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NIOSH INVESTIGATORS
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SUMMARY

In July 1993, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation from the Maine Department of Human Services. NIOSH was asked to investigate musculoskeletal conditions of the upper extremities, in particular "rakers' tendinitis," which was reported among harvesters who raked wild blueberries in Maine.

Annually thousands of seasonal workers rake wild blueberries in various parts of Maine, mostly in the month of August. A field survey consisting of a symptom questionnaire, limited physical examinations, and ergonomic assessment of raking, was conducted at C & D Corporation, a blueberry grower/processor in Deblois, Maine.

A convenience sample of 134 rakers was recruited on-site over a 3-day period in August. Their median age was 30 (range: 13 to 69); 73% of participants were males and 27% females; 10% of the participants were children (age 12 to 18). Participants reported moderate to severe pain, which was felt after the start of raking in the back (14%), in the hand/wrist (12%), and in the elbow (8%). On physical examinations, 10% had some hand/wrist pain accompanied by a positive Phalen's or Tinel's test (suggesting carpal tunnel syndrome), or a positive Finkelstein's test (suggesting de Quervain's disease, a tenosynovitis of the abductor pollicis longus and the extensor pollicis brevis).

Ergonomic analysis of raking revealed that rakers worked mostly in stooped posture and frequently carried loaded buckets (up to 13 kg each). The metal rakes varied in size (35 to 60 cm wide) and weight (1.2 to 2.1 kg). The typical raking motion involved constant firm grip on the handle, and repetitive ulnar (toward the little finger) and radial (toward the thumb) deviations of the wrist. The force of lifting the rake was estimated to be 87 newtons (S.D. $\pm$ 17.5), and the motion was repeated 32 times/min (S.D. $\pm$ 13). These repetitive and forceful motions could cause friction on the tenosynovium and explain a high prevalence of tendinitis.

On the basis of these evaluations, NIOSH investigators determined that potential musculoskeletal hazards, resulting in cumulative trauma disorders (CTDs) existed at C & D Corporation, Deblois, Maine. Recommendations to reduce such hazards are included in this report.

KEYWORDS: SIC 0171 (berry crops, blueberry farms), blueberry rakers, back pain, carpal tunnel syndrome (CTS), cumulative trauma disorders (CTDs), de Quervain's disease, ergonomics, repetitive strain injuries (RSI), tendinitis, tenosynovitis.

INTRODUCTION

In July 1993, NIOSH received a request from the Maine Department of Human Services to investigate "rakers' tendinitis" which was reported among seasonal harvesters who raked wild blueberries in Maine. Such cases were initially reported from Rakers' Mobile Clinic to Maine's Occupational Health Nurses in Agricultural Communities [OHNAC], a program established by a cooperative agreement with NIOSH. A field survey consisting of a symptom questionnaire, limited physical examinations, and ergonomic assessment of raking, was conducted in August 1993 at C & D Corporation, a blueberry grower/processor in Deblois, Maine.

Low growing shrubs of wild blueberry grow naturally in the fields and hills of Maine and the eastern provinces of Canada. Annually, in Maine, approximately 30,000 acres of blueberry fields are commercially tended[1] and the berries are harvested by thousands of seasonal workers, usually from late July through early September. The collected blueberries are washed and then frozen or canned at local factories and shipped to domestic and overseas food processors. Only a small fraction of the wild crop is sold fresh.

In 1993, about 310 million pounds of blueberries were harvested in North America, of which 58 percent was the cultivated crop (in states such as Michigan, New Jersey and Oregon). The remaining 42 percent was the wild crop from Maine and the eastern provinces of Canada, in about equal amount (21%, about 64.5 million pounds each).[1] This yield was said to be a significant increase from the past years and attributed to increased use of irrigation, fertilizers, and herbicides.[2]

In contrast to cultivated blueberries which may be hand picked, wild blueberries, which are smaller and firmer, are harvested by the raking method.[3] Workers comb through the low-lying bush (height <10 inches) with a hand-held metal rake to scoop up the berries, lift the rake, and tilt it to pour the berries into the container. This action is repeated many times an hour during the work period, which may last up to 8 or more hours a day. Although the harvesting has been partly mechanized in flat land areas, manual raking is still very common in uneven terrains.

At this company, a total of about 1,300 rakers were hired in the 1993 harvest. Rakers were assigned to one of 14 "crews" consisting of 50 to 60 individuals, but they were allowed to sign up and sign out at their will, resulting in a very high turnover rate. Therefore, rakers are not really employees of C & D Corporation but considered to be independent contractors.

This survey was conducted for the purpose of obtaining general information on the workers' raking methods and other work practices, and rakers' musculoskeletal problems. An interim report was published as a letter to the editor of a medical journal in 1994.[4]

BACKGROUND

Cumulative trauma disorders (CTDs) of the musculoskeletal system occur in workers whose jobs require repetitive exertion, often of the upper extremities (UE-CTDs).[5,6] CTDs affect the bursa, tendon, tendon sheath (tenosynovium), and sometimes the nerves of the involved area. Such disorders are usually diagnosed as bursitis, tendinitis, synovitis, tenosynovitis, or ganglionic cysts, and secondary nerve entrapment. Sometimes strain and sprain are included in this group, particularly in case of back disorders. When the median nerve is entrapped in the wrist, the resultant symptom complex is called carpal tunnel syndrome (CTS).[7] When the abductor and extensor tendons of the thumb become inflamed at the wrist, the condition is called de Quervain's disease.[8]

Studies have shown that these disorders are usually precipitated or aggravated by job/tasks which require repetitive exertion, particularly if the tasks necessitate application of force in an awkward motion or posture. The motions and postures associated with UE-CTDs are extension, flexion, and radial and ulnar deviation of the wrist, pinch grip, twisting movements of the wrist and elbow, and shoulder abduction.[5,6] These types of motions and postures are frequently necessitated in many industrial manufacturing and assembly jobs as well as in crop harvesting and other agricultural activities.[9,10,11] Examples of occupations with a high incidence of CTDs are meat processing and packing, electronic assembly, garment manufacturing, fish filleting, and hop picking.

