Ergonomic Considerations of Manually Harvesting Maine Wild Blueberries

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Abstract

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, in particular wrist disorders (informally called "rakers' tendinitis") which were 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 a blueberry grower and processor in Maine.

A convenience sample of 134 rakers was recruited on-site over a three-day period in late August. Their median age was 30 (range: 13 to 69); 73% of participants were males; 10% of the participants were children (age 13 to 17). 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 (consistent with carpal tunnel syndrome), or a positive Finkelstein's test (consistent with de Quervain's disease).

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 (42 to 47 cm wide) and weight (1.2 to 2.3 kg). The typical raking motion involved a 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 through the blueberry bushes was estimated to be 87 Newtons (S.D. ± 17.5), and the motion was repeated 32 times/min (S.D. ± 13). These repetitive and forceful motions could cause friction on the tenosynovium and explain a high prevalence of tendinitis. Recommendations for improvements to the rake and raking methods are suggested.

Keywords. Blueberries, Tendinitis, Musculoskeletal disorders, Harvesting.

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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 121 km^2 of blueberry fields are commercially tended (Yarborough, 1994) and the berries are harvested by thousands of seasonal workers, usually from late July through early September. The collected blueberries are washed, 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 141 million kg of blueberries were harvested in North America, of which 58% was the cultivated crop (in states such as Michigan, New Jersey, and Oregon). The remaining 42% was the wild crop from Maine and the eastern provinces of Canada (about 29 million kg each) (Yarborough, 1994).

Cultivated berries may be hand-picked, but the smaller, firmer wild blueberries are harvested by raking (McWilliams, 1994). Workers comb through the low-lying bush with a hand-held metal rake to scoop up the berries, lift the rake, and tilt it to pour the berries into the container (fig. 1). This action is repeated many times an hour during the work period, which may last up to eight or more hours a day.

Figure 1–Raking of wild blueberries.

Although the harvesting has been partly mechanized in flat land areas, manual raking is still very common in uneven terrain.

In July 1993, the National Institute for Occupational Safety and Health (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.

To date no ergonomic assessment of blueberry raking has been reported. Hence, a field survey consisting of a symptom questionnaire, limited physical examinations, and an ergonomic assessment of raking, was conducted in August 1993 at a blueberry grower and processor in Maine. The goal of this study is to determine if blueberry raking is related to symptoms and signs of upper extremity disorders.

Process Description

At this company, 1,269 rakers were hired in the 1993 harvest. Rakers were assigned to one of 14 "crews" consisting of 50 to 60 individuals. They were allowed to sign up and sign out at their will.

During the harvest, each raker has his or her own rake (fig. 2) and plastic buckets. Gloves were not provided and none were being worn. Each raker is assigned to a roped-off section of the blueberry field. Sturdy plastic boxes (measuring 41 × 51 cm and 14 cm deep) are provided by the company to transport the blueberries from the field to the processing plant. The rakers are paid by the number of boxes filled to the top with berries (approximately 11 kg). Workers are paid anywhere from $2.00 to $3.50 per box depending on the field. They rake an average of five boxes per hour. It is an incentive pay system, the more the worker rakes, the more they get paid.

To extract the berries from the plant, the raker grips the rake's handle, places the tines of the rake (fig. 3) under the bush, and pulls it up through the plant. The raker continues to comb the blueberry plants until the rake is half full or more. Anywhere from 10 to 100 raking motions are needed to fill a rake depending on the plant

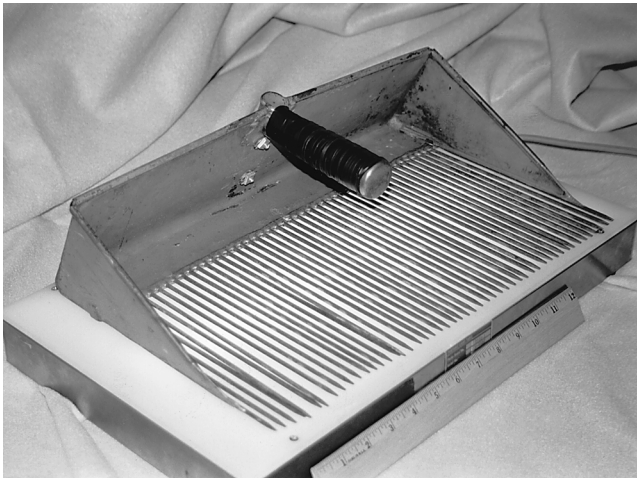

Figure 2–Traditional blueberry rake.

