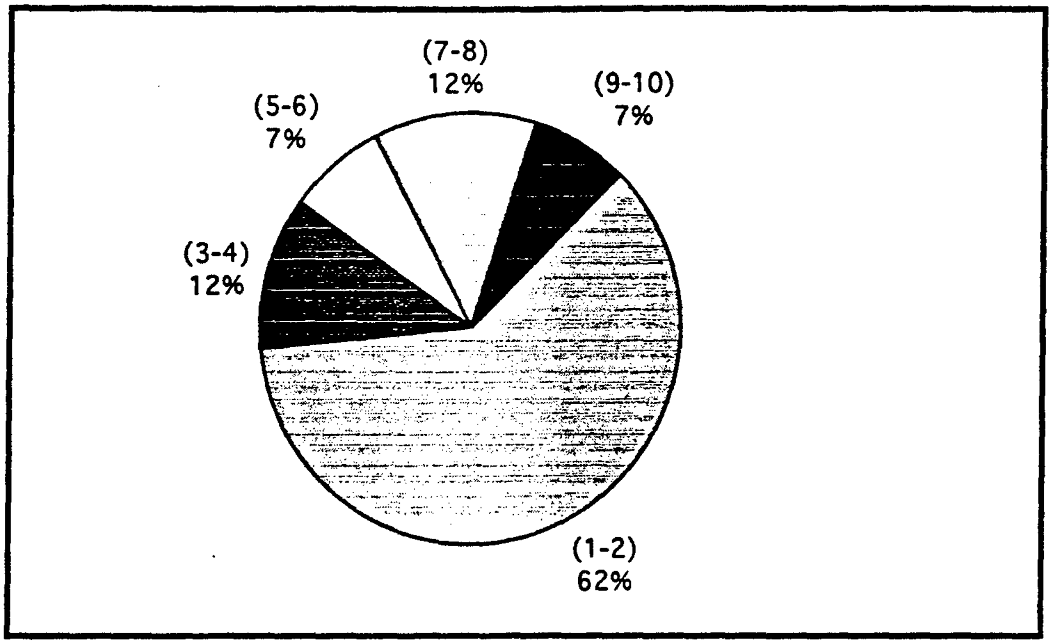
7b. Fatigue in Wrists (1 = none, 10 = severe):



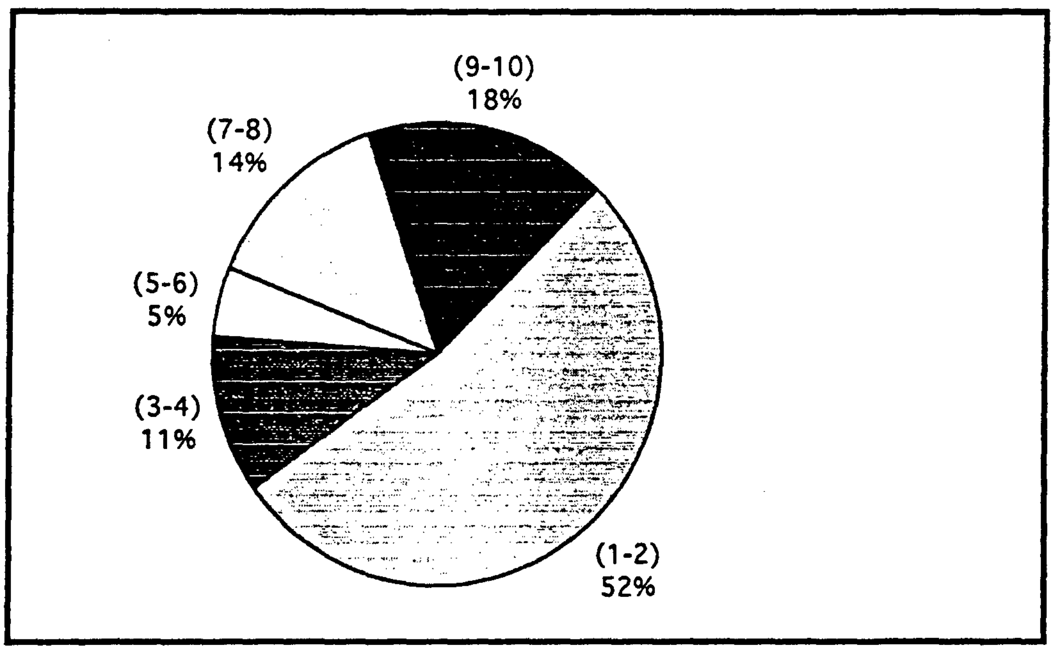
7c. Fatigue in Hands (1 = none, 10 = severe):