Motion-related but non-work-related risks for CTDs include hobbies and recreational activities, such as knitting, sewing, woodworking, playing tennis, or playing musical instruments. All of these pastimes could impose physical demands on the musculoskeletal system similar to those of the jobs mentioned above.

Some of the most frequently reported CTDs are carpal tunnel syndrome (CTS) and de Quervain's disease. CTS is caused by compression of (the small blood vessels going into and out of) the median nerve inside the carpal tunnel at the wrist.[12] Its symptoms include pain, numbness, tingling, or burning in the hand and fingers along the distribution of the median nerve. Such symptoms often occur during the night (nocturnal) to awaken patients from sleep, and pains also radiate to upper parts of the affected hand/arm. In the advanced stage, wasting of the thenar muscle (at the base of the thumb) may occur to cause weakness in gripping.[7,12]

In work-related CTS, the compression of the median nerve is primarily caused by inflammation of the flexor tendons (which bend the fingers) and tendon sheaths as a result of repeated friction from manual work. When the tissues inside the tight tunnel swell, the median nerve which is softer than the tendons gets squeezed. Therefore, CTS may be associated with non-exertional conditions such as diabetes mellitus, rheumatoid arthritis, or hormonal factors such as pregnancy and use of oral contraceptive pills,[13] which increase the pressure inside the carpal tunnel but not necessarily accompanied by flexor tendinitis, at least initially.

In contrast, de Quervain's disease is caused by inflammation of the tendons which abduct and extend the thumb (the abductor pollicis longus and the extensor pollicis brevis, respectively). Although these tendons are outside of the carpal tunnel and, therefore, do not affect the median nerve, the effect of repetitive motions are similar to CTS in causing tenosynovitis. Inflammation of these tendons and tendon sheaths is caused by manual work which require repetitive stretching and bending of the thumb, and/or radial and ulnar deviations of the hand.[14,15,16] Such motions are commonly involved in job/tasks such as using a knife to cut fruit or meat on board, operating switches, etc. When such motions are made repeatedly, the tendons which glide under the ligamentous band on the back of the hand (called extensor retinaculum) become inflamed, resulting in tenosynovitis. It is felt as pain at the root of the thumb on the back of the wrist.

Several factors are known to be involved with the causation of work-related CTDs. Among these are muscular force needed to do the task, high frequency of motions (short length of task cycles), awkward hand/wrist postures (high degree of being away from the neutral position), and insufficient time for recovery (rest period).[6] One study found that workers performing jobs with force levels of 4 kg or more were several times as likely to develop hand/wrist CTDs as those workers whose jobs required muscular force of 1 kg or less. Job tasks with cycle time lasting 30 seconds or less were found to be associated with an incidence of UE-CTDs three times greater than those jobs where the cycle time was greater than 30 seconds.[17]

Because of the complexity of repetitive motion patterns as well as a wide range of individual differences, currently no standards have been established to indicate the safe or unsafe level of repetitive muscular activities. There are also indications that the above factors (force, repetition, posture, and rest period) are probably interacting, making it difficult to use only one factor as an index for evaluation.[18] In general, however, it can be said that a task which would require larger force, more repetition, and more bending or twisting of a body part would be more hazardous than a task which would require smaller force, fewer repetition, and less bending or twisting.

EVALUATION METHODS

The potential CTD hazard of blueberry raking at C & D Corporation was evaluated by the following methods:

The management had estimated that for the 1993 season the harvest would start about August 4th and last through Labor Day. We selected Aug. 24-26 as survey dates by reasoning that we would be more likely to observe musculoskeletal problems after 3 weeks of raking rather than early in the harvest. An appropriate consent form, questionnaire, and hand examination form were prepared and pre-tested.

A. Medical

The questionnaire addressed demographic, occupational, and symptom information. Physical examinations of the hand and wrist included Phalen's test, Tinel's test on the median nerve, and Finkelstein's test [See Appendix 1]. Since the examiners administered the questionnaire before the physical examination, they were not blinded to the raker's medical history or symptoms. The survey team consisting of three interviewer-examiners and one ergonomist was taken by the management to 9 of 14 harvesting crews in various fields. Proximity to the company's office/ factory was the primary factor in site selection. One crew consisted of about 50 to 60 rakers who were at least 12 years old. Whoever was available and willing to participate was included in the study on a "first met and first agreed to" basis (a convenience sample). When a raker refused participation, another raker working nearby was approached. Participation rate [number of consenting divided by number of approached] was not determined exactly, but was estimated to be only about 50%. Two most frequently cited reasons for non-participation were; first, some rakers did not want to stop raking to be interviewed for about 20 minutes, and second, some rakers did not want to talk to a stranger from the government.

After the 1993 harvest season closed, the company provided NIOSH with the demographic information on all rakers for the season so that the representativeness of the study participants could be compared.

B. Ergonomic

Evaluation of ergonomic stresses in blueberry raking were conducted by observation, field measurements of the size and weight of the rakes used by rakers, estimation of muscular forces exerted in raking under simulated conditions, and analysis of videotapes for body postures.

RESULTS

A. Medical

Demography

As shown in Table 1, a total of 134 rakers (one with some information missing) participated in the study; thus the rate of the convenience sampling was about 10%. Ninety-seven were males (73%) and 36 were females (27%). Compared to the company record, this gender distribution was similar to that of all rakers. The age distribution is shown in Table 2. The median age among the study participants was 30 (range: 13 to 69), while it was 28 (range: 12 to 88) for all rakers. Our study participants under-represented the youngest age group (12 to 17 years old) and over-represented the rakers in their 40's and 50's.

Racial/ethnic distribution of the participants is presented in Table 3, but the employer did not collect similar information. About 71 percent of the participants were Whites, with the majority of them having their permanent address in Maine; 23 percent were North American Natives, mostly from the Canadian Province of Nova Scotia; 6 percent were Hispanic; and one respondent was Black.

Work History of Rakers

Table 4 presents the types of work or job done by the participants outside of blueberry raking, since the latter is limited to only about one month in a year. Agricultural or forestry work was most frequently reported, followed by being a student (high school and college), manufacturing jobs, homemaker, and construction work.

Table 5 shows the number of years of blueberry raking, counting the current year as one. The median was 5 years (range: 1 to 42 years).