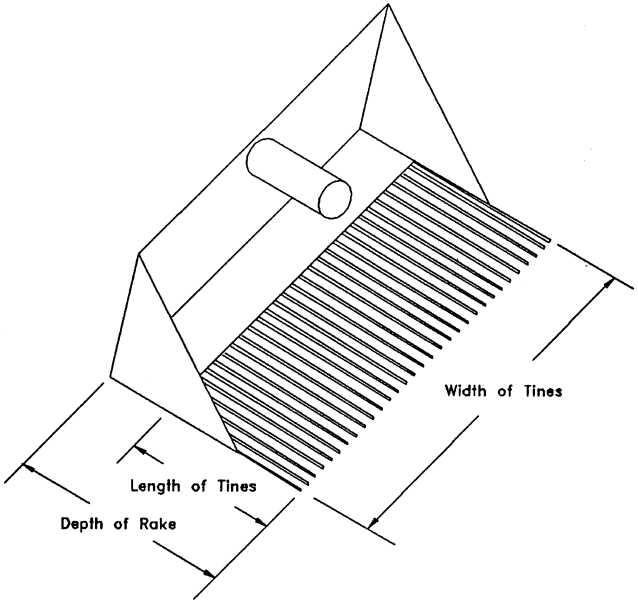

Figure 3–Drawing of blueberry rake.

thickness and quantity of berries on the plants. When the rake is full of berries, the raker pours the berries into the bucket. Approximately 5 to 15 full rakes are needed to fill a bucket. When two buckets are full, the raker carries them to the edge of the section.

Before the berries are poured into the box supplied by the company, they are winnowed (removal of debris by use of air) 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. The boxes of berries are then stacked at the edge of the raker's section to be counted.

Another method of raking is called "sweeping". Sweeping consists of pushing the rake with long, sweeping, half circle motions through the blueberry bushes. This method is not allowed by the employer except when the blueberries are very dry and sparse. Since this method was rarely allowed, no further information was collected on this method. Another type of rake is a "roller rake" or "speed rake". This rake has a long handle (about 1.2 m) and a cylindrical roller (like a pie roller) attached to the bottom (fig. 4). This rake enables the worker to push it through the bushes in a standing position. Only a couple of "roller-rakes" were observed during the survey and only the physical characteristics of the rake were collected.

Methods

Ergonomic Assessment

Evaluation of ergonomic stresses in blueberry raking was conducted by observation, field measurements of the rakes, estimation of the forces required, and analysis of videotapes for body postures.

Rakers were chosen for the ergonomic assessment based on their willingness to participate, regardless of their participation in the medical questionnaire and

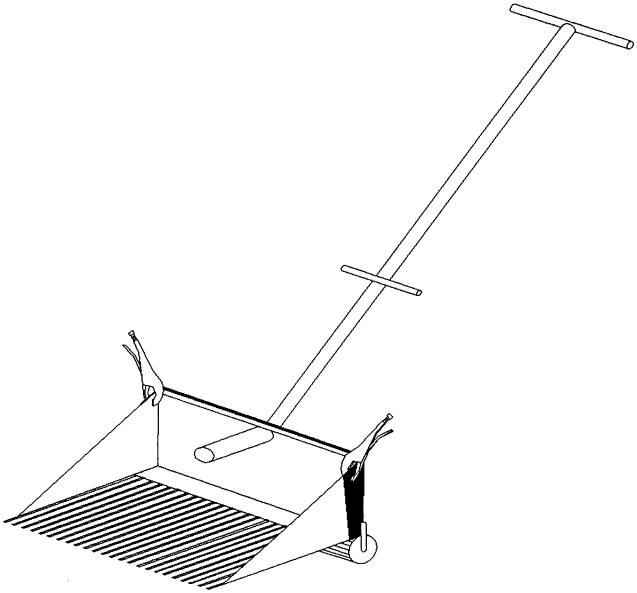

Figure 4–Drawing of "roller rake".

evaluation, or whether or not they had some musculoskeletal symptoms. The dimensions and weight of the rake were measured and workers were asked for their height and weight. Rakers were videotaped for later viewing to determine raking motions and repetition rate. The NIOSH lifting equation was used to evaluate workers who lifted full buckets of blueberries (Waters et al., 1993).