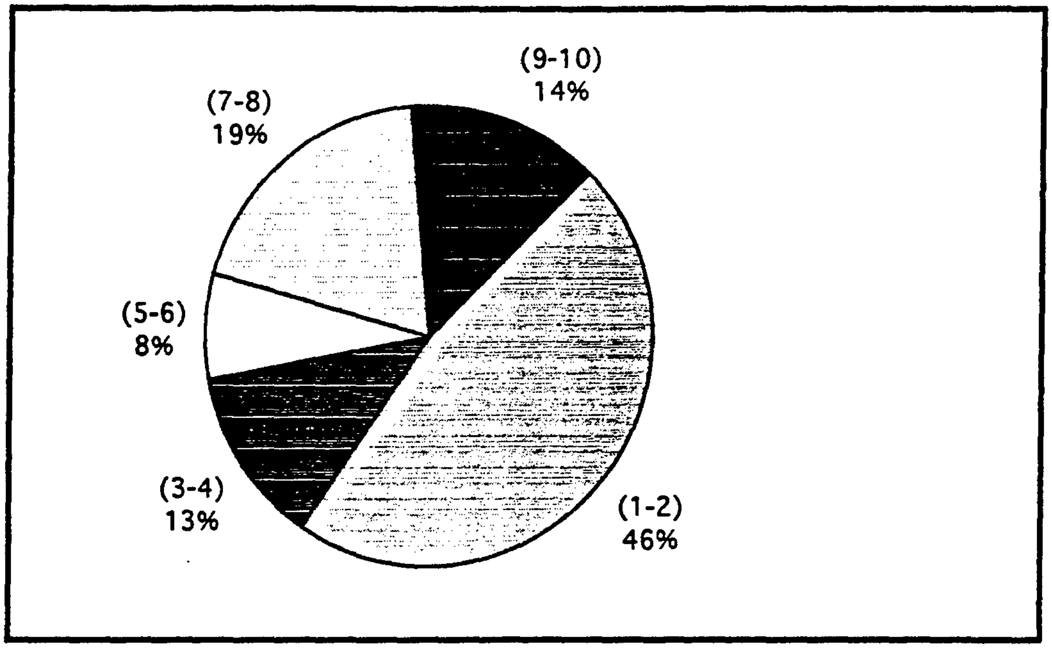
7d. Pain in Arms (1 = none, 10 = severe):



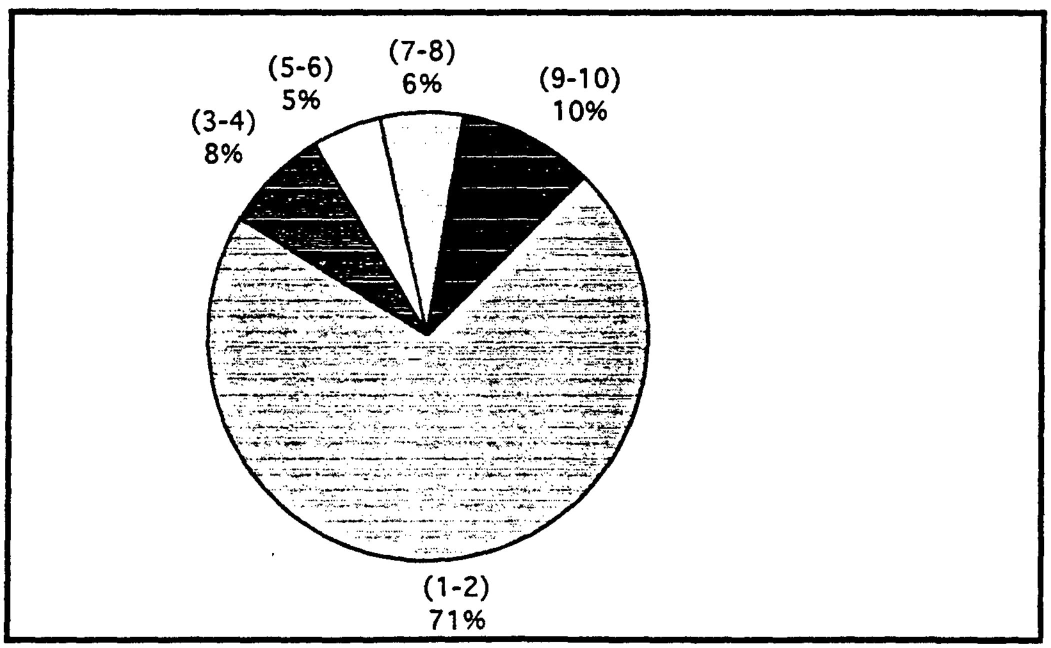
7e. Pain in Wrists (1 = none, 10 = severe):