Table 6 presents the dates in August 1993, on which the participants started raking blueberries. Based on this information, the number of days the participants had raked blueberries prior to the interview are shown in the right hand column. The median starting date was August 4, meaning that the median number of raking days prior to the interview was 20 to 22 days. However, not everyone necessarily raked every day, although the berries were harvested every day during the month. Also, rakers were allowed to join or quit raking at anytime.

History of Musculoskeletal Disorders and Symptoms:

A history of tendinitis was reported by 16 (12%) participants; 5 of them experienced it in 1993, and a history of carpal tunnel syndrome was reported by 7 (5%). However, due to the questionnaire design, their temporal relationship to blueberry raking could not be established. None had a history of de Quervain's disease.

Table 7 shows the locations of pain reported by rakers as having occurred after the start of raking. The most frequently reported pain location was the back (36 rakers; 27%), and in half of the cases the pain was moderate to severe. Hand/wrist pain was reported by 27 (20%) rakers, and the pain was moderate to severe in 59% of them. Seven rakers (5%) reported numbness and tingling in the hand. Elbow pain was reported by 15 (11%) rakers, and the pain was moderate to severe in 67% of them.

Physical Examinations

Finkelstein's test was positive in 29 rakers (23%), Phalens' test in 12 (9%), and Tinel's sign in 9 (7%). Ten percent (10%) of the rakers were positive for both the presence of hand pain and either a positive Finkelstein's test or a positive Phalen's or Tinel's test. Based on these criteria, 5 (4%) of the participants had carpal tunnel syndrome, and another 5 (4 %) had de Quervain's disease, and 3 (2%) had both.

Relationship between Raking and Pains in the Hands or Back

The study participants raked from 3 to 12 hours daily, with the median of 8 hours a day. According to the company record, the mean daily harvest for the entire crew for the season was 5.3 boxes/hour (range: 3.0 - 6.6).

The length of time between the beginning of blueberry raking and the onset of pain (latency) ranged from 1 day to 16 days for various parts of the body. However, the mode (most frequently reported latency) was 1 day for the back, elbow, or hand, meaning that for many people who reported pain, the pain started within a few days after they had started raking.

A relationship between the raking hand and hand pain is shown in Table 8. Whether rakers used mostly the right hand or both hands equally, the percentages of rakers with no hand pain were about equal. [Raking mostly with the left hand was not considered since the numbers were few.] Among people who reported hand pains, workers who raked mostly with the right hand tended to report hand pain on that side, while for those who raked mostly with both hands equally, the side of hand with pain was about evenly distributed. The result was statistically significant at $p<0.02$ level. [Since the numbers in some cells are small or zero, the result may have to be interpreted with caution.]

There was no statistically significant association between the speed of initial raking (slow or not slow) and hand pain (Table 9). The "speed of initial raking" was assessed by the question, "Did you start raking slowly in the beginning of the season?" But no quantitative criterion was used.

Tables 10a and 10b present the effect of past raking experience on the distribution of back pain cases (10a) and hand pain cases (10b). "Raking for the first time this year (1993)" was counted as one year. For both back pain and hand pain, the distribution of percentages within the row shows that with more years of past raking, the prevalence of rakers with no pain tended to increase, while the prevalence of rakers with pain tended to decrease. The trend was statistically significant for both back pain ($p=0.03$) and hand pain ($p=0.01$). [A similar result was obtained when the column percentages were examined.]

B. Ergonomic Evaluation

Process Description:

The process of raking blueberries requires that each raker has his/her own rake, 5-gallon plastic buckets and any gloves they may need. The wild blueberry plants grow often on uneven terrain; the plants are trimmed low to the ground, approximately seven inches high. Each raker is assigned to a roped off section (8 to 12 feet wide) of blueberry field. Sturdy plastic boxes (measuring 16 x 20 inches and 5.5 inches deep) used to transport blueberries from the field to the processing plant are provided by the company. The rakers are paid by the number of boxes filled to the rim of the box with berries (approximately 23.5 pounds or 10.7 kg net).

For raking, the raker grips the rake's handle, places the tines of the rake (see Figure 1) under the bush and pulls it up through the plant to extract the berries into the rake. The raker continues to comb the blueberry plants until the rake is half full or more. Anywhere from 10 to 100 raking motions were needed to fill a rake depending on the plant thickness and quantity of berries on the plants. When the rake is full of berries the raker pours the berries into the five-gallon bucket. When two buckets are full, the raker carries them to the edge of their section facing the passage way.

Before the berries are poured into the box supplied by the company, they are winnowed by either a winnowing machine or, when it is not readily available, by natural wind. To winnow the berries by wind, the raker holds the bucket above shoulder height and pours them into the box on the ground. Although this method allowed the leaves and other debris to blow away, some berries also spilled onto the ground and were wasted. The boxes of berries are then stacked at the edge of the raker's section for the crew leader to count. The raker is paid based on the number of full boxes, for which the receipt is issued for the pay record. Other workers picked up the boxes onto the truck and took them to the factory to be cleaned and processed.

Another method of raking was observed which was called "sweeping." Sweeping consisted of pushing the rake in half circle motions through the blueberry bush with long sweeping motions. It was said that this method was not allowed by the employer except when the blueberries were very dry and sparse. Also, a few rakers were observed raking berries with a "roller rake." This device is a rake with a long handle (about 4 feet) and a cylindrical roller (like a pie roller) attached to the bottom. This enabled the raker to push the rake through the bush in a standing position. Only a few such "roller-rakes" were observed during the survey.

During the investigation, rakers were videotaped for later viewing to determine raking motions and repetition rate. Rakers were chosen based on their willingness to participate, regardless of their participation in the medical evaluation, or whether or not they had some musculoskeletal symptoms. The dimensions and weight of the rake were taken and rakers were asked for their own height and weight.

Force: The force required to rake the blueberries was measured by tying a strap to the rake and attaching a force gauge to the strap. It was assumed that the force which was required to pull the rake up through the bush as measured on the force gauge simulated the force needed to rake blueberries.

Repetitions: The number of repetitions required to rake blueberries was determined by counting the worker's movements while watching the videotape. Each of 10 workers was viewed for 10 minutes. The number of times that the worker lifted the rake through the blueberry bushes during each minute was recorded.