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

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 min. The number of times that the worker lifted the rake through the blueberry bushes during each minute was recorded; each lift was considered to be one cycle. The duration of the lift was measured by counting the videotape frames (each frame is 1/30 s) while the worker was lifting the rake up through the plants.

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. These deviation angles were estimated by viewing the videotapes. From the videotapes a picture was printed from which the wrist angle was determined. A video picture was printed in the two most extreme motions for a typical cycle (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. The workers were videotaped from the side to capture a clear view of the wrist radial and ulnar deviation. However, this method has some inherent error because the worker might not be turned exactly 90° from the camera. 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.

The compressive force while raking at the worker's L_5/S_1 was computed using a computer program entitled, Two Dimensional Static Strength Prediction Program (The Regents of the University of Michigan, 1990). The posture of the worker was input into the program along with the worker's self-reported height and weight. If height and weight were not known, 50th percentile values were used (Kroemer et al., 1990). 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.

Medical Questionnaire and Evaluation

The management had estimated that for the 1993 season the harvest would start about 4 August and last through Labor Day. The survey dates of 24-26 August were selected by reasoning that it would be more likely to observe musculoskeletal problems after three weeks of raking than earlier in the harvest. An appropriate consent form, a questionnaire, and a hand examination form were prepared (these items are available upon request from the first author).

The questionnaire addressed demographic (sex, age, race, height, weight, and residence), occupational (primary occupation, years raking, raking hand, type of rake, number of days raked this year, number of boxes raked per day, hours per day spent raking, and speed of raking), and musculoskeletal symptom information (if the worker had ever been told by a doctor that they had specific diseases, if they had developed any pain from this raking season, and if so, the location and severity of that pain) for the following body parts: neck, back, shoulder, elbow/forearm, hand/wrist, knee, and ankle/foot. Work-related pain was defined as localized pain of a moderate to severe degree which were felt after the start of raking work for the current harvest season. 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. Physical examinations of the hand and wrist included Phalen's test, Tinel's test, Finkelstein's test, and a visual test for ganglionic cysts. A positive Finkelstein's test suggests the presence of de Quervain's disease (Finkelstein, 1930; Lapidus and Fenton, 1952). A positive Phalen's or Tinel's test suggests the presence of median nerve compression (Katz et al., 1990). Since the examiners administered the questionnaire before the physical examination, they were not blinded to the raker's medical history or symptoms.

Nine of fourteen harvesting crews in various fields were visited. Proximity to the company's office/factory was the primary factor in site selection. Whoever was available and willing to participate was included in the study on a "first met and first agreed to basis" (a convenience sample). The convenience sample was used because the transient worker population would be difficult to pre-select and locate in a timely fashion. When a raker refused participation, another raker working nearby was approached. Participation rate was not determined but was estimated to be only about 50%. 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 determined.

Results

Ergonomic Assessment

The rakes examined in this evaluation were made of steel or aluminum. The size of the rakes depended on the number of tines. Most rakes had 55 or 60 tines. The width at the tines of these rakes ranged from 42 to 47 cm, the depth ranged from 23

to 25 cm, and the length of the tines ranged from 15 to 20 cm (fig. 3). Two 70 tine rakes were also observed. The handles of the rakes ranged from 102 mm to 114 mm and the handle diameter was 32 mm. The rakers reported that most of the rakes were made locally by either of two small shops.

The average weight of the five 60 tine rakes was 1.7 kg with a standard deviation of 0.3 kg. The range was 1.2 kg (aluminum) to 2.1 kg (steel). 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. The 70 tine rakes both weighed 2.3 kg.

A "roller-rake" with a long handle described previously weighed 8.3 kg and the handle was approximately 1.2 m long (fig. 4). The rake primarily consisted of a traditional rake connected by two locking pliers to a handle which had a roller on the bottom. The roller was approximately 8 cm in diameter and enabled the rake to move along the ground more easily. The amount of force to push the rake through the blueberries with the roller-rake was not measured; therefore, an exact calculation of the forces on the worker's joints was not possible. It was apparent from watching the worker that it took a great deal of force to use the roller-rake. Considering the posture of the worker when using the roller-rake, the stress on the worker's lower back was probably reduced when compared to the traditional rake.