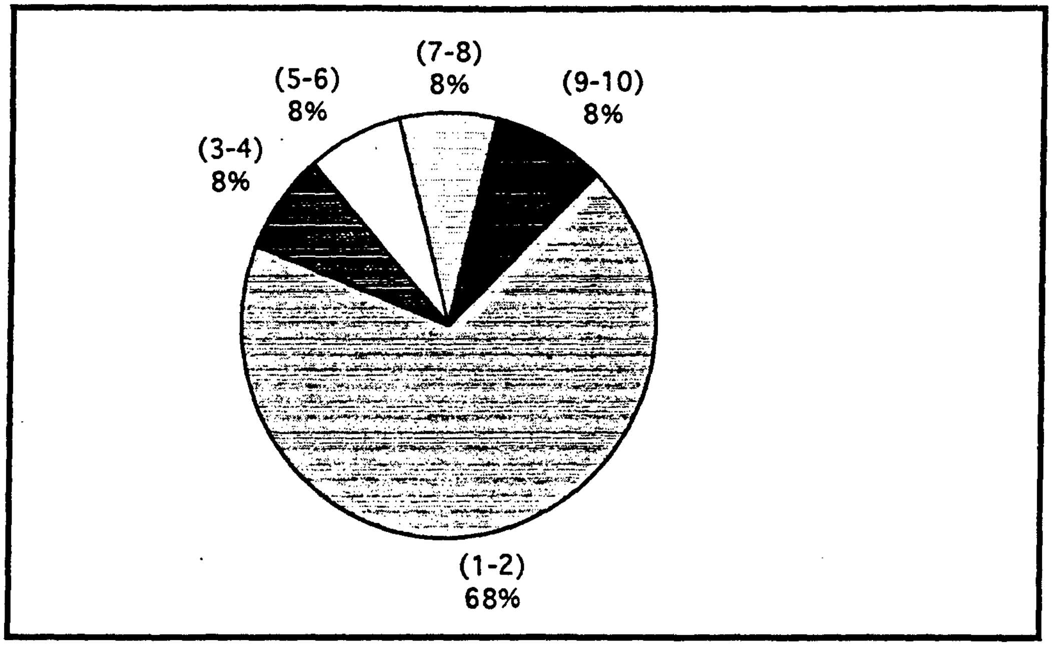
7.f Pain in Hands (1 = none, 10 = severe):



7g. Numbness in Hands (1 = none, 10 = severe):



7h. Tingling in Hands (1 = none, 10 = severe):