Wrist Deviations: For the purpose of this study, wrist motions of rakers were the focus, since it had been indicated that tendinitis at the wrist was the issue. Because of the shape of the rake and position of the handle, the required hand motion for raking mostly involved ulnar and radial deviations at the wrist, and these deviation angles were approximated by viewing the videotapes. From the videotapes a picture was printed from which an angle could be determined. A video picture was printed in the two most extreme motions for a typical lift (rake through the berries). From the video picture, three points were identified (the lateral epicondyle, the center of the wrist, and the third phalange) to determine the angle between the forearm and the hand. Other wrist angles such as flexion/extension or pronation/supination were noted from viewing the videos. However, for the purpose of this survey, no attempt was made to quantify these deviations.

Ergonomics Results

1. The dimensions and weight of the rakes

The rakes examined in this evaluation were made of steel or aluminum. Rakers reported that most of the rakes were made locally by either of two small shops. The size of the rakes was different depending on the number of tines. When three 60-tine rakes were measured, the width at the tines (see Figure 1) was 45 and 47 cm (18 and 18½ inches), the length of the rake was 23 and 25 cm (9 and 10 inches), of which the tine portion was 20 cm (8 inches). When five 55-tine rakes were measured, the width at the tines ranged from 42 to 46 cm (16½ to 18 inches), the length of the rake ranged from 23 to 25 cm (9 to 10 inches), and the length of the tines ranged from 15 to 20 cm (6 to 8 inches). One 70-tine rake was 21 inches wide at the tines, 10 inches long, and had 7 inch long tines. The height (or depth) of the rake was about 3 inches.

For the weight, a total of 12 rakes were measured, five 55-tine, five 60-tine, and two 70-tine. The average weight of the five 60-tine rakes was 1.7 kg (3.7 lbs) with a standard deviation of 0.3 kg and the range was 1.2 kg (=2.6 lbs; aluminum rake) to 2.1 kg (=4.6 lbs; steel rake). The weight of the five 55-tine rakes ranged from 1.2 kg to 2.0 kg, with an average of 1.7 kg and a standard deviation of 0.3 kg.

2. Estimate of force

The force required to pull the hand rake through the blueberry bushes averaged 87 N (newtons; = 19.4 lb) with a standard deviation of 17.5 N (3.9 lb) for three attempts.

A "roller-rake" with a long handle described above weighed 18.3 lb (8.3 kg) and the handle was approximately 4 ft long. The rake primarily consisted of a traditional rake connected by locking pliers to a handle which had a roller on the bottom. The roller was approximately 3 inches in diameter and enabled the rake to move along the ground more easily.

The buckets used to hold the berries before winnowing had a volume of about 5 gallons. A bucket full of blueberries averaged 13 kg (29 lb) with a standard deviation of 1.1 kg (2.4 lb) when measuring four buckets from different fields.

3. Repetitions

The average number of lifts per minute was counted for each worker while raking blueberries using the traditional rake by viewing a 10 minute interval on the videotape. The average number of lifts per minute was 32 with a standard deviation of 13, as shown in Table 11. Each time the rake was pulled through the blueberry bushes, the movement was considered one cycle. The repetition rate for this job is very high especially considering that this task is performed for many hours a day.

4. Wrist Deviations

The radial and ulnar wrist deviations of five rakers during the harvest were approximated. Table 12 shows the extreme radial and ulnar deviations of these rakers. All of the five rakers moved their wrist in the radial and ulnar direction while raking the blueberries. Each raker ulnarly deviated the wrist as he/she was placing the rake underneath the bushes. As the raker moved the rake through the bush, the wrist was moved in the radial direction. The range of radial and ulnar deviation was 15° to 45°. However, each raker had a slightly different method, some relied more on movement of their elbow and shoulder than movement of their wrist. One raker who raked with only one hand seemed to use his shoulder and elbow to pull the rake through the bushes.

Of five rakers, four used both hands to rake the blueberries. Since there is only one handle on a rake, the other hand held the corner of the rake to provide stabilization of the rake. This hand-hold required a pinch grip with the thumb on the inside of the rake and the other fingers on the outside of the rake. Raking with two hands would also control the torque on the rake when pulling through the bushes. Bushes require different amounts of force to pull through them. So, the rake often moves through the bush easier at one side than the other causing the rake to turn. The forearm muscles must be used to counter-act this rotation. Most people did not appear to have the strength to rake with only one hand over the entire day at such a high repetition rate.

5. Back Compression

Appendix 2 shows the calculations for back compression while performing blueberry raking tasks. The average compression at the L_5/S_1 was 548 lb with a standard deviation of 68 lb. None of the rakers' compression on the L_5/S_1 was above the maximum of 770 lb suggested for a safe lift. However, lifting of two full buckets of blueberries was found to exceed the NIOSH recommended weight limit.

DISCUSSION

Since this was a cross-sectional survey based on a convenience sample, the results should be interpreted with caution. Nonetheless, the above results seem to indicate in general that: first, there were many rakers with back pain, hand/wrist pain, and/or elbow pain; second, raking work caused high musculoskeletal stress/strains on these parts of the body; and third, medical findings were consistent with the ergonomic hazards identified. Further, it was very likely that some rakers who had developed serious hand or back pains might have left the field; hence our study is likely to underestimate the prevalence of morbidity.

Hand/Wrist pain:

Since it was difficult to study a reference population of non-rakers, with which to compare our results, we used respondent's own assessment that the pain started after he/she had begun raking. This may have caused some over-estimation of pain experience.

In 1994, as a supplement to this survey, a questionnaire was administered to the students of three high schools in the blueberry growing region of Maine.[19] It showed that 56% of students who responded to the questionnaire stated that they raked blueberries during the 1994 harvest season, and that 51% of rakers reported hand/wrist pain during the harvest period, compared to 14% of non-rakers, yielding a relative risk of 2.0 [95% Confidence interval 1.7 - 2.2].

The findings of our ergonomics survey amply documented that raking work involved repetitive and forceful movements of the hands/wrist, which frequently occurred in the plane of radial and ulnar deviation. Such motions have been known to cause the local tenosynovitis.[15,16] Therefore, our findings and the survey results of student rakers are compatible with the empirical notion that excessive use of certain parts of the musculoskeletal system do cause acute local disorders.