The average number of raking cycles per minute was 32 with a standard deviation of 13, as shown in table 1. This job can be classified as a high repetition job based on the short cycle time of the raking task. The raking task is performed for most of the work day except for short periods spent transferring the berries, winnowing the berries, and carrying buckets.

The maximum force required to pull the rake through the blueberry bushes averaged 87 N (9 kg) with a standard deviation of 17.5 N (1.8 kg) for three attempts. This force was assumed to be the force required to rake the blueberries. This maximum force was required once per cycle which was on average, once every 2 s. The duration of the upward exertion to pull the rake through the berries was approximately 1/3 s. The worker was required to hold the rake with berries in it almost all the time.

The radial and ulnar wrist deviations of five rakers during the harvest were estimated. Table 2 shows the extreme radial and ulnar wrist deviations for the raking hand. The five rakers generally moved their wrist in the radial and ulnar direction while raking the blueberries. Each raker ulnarly deviated the wrist as he or 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 movement in the radial and ulnar direction ranged from 15° to 45°. However, each raker had a slightly

Table 1. Lifts per minute for blueberry raking

Worker (no.)	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 2. Radial and ulnar wrist deviations required to rake blueberries

Worker No.*	Number of Hands Used to Hold Rake	Radial and Ulnar Deviation		Range of Movement (°)
		Minimum (°)	Maximum (°)	
1	2	25 Ulnar	5 Ulnar	20
2	1	10 Ulnar	15 Radial	25
3	2	10 Ulnar	10 Radial	20
4	2	5 Ulnar	10 Radial	15
7	2	30 Ulnar	15 Radial	45

* Worker numbers correspond with those in previous tables.

different method, some relied more on movement of their elbow and shoulder than movement of their wrist. Raker number four (see table 2) had a small range of wrist movement and used his shoulder and elbow to pull the rake through the bushes. Some workers tended to use body parts other than their wrists to rake the berries.

Of 10 rakers, 7 used both hands at once to rake the blueberries. Since there is only one handle on the rake, the other hand held onto 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 also controlled the torque on the rake when pulling through the bushes.

The posture assumed while raking blueberries was a stooped posture. The worker's torso was bent over most of the time while the wrist, arm, and shoulder were used to move the rake through the berries. The worker usually stood up straight after filling a rake, so that the rake could be dumped into the bucket. Workers who raked with only one hand at a time usually rested their opposite elbow on the corresponding knee. This technique provided support for their upper body.

Using the Two Dimensional Static Strength Prediction Program, the average compression at the L_5/S_1 was 249 kg with a standard deviation of 31 kg for 10 workers who were raking blueberries in the typical bent over posture. None of the rakers' compression on the L_5/S_1 was above 350 kg suggested for a safe lift (Waters et al., 1993). The results for each of the 10 workers is shown in table 3. However, workers maintained this position for a large portion of their work period.

The buckets used to hold the berries before winnowing had a volume of about 19 L. A bucket full of blueberries averaged 13 kg with a standard deviation of 1.1 kg based on a sample of four buckets from different fields. Lifting two full buckets of blueberries (26 kg) was found to exceed the NIOSH recommended weight limit of 21 kg for the task.

Medical Questionnaire and Evaluation

Demographics of the study population are compared to the company records for those rakers employed during the 1993 season. As shown in table 4, the age of study participants was different than that of all rakers; the youngest age group (17 years and under) was under-represented and rakers in their 50s and 60s were over-represented. The crew leaders indicated that many of the local children had returned to school during the week of our study.

Many types of work or jobs were done by the participants outside of blueberry raking, since the latter is limited to only about one month in a year. Agricultural or forestry jobs were most frequently reported, followed by students, manufacturing jobs, homemakers, and construction jobs. The median number of years the

Table 3. Back compression required for blueberry raking

Worker (no.)	Gender	Height (cm)	Weight (kg)	Horizontal Distance of Rake (cm)	Vertical Distance of Rake (cm)	Back Compression L_5/S_1 (kg)
1	F	160	54	51	25	224
2	M	175	77	36	20	271
3	F	157	54	3	28	213
4	M	180	66	25	5	219
5	M	180	79	13	30	311
6	F	168	59	18	15	223
7	M	173*	74*	36	10	271
8	M	173*	74*	38	5	239
9	M	173*	74*	46	13	264
10	M	173*	74*	36	15	251
Average				30	17	249

* Based on 50th percentile U.S. civilian population.