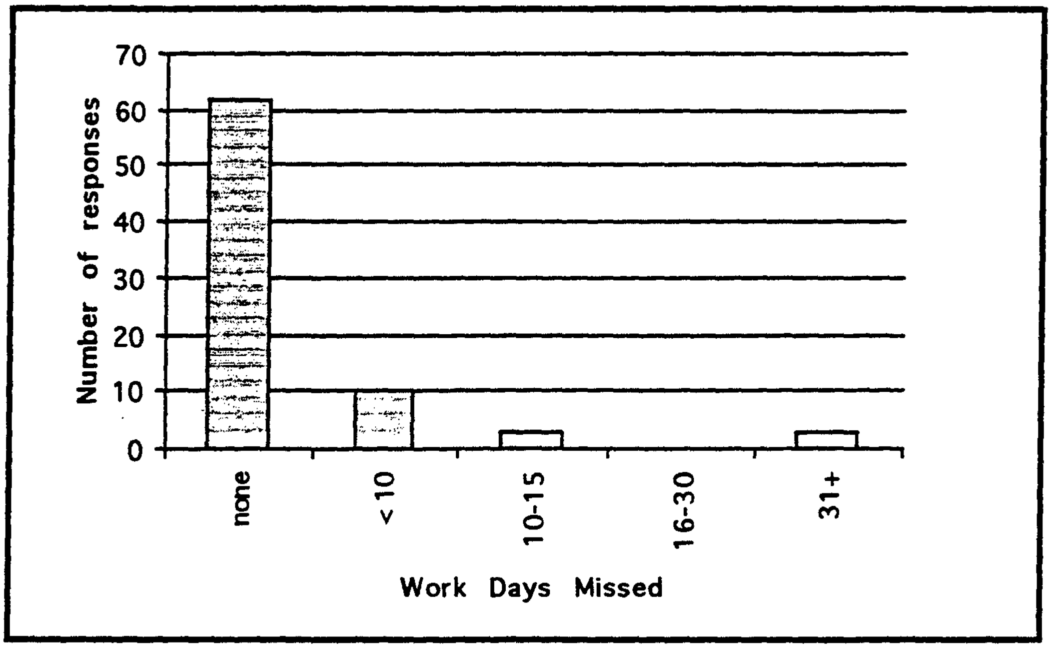
8. ***Have you changed the way you perform the tasks of screen printing as a result of fatigue, pain, numbness and/or tingling in the hand, wrist, or arms?*** Eighty survey participants responded as follows:

YES = 55% **NO = 45%**

9. ***During the past ten years have you ever been unable to work due to job-related fatigue, pain numbness and/or tingling in the hand, wrist, arm(s)?*** Eighty survey participants responded as follows:

YES = 20% **NO = 80%**

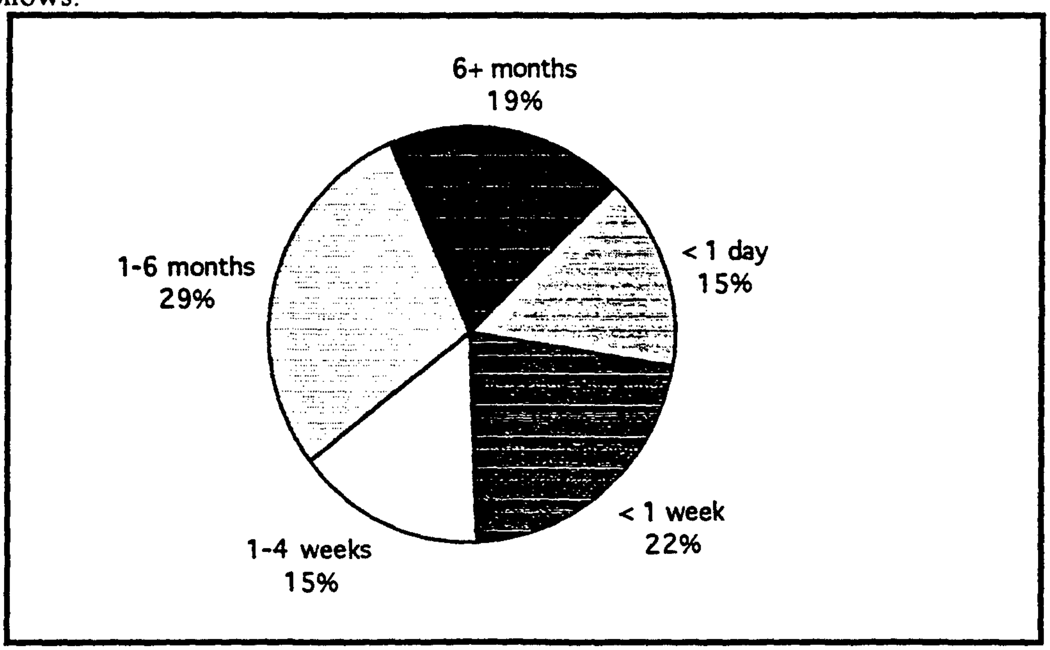
10. If "yes" in question 9, approximately how many days of work have you missed during the past ten years due to job-related fatigue, pain, numbness, and/or tingling in the hand, wrist, or arm(s)? Survey participants responded as follows:



11. Have you screen printed manually with a padded handle? Survey participants responded as follows:

YES = 53% NO = 47%

11a. If yes, for how long have you used a padded handle? Survey participants responded as follows:



11b. If yes, what is the effect of the padded handle in the following categories? Of the 42 survey participants using padded handles, responses on the effects were as follows:

	Decreased	No Change	Increased
1. Fatigue in Arms	38%	44%	18%
2. Fatigue in Wrists	47%	47%	6%
3. Fatigue in Hands	60%	32%	8%
4. Pain in Arms	27%	63%	10%
5. Pain in Wrists	36%	58%	6%
6. Pain in Hands	55%	39%	6%
7. Numbness in Hands	41%	55%	4%
8. Tingling in Hands	39%	51%	10%

	1	2	3	4	5	6	7a	7b	7c	7d	7e	7f	7g	7h	8	9	10	11	11a	11b-1	11b-2	11b-3	11b-4	11b-5	11b-6	11b-7	11b-8
1	1.00																										
2	0.05	1.00																									
3	0.58	-0.08	1.00																								
4	-0.06	-0.56	0.09	1.00																							
5	-0.13	-0.17	-0.14	0.13	1.00																						
6	-0.03	0.06	-0.11	0.02	0.61	1.00																					
7a	0.01	-0.14	0.06	0.15	0.14	0.14	1.00																				
7b	-0.18	-0.10	-0.14	0.23	0.13	0.14	0.66	1.00																			
7c	-0.09	-0.18	-0.11	0.23	0.24	0.20	0.57	0.69	1.00																		
7d	0.01	-0.09	0.17	0.16	0.11	0.07	0.56	0.49	0.53	1.00																	
7e	-0.07	-0.16	-0.06	0.28	0.16	0.05	0.51	0.80	0.59	0.60	1.00																
7f	-0.02	-0.08	0.00	0.19	0.26	0.15	0.47	0.72	0.69	0.60	0.77	1.00															
7g	-0.01	-0.13	0.14	0.25	0.17	0.00	0.51	0.47	0.43	0.64	0.63	0.60	1.00														
7h	0.00	-0.18	0.18	0.35	0.10	0.03	0.46	0.44	0.40	0.65	0.58	0.56	0.87	1.00													
8	-0.07	0.12	-0.11	-0.11	-0.13	-0.03	-0.25	-0.06	-0.10	-0.19	-0.04	0.05	-0.18	-0.17	1.00												
9	-0.05	0.10	0.06	-0.06	-0.10	-0.22	-0.28	-0.31	-0.30	-0.37	-0.38	-0.34	-0.42	-0.43	-0.07	1.00											
10	-0.02	-0.10	0.07	0.07	0.13	0.09	0.20	0.19	0.18	0.28	0.32	0.28	0.35	0.31	-0.01	-0.39	1.00										
11	0.10	0.06	0.16	0.12	-0.05	0.12	-0.20	-0.31	-0.25	-0.25	-0.29	-0.25	-0.15	-0.12	0.26	-0.01	-0.02	1.00									
11a	-0.06	-0.02	-0.13	-0.21	-0.08	-0.15	0.06	0.26	0.22	0.17	0.25	0.22	0.09	0.06	-0.24	0.02	0.12	-0.73	1.00								
11b-1	-0.15	0.02	-0.15	-0.14	0.03	-0.01	0.33	0.31	0.17	0.16	0.27	0.16	0.19	0.09	-0.18	-0.12	0.07	-0.61	0.58	1.00							
11b-2	-0.20	-0.01	-0.24	-0.13	0.03	-0.06	0.23	0.34	0.21	0.13	0.30	0.15	0.13	0.09	-0.18	-0.13	0.08	-0.65	0.63	0.87	1.00						
11b-3	-0.13	-0.11	-0.23	-0.08	-0.03	-0.11	0.20	0.30	0.16	0.11	0.32	0.14	0.11	0.08	-0.15	-0.15	0.09	-0.64	0.60	0.83	0.92	1.00					
11b-4	-0.12	0.01	-0.18	-0.14	0.10	-0.01	0.18	0.30	0.16	0.21	0.36	0.25	0.20	0.11	-0.16	-0.16	0.17	-0.58	0.55	0.82	0.87	0.82	1.00				
11b-5	-0.21	-0.07	-0.22	-0.10	0.10	0.00	0.16	0.31	0.17	0.14	0.38	0.17	0.14	0.09	-0.17	-0.16	0.18	-0.59	0.52	0.79	0.92	0.86	0.90	1.00			
11b-6	-0.19	-0.08	-0.27	-0.08	0.05	-0.04	0.13	0.29	0.14	0.15	0.31	0.23	0.12	0.08	-0.15	-0.16	0.19	-0.60	0.54	0.75	0.88	0.87	0.89	0.91	1.00		
11b-7	-0.17	-0.06	-0.22	-0.09	0.12	-0.03	0.12	0.23	0.11	0.13	0.30	0.18	0.15	0.05	-0.13	-0.15	0.20	-0.56	0.50	0.78	0.81	0.80	0.92	0.88	0.89	1.00	
11b-8	-0.21	-0.08	-0.24	-0.06	0.13	-0.02	0.10	0.23	0.11	0.11	0.30	0.17	0.13	0.08	-0.13	-0.15	0.20	-0.56	0.48	0.77	0.83	0.82	0.91	0.89	0.90	0.98	1.00