It is also known that prolonged and/or repeated insults to the region will lead to chronic and often irreversible tendinitis with chronic pain and impaired functions such as diminished range of motion. However, the cross-sectional design of this survey allows us only to speculate, not to conclude, on this aspect.

With regard to the potential area of intervention in work practices among the participating rakers, this investigation was able to underscore some ergonomic principles, while it failed to do so in others.

It is ergonomically advisable to alternate body parts to do the task whenever possible, since such would give a rest period to the unused hand. Thus, we had expected that using both hands equally would be more protective than using one hand most of the time. In this survey, however, rakers were often observed using the non-raking hand to support the rake. We are not sure whether or not such supportive use of the other hand was considered by respondents as "using both hands equally" for raking. Therefore, there might be some response errors. As shown in Table 8, about 80% of participants did not develop hand pains, but when the remaining 20% did develop pain, the location of the pain corresponded to the usage, and it is likely that the degree of the usage was beyond the normal capacity of the individual's physiologic tolerance.

It has also been well accepted ergonomically that the initial work conditioning to musculoskeletal stress is important to prevent or reduce the likelihood of developing CTDs.[20] It is based on a physiologic principle that the body can increase the tolerance to stresses by gradual training up to a certain degree. During the survey, we often heard from experienced rakers that they do not start raking at a fast pace in the beginning of the season. Perhaps they have learned it from their own experience or by word of mouth. However, our survey data failed to statistically prove this prediction. This non-positive result may be due to a likelihood that people who had developed pain might have left by the time of the survey.

On the other hand, our data have shown that many years of raking experience in the past were protective against development of pains in the hand and back. Again, this may be a manifestation of a survival effect, meaning that people who can do the job without developing pains would tend to come back. Also, experienced rakers might have learned to rake blueberries in a "safe" manner. To provide more definitive answers to these questions would require a prospective study with a large enough number of participants to give the necessary statistical power.

It has also been established ergonomically that keeping the wrist as neutral as possible during manual work is protective against development of tendinitis and carpal tunnel syndrome. In other word, flexions/extensions and radial/ulnar deviations at the wrist should be avoided as much as possible while raking. However, due to technical difficulties, the wrist angles of participants in their raking motions were not measured systematically in this field study.

Back pain:

Moderate to severe back pain which started after the start of raking was reported by 14% of rakers in this cross-sectional survey. As a reference, the 1988 National Health Interview Survey (NHIS), Occupational Health Supplement (OHS) data reported that "back pain [for 7 or more consecutive days in the 12 month period before the survey] caused by activities at work" among male farm workers was reported to be 19%, compared to the overall prevalence of 11% among male workers.[21] Since the definitions of these back pains are different, comparison of these numbers is difficult.

Continuous raking in a bent-over posture is very likely to cause static and postural fatigue, discomfort, and pain in the low back. Although the compression at the L_5/S_1 discs did not exceed the 770-lb maximum as calculated by the formula,[22] the compression is still fairly high (548 lb) and is constant over most of the day [see Appendix 2]. Therefore, the amount of time that the worker performs the job in a bent over posture should be reduced to prevent low back pain. As long as the hand-held rake is used, stooped raking posture is inevitable, due to the low-lying nature of the wild blueberry bush. During our survey, rakers were observed to rest and stretch their back from time to time to overcome this discomfort.

A drastic engineering solution to this problem would be to mechanize the harvesting of blueberries, and it has been practiced in some areas where the terrain is fairly flat.

RECOMMENDATIONS

1. Engineering Controls

Machine harvesting has been practiced where the terrain is suitable for mechanization. Machine harvesting will eliminate the musculoskeletal problems of hand raking. However, if mechanization is impractical or unfeasible, an improvement of the raking tool should be considered. To avoid stooping posture and repetitive motions of the hand/wrist, the long-handled rake with a roller or two wheels may be a logical improvement. At present, this type of rake is "home-made," used sporadically, and its future popularity is still uncertain. Also, the impact of the roller-rake on the blueberry plants, if its use becomes widespread, is unclear. Attachment of two wheels to the rake instead of a cylindrical roller may be less damaging to blueberry plants.

Aluminum rakes are naturally much lighter than steel rakes of similar size and therefore should be ergonomically safer. However, the use of an aluminum rake does not necessarily result in protection of health, if the benefit of lighter weight is offset by the use of a larger rake by a harvester for more yield per scoop. It is reported that in Finland the blueberry rakes are made of hard plastics and much lighter in weight. This option has an obvious ergonomic advantage and should be explored further.

2. Education and Training

a. Work conditioning

Since it is not known precisely at which frequency an inflammation can start, it will be necessary for each individual raker to find out his/her own safe rate of raking. In particular, unexperienced rakers should be cautioned not to get carried away by the incentive pay.

Each raker is paid by the amount of blueberries he/she has harvested. Although the raking effort is strictly voluntary, and one can rake as little or as much as one wishes to, the incentive for increasing the amount of harvest may override the incentive to work safely. We heard that experienced rakers do not rush but rake at a steady pace. In particular, rakers should not rake fast, at least for a few days at the beginning of the raking season. Although we could not confirm the effectiveness of such a practice by our data, it is consistent with the practice of "work-hardening" or "conditioning" of the musculoskeletal system.[20]

b. Hand Motion/Posture for Raking

Another ergonomic principle is that joint posture should be kept as neutral as possible to reduce tendon friction.[6] Therefore, the wrist should be kept in a neutral position (to avoid deviations) as much as possible during raking to reduce the risk of tendinitis.

c. Reduction of carrying loads

Most rakers tended to fill up the two buckets before they were taken to the edge of the lot for winnowing. While the recommended weight limit for this task is 47 lb., two buckets full of blueberries weighed 58 lb. Therefore, to reduce the weight carried at one time, the buckets should not be filled to the top.

d. Prevention of Injuries

Raking blueberries is a very labor intensive work for many days under the hot sun. Rakers are allowed to drive their automobiles into the passage ways in the field and bring in families and dogs. When workers are tired or much involved with raking, chances for injury may increase. We witnessed or heard of several puncture wounds inflicted by the tines of the rake which had been left on the ground. Sometimes an automobile runs over it to damage both the tool and the tire. To prevent such injuries and losses, rakers should be instructed to leave the rake only on a harvest bucket or in some conspicuous place while not in use. It should never be left on the ground in the bush or along the passage way. Painting the rake a bright white or yellow color [with non-lead paint] should be helpful for this purpose.