Table 4. Demographics

	Gender or Age	Study Participants Number (%)	All Workers Number (%)
Gender*	Female	36 (27)	327 (26)
	Male	97 (73)	942 (74)
Age† (years)	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)
	70-88	0 (0)	7 (1)

* There is no statistical difference between the gender of study participants and all workers at the facility ($p = 0.74$).

† There is a statistical difference between the age of study participants and all workers at the facility ($p = 0.01$).

respondent has raked blueberries, counting the current year as one, was five years (range was 1 to 42 years).

The median number of raking days of the participants prior to the interview was 21 days. However, not everyone necessarily raked every day, although the berries were harvested every day during the month. The study participants raked from 3 to 12 h daily, with the median of 8 h a day. According to the company record, the mean daily harvest for all the rakers for the season was 5.3 boxes/h (range was 3.0 to 6.6).

A history of tendinitis (during a workers lifetime) in the hand or wrist was reported by 16 (12%) participants; five of them also experienced it during the past year (during 1993). A history of carpal tunnel syndrome was reported by seven (5%) participants. All of the cases preceded the 1993 harvest season. 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 5 shows the locations of pain reported by rakers as having occurred after the start of raking, this table excludes pre-existing pain. 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 of those rakers with

Table 5. Location of work-related pain since the start of raking*

Location	Positive	Percent †	No. Reporting Moderate to Extreme Severity ‡
Neck	1	1	
Back	36	27	18
Shoulder	4	3	2
Elbow	15	11	10
Hand/Wrist	27	20	16
Numb/tingling	7	5	
Knee	4	3	1
Foot	1	1	

* Work-related pain was defined as localized pain which was felt after the start of raking work for the current harvest season, excluding pre-existing pain.
† From a total of 133 participants (some participants did not answer all questions).
‡ Severity scale: 1 = slight, 2 = mild, 3 = moderate, 4 = severe, 5 = extreme.

hand/wrist pain 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.

Finkelstein's test was positive in 29 rakers (22%), Phalens' test in 12 (9%), and Tinel's sign in 9 (7%) (some participants tested positive for more than one test). Thirteen of the rakers presented hand pain and a positive physical exam. Based on these criteria, five (4%) rakers had symptoms and physical findings consistent with carpal tunnel syndrome, and another five (4%) had symptoms and physical findings consistent with de Quervain's disease, and three (2%) had symptoms and physical findings of both.

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 body parts. However, the mode was 1 day for the back, elbow, or hand, meaning that for many people who reported pain, the pain started shortly after they had started raking. There was no statistically significant association between the speed of initial raking (slow or not slow) and hand pain.

Table 6 shows that there was no association between people who began the season raking slowly and incidence of hand pain.

The effect of past raking experience on the proportion of back pain and hand pain are shown in tables 7 and 8, respectively. "Raking for the first time this year" was counted as 1 year. A Wilcoxon-Mann-Whitney Test was run to compare the distribution of years of past raking for those who reported back pain and those who did not. The test was significant, which indicates that the years of past raking are not equal for those who reported back pain and those who didn't ($p = 0.03$). In particular, those who did not report back pain indicate a typically higher number of years raked than those who do report back pain. The results were the same for the hand pain symptom ($p = 0.01$).

Table 6. Speed of initial raking and experience of hand pain*

Raking Speed	Hand Pain	No Hand Pain	Total
Slow initially	26	59	85
Always raked the same	11	36	47
Total	37	95	132

* Chi-square test: $p = 0.379$ (not significant).

Table 7. Proportion of back pain by years of past raking

Post-raking Back Pain?*	Years of Past Raking					
	1 Yr†	2 Yr	3 to 5 Yr	6 to 10 Yr	> 10 Yr	Total
No	13	15	18	17	27	90
Yes	9	8	6	8	4	35
Total	22	23	24	25	31	125‡

* By Wilcoxon-Mann-Whitney nonparametric test, the distribution of number of years of past raking differs for those who reported back pain and those who did not (p = 0.03).
† "1 year" means that 1993 was the first year of raking.
‡ Some participants did not answer all questions.

Table 8. Proportion of hand pain by years of past raking

Post-raking Hand Pain?*	Years of Past Raking					
	1 Yr†	2 Yr	