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FAXBAK SURVEY BEST AVAILABLE COP

:ional Institute of Health (NIH) has funded a study ıual squeegee handles and their possible ıship to the development of carpal tunnel me (CTS). Your time and effort in filling out and ıg this survey will contribute to an increased tanding of our profession.

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how many years have you screen printed manually?
under 1 year ☐ 11-20 years
1-5 years ☐ more than 20 years
6-10 years

at is your height?
_ feet ______inches

at is your age in years? ____

at is your gender?
Male ☐ Female

at is the average number of hours per week that you nd screenprinting manually?
__________ hours

v many days per month do you screen print manually?
__________ days

e you ever experienced the following? If so, please mark the ropriate box and rate the degree of severity for that symptom.

	None 1									Severe 10
Fatigue in arm(s)	•	•	•	•	•	•	•	•	•	•
Fatigue in wrist(s)	•	•	•	•	•	•	•	•	•	•
Fatigue in hand(s)	•	•	•	•	•	•	•	•	•	•
Pain in arm(s)	•	•	•	•	•	•	•	•	•	•
Pain in wrist(s)	•	•	•	•	•	•	•	•	•	•
Pain in hand(s)	•	•	•	•	•	•	•	•	•	•
Numbness in hand(s)	•	•	•	•	•	•	•	•	•	•
Tingling in hand(s)	•	•	•	•	•	•	•	•	•	•

/e you changed the way you perform the tasks of screen ıting as a result of fatigue, pain, numbness and/or tingling ıe hand, wrist or arm(s)?
yes ☐ no

ing the past ten years have you ever been unable to work : to job-related fatigue,pain, numbness and/or tingling in hand, wrist or arm(s)?
yes ☐ no

ɔu answered yes to the previous question, approximately v many days of work have you missed during the past ten rs due to job-related fatigue, pain, numbness, and/or gling in the hand, wrist or arm(s).
__________ days

11. Have you screen printed manually with a padded handle?
☐ yes ☐ no

a. If yes, for how long have you used a padded handle?
☐ less than one day
☐ more than a day but less than a week
☐ more than a week but less than a month
☐ 1-6 months
☐ 6 months or more

b. If yes, what is the effect of the padded handle in the following categories?

Fatigue in arm(s)
☐ Decreased ☐ No Change ☐ Increased

Fatigue in wrist(s)
☐ Decreased ☐ No Change ☐ Increased

Fatigue in hand(s)
☐ Decreased ☐ No Change ☐ Increased

Pain in arm(s)
☐ Decreased ☐ No Change ☐ Increased

Pain in wrist(s)
☐ Decreased ☐ No Change ☐ Increased

Pain in hand(s)
☐ Decreased ☐ No Change ☐ Increased

Numbness in hand(s)
☐ Decreased ☐ No Change ☐ Increased

Tingling in hand(s)
☐ Decreased ☐ No Change ☐ Increased

Thank you for taking time to help in this study. On March 31, 1996 all returned surveys will be entered into a drawing for a Union Mixopake Mixing System Kit which enables textile printers to match all 1000 C colors of the Pantone Color Guide. The kit is a contribution courtesy of Full Line Distributors and Union Ink Company.

Please fax the completed survey to William Musser, Principal Investigator for NIH Grant No. IR430H03357-01, at (541) 484-5828 or mail to P.O. Box 5556, Eugene, Oregon 97405.

Name ______________________________
Company Name ______________________________
Address ______________________________
City ______________________________
State ______________________ Zip ____________
Telephone (   ) ____________________
Fax (   ) ____________________

ou may copy this for each printer in your shop. Your time is appreciated.