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Table 1. Gender Distribution of Blueberry Rakers, 1993

	Study Participants		All Rakers	
Gender	Number	Percent	Number	Percent
Male	97	73	942	74
Female	36	27	327	26
Total	133	100	1269	100

Table 2. Age Distribution of Blueberry Rakers, 1993

Age	Number	Percent	Number	Percent
12 - 17	13	10	198	16
18 - 29	50	38	511	40
30 - 39	31	23	309	24
40 - 49	20	15	164	13
50 - 69	19	14	80	6
70 +	0	0	7	1
Total	133	100	1269	100
Median (Range) Yrs	30 (13 - 69) Years old		28 (12 - 88) Years old	

Table 3. Known Race/Ethnicity and "Permanent" Address

Race/Ethnicity	Number	Percent	"Permanent" Address
White	93	70	75 (81%) were in Maine
North Am Indian	31	23	26 (84%) were in Canada
Hispanic	8	6	3 (38%) were in Mexico
Black	1	1	

Table 4. Work/Job outside of blueberry raking season

Type of Work	Number	Percent*
Agricultural or forestry	29	22
Student	26	20
Manufacturing	14	10
Homemaker	10	8
Construction	8	6
Various other works**	38	29
Retired	2	1
Not reported	6	4

* Based on 127 responses

** Spread over transportation, sales, fishery, domestic, clerical, service, health care, and other types of jobs.

Table 5. Years of blueberry raking in the past

The current year was counted as one. Median 5 years [Range 1 to 42 years]

Number of years	Number of responses	Percent
1	24	18
2	25	19
3 - 5	26	19
6 - 10	25	19
11 - 42	33	25

Table 6. First day of raking in August 1993

Date in August 1993	Frequency	Percent	Days of raking before survey Survey dates: August 24-26
1 - 3	32	24	21 - 25
4	44	33	20 - 22
5 - 10	37	28	14 - 21
11 - 25	19	15	1 - 15

Table 7. Location of pain reported by rakers (133)

Location	Positive*	Percent	Severity** 3,4,5	%***
Neck	1	1		100
Back	36	27	18	50
Shoulder	4	3	2	50
Elbow	15	11	10	67
Hand/Wrist	27	20	16	59
Numb/tingling	7	5		
Knee	4	3	1	25
Foot	1	1		

* Exclude pre-existing pains.
** Severity scale: 1=slight, 2=mild, 3=moderate, 4=severe, 5=extreme
*** Percentage of the 4th column to the 2nd column

Table 8. Relationship between the raking hand and hand pain

Raked mostly with	Right hand pain only	Left hand pain only	Pain in both hands	No hand pain	Total
Right hand	9 (16%)	0	1	48 (83%)	58
Left hand	1	0	2	3	6
Both hands	5 (7%)	4 (6%)	5 (7%)	56 (80%)	70
Total	15	4	8	107	134

Fisher's Exact Test (2-tailed): p = 0.019
Note: 67% of the cells have expected counts less than 5. Chi-square may not be a valid test.

Table 9. Speed of initial raking* and experience of hand pain

	Hand pain +	Hand pain -	Total
Raked slow initially	26	59	85
Did not rake slow initially	11	36	47
Total	37	95	132

* "Did you start raking slowly in the beginning of the season?"

Chi-square test: p = 0.379 (Not significant)

Table 10-a. Distribution of [post-raking] back pain by years of past raking

Back Pain	1 Year*	2 Yrs	3 to 5	6 to 10	>10Yrs	Total
No [Row %]**	14	17	20	19	30	100
Yes [Row %]**	26	23	17	23	11	100

* 1 year means that 1993 was the first year of raking.
** By Kruskal-Wallis nonparametric Test, these row rankings are significantly different at p=0.03 level.

Table 10-b. Distribution of [post-raking] hand pain by years of past raking

Hand Pain	1 Year*	2 Yrs	3 to 5Y	6 to 10	>10Yrs	Total
No [Row %]**	15	16	21	20	28	100
Yes [Row %]**	30	30	15	15	10	100

* 1 year means that 1993 was the first year of raking.
** By Kruskal-Wallis nonparametric Test, these row rankings are significantly different at p=0.01 level.

Table 11. Lifts per minute for blueberry raking

Worker	Lifts/min Average	Lifts/min s.d.	Gender
1	26.9	8.6	F
2	23.9	5.5	M
3	24.2	5.6	F
4	52.5	3.0	M
5	26.7	5.6	M
6	26.2	5.4	F
7	22.7	9.8	M
8	47.9	13.6	M
9	46.3	6.8	M
10	25.7	9.9	M
Average	32.3	13.4	

Table 12.

Radial and ulnar wrist deviations required to rake blueberries

Worker*	Number of Hands used to hold rake	Range of Radial and Ulnar Deviation	
1	2	25° Ulnar	5° Ulnar
2	1	10° Ulnar	15° Radial
3	2	10° Ulnar	10° Radial
4	2	5° Ulnar	10° Radial
7	2	30° Ulnar	15° Radial

* Worker numbers correspond with those in previous tables.

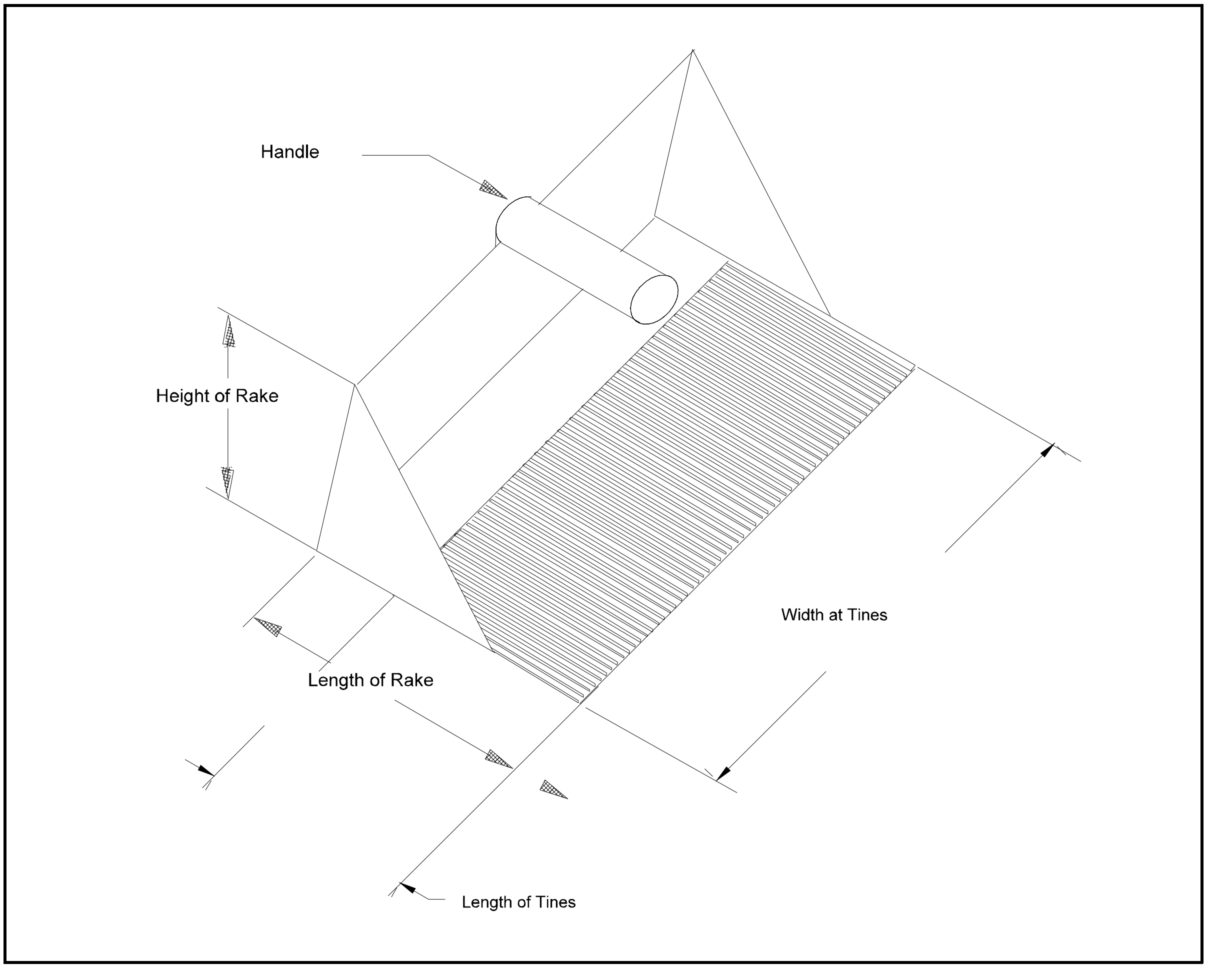

Figure 1 Traditional Blueberry Rake

Appendix 1. Phalen's, Tinel's and Finkelstein's tests

Phalen's test requires the subject to bend the wrists maximally and keep the backs of the hands together for 60 seconds. If he/she feels numbness and/or tingling in the distribution of the median nerve (usually the first three fingers and the radial side of the 4th finger) within 60 seconds, it is positive. In Tinel's test, the mid-point of the palmar side of the subject's wrist is tapped with the examiner's finger. It is positive, if pain, numbness, and/or tingling is felt in the distribution of the median nerve. A positive Phalen's and/or Tinel's test suggests the presence of median nerve compression (carpal tunnel syndrome).[23]

In Finkelstein's test, the subject is asked to make a light fist with the thumb wrapped inside other fingers. Then the examiner gently makes an ulnar deviation of the subject's fist (by bending it toward the little finger). If a sharp pain is felt at the anatomical snuffbox (at the tip of the radial styloid), the test is positive and suggests the presence of de Quervain's disease.[14,15]

Appendix 2. Calculation of Maximum Compressive Force on L_5/S_1

The compression at the L_5/S_1 discs was computed for ten workers who were raking blueberries in the typical bent over posture. The average compression at the L_5/S_1 was 548 lb with a standard deviation of 68 lb. The results for each of the ten workers is shown in Table 13. None of the workers' compression on the L_5/S_1 was above the maximum of 770 lb suggested for a safe lift.[22] However, workers maintained this position for a large portion of their work period.

The average weight of a full bucket of berries was 29 lb (13 kg). The compressive force on the L_5/S_1 was computed for four workers who were each carrying two full buckets of berries. The results are shown in Table 14. The average compressive force on the L_5/S_1 was 306 lb.

The compressive force on the L_5/S_1 for workers who winnowed the blueberries by wind was also determined. To winnow the blueberries by wind the worker pours the blueberries from a bucket (29 lb) which is positioned over the workers shoulders to a box positioned on the ground. The compressive force on the L_5/S_1 was 262 lb. and the recommended weight limit for this task was 35 lb. Since the bucket with berries weighed 29 lb, this task is not necessarily an ergonomic hazard.

One worker used a blueberry rake which had a long handle. The amount of force to push the rake through the blueberries with the handled rake was assumed to be 50 lb although it was not measured. The compression at the L_5/S_1 was 117 lb. Although the back compression is low, the resultant moments at the shoulders and knees are large enough that the whole population could not perform this task.

The maximum compressive force of the L_5/S_1 should be 770 lb for a safe lift.[22] Any job that requires a higher compressive force at the L_5/S_1 may pose a risk of lower back pain or injury to the worker.

A still picture was made from the videotape for each posture to be analyzed. The posture that the workers assumed the most was chosen for analysis. The compressive force at the worker's L_5/S_1 was computed using a computer program entitled, "Two Dimensional Static Strength Prediction Program."[24] The posture of the worker was input into the program along with the worker's height and weight. If height and weight were not known, 50th percentile values were input. The picture of the worker only showed a two dimensional view of one side of the worker; therefore, it was assumed that the other side was identical. The force held by the worker while blueberry raking was determined using a force gauge. The computer program used anthropometric data to determine the size and weight of the worker's body parts. These data were used to determine the forces and moments acting upon the L_5/S_1 discs. Ten workers were observed while raking blueberries.

The L_5/S_1 disc compression was also figured for other tasks: (1) carrying two buckets of berries, (2) winnowing the berries by hand, and (3) raking blueberries with a rake which had an extended handle. For the first and third tasks, the computer program "3D Static Strength Prediction Program"[25] was used because the worker was positioned asymmetrically.

Recommended Weight Limit

The NIOSH lifting equation[22] was used to determine the recommended weight limit for tasks associated with raking blueberries. The equation is as follows:

RWL = LC x HM x VM x DM x AM x FM x CM

Where:

RWL -	recommended weight limit (lb).
LC -	load constant (51 lb).
HM -	horizontal multiplier (10/H) where H is the horizontal distance of the hands from the midpoint between the ankles (in).
VM -	vertical multiplier $(1-(0.0075\ \lvert V-30 \rvert))$ where V is the vertical distance of the hands from the floor (in).
DM -	distance multiplier (0.82 + (1.8/D)) where D is the vertical travel distance between the origin and destination of the lift (in).
AM -	asymmetric multiplier (1-(0.0032A)) where A is the angular displacement of the load from the sagittal plane (°).
FM -	frequency multiplier based on the rate of lifting (from Waters et al, 1993).
CM -	coupling multiplier based on the quality of the coupling between the hands and the load (from Waters et al, 1993).

The NIOSH lifting equation was used to determine the recommended weight limit for lifting two full buckets of blueberries. The current weight lifted was 29 lb for each bucket for a total of 58 lb. The parameters needed are as follows:

LC - 51 lb.

HM - H was less than 10 in, HM is 1.0.
VM - V was 29 in, VM is 0.99.
DM - D was 17 in, DM is 0.93.
AM - the angle of asymmetry was 0°, AM is 1.0.
FM - lifting of buckets was done for less than 1 h per day and the frequency was 0.2 lifts/min or less, FM is 1.0.
CM - the coupling was good and the lift was less than 30 in, CM is 1.0.

For lifting of two full blueberry buckets, the recommended weight limit is:

RWL = 51 x 1.00 x 0.99 x 0.93 x 1.00 x 1.00 x 1.00 = 47 lb.

The NIOSH lifting equation can also be used to determine the recommended weight limit for winnowing blueberries by hand. The current weight lifted is 29 lb. The parameters needed are as follows:

LC - 51 lb.
HM - H was less than 10 in, HM is 1.0.
VM - V was 57 in, VM is 0.80.
DM - D was 45 in, DM is 0.86.
AM - the angle of asymmetry was 0°, AM is 1.0.
FM - hand winnowing of the blueberries was done for < 1 h per day and the frequency was 0.2 lifts/min or less, FM is 1.0.
CM - the coupling was good and the lift was greater than 30 in, CM is 1.0.

For winnowing the blueberries by hand the recommended weight limit is:

RWL = 51 x 1.00 x 0.80 x 0.86 x 1.00 x 1.00 x 1.00 = 35 lb.

The design of the rake requires that the wrist be moved from an ulnar deviation to the radial direction with about 20 lb of force while controlling for the rotation of the rake. Some rakers overcome the rotation of the rake by using the second hand; however, the second hand must maintain a pinch grip because there is no second handle. Although there does not appear to be extreme flexion/extension or pronation/supination of the wrist while raking, the frequency and degree of the radial and ulnar deviations of the wrist multiplied by the amount of force required may become large,[17] hence musculoskeletal disorders in the wrist are likely to occur for workers performing this job. To maintain the neutral position of the wrist to avoid radial and ulnar deviations, the raking motion must be performed by cranking motions of the arm and forearm at the elbow and shoulder joint, respectively.

Analysis of the ergonomics of using the roller-rake which had a long handle was attempted. The rake weighed 18 lb because it is made of steel and two locking pliers are used to hold the rake and the handle together. The compressive force on the L_5/S_1 while using this rake was 171 lb. Its use reduces the worker's risk of developing lower back pain when compared to using the traditional rake. The advantages of the long-handled rake are that the worker does not have to bend over for most of the day and the frequency of lifting is greatly reduced. However, the use of this rake may pose stresses on the shoulder and knee joints because of the force required to push it through the bushes. The ground is very uneven, so the rake does not roll easily through the bushes. There is much room for improvement of this rake. If this rake was made professionally, it could be made lighter and connected together with welded joints. Also, wheels that are larger in diameter than the roller could be positioned on the side of the rake for easier rolling through the blueberry bushes. Some of the workers were concerned that the use of the roller-rake might squash the blueberry bush and/or berries. In this respect, the rake mounted on two wheels may be more acceptable. At any rate, the use of this type of rake needs to be further researched from the aspects of both ergonomics and productivity, since the employer would not likely permit the use of a tool which may be detrimental to the quality of the produce.

Table 13. Back compression required for blueberry raking

Worker	Gender	Height (in)	Weight (lb)	Horizontal Distance of rake (in)	Vertical distance of rake (in)	Back Compression L_5/S_1 (lb)
1	F	63	120	20	10	494
2	M	69	170	14	8	597
3	F	62	119	1	11	469
4	M	71	145	10	2	483
5	M	71	175	5	12	686
6	F	66	130	7	6	491
7	M	68*	163*	14	4	596
8	M	68*	163*	15	2	527
9	M	68*	163*	18	5	581
10	M	68*	163*	14	6	554
Average				11.8	6.6	548

* based on 50th percentile U.S. civilian population[26]

Table 14. Back compression required for carrying two full buckets of blueberries (58 lb)

Worker	Gender	Height of Worker (in)	Weight of Worker (lb)	Vertical distance of bucket (in)	Horizontal Distance of bucket (in)	Back Compression L_5/S_1 (lb)
1	F	63	120	28	3	285
3	F	62	119	27	1	412
5	M	71	175	31	3	267
7	M	68*	163*	30*	1	259
Average				29	2	306

* based on 50th percentile U.S. civilian population[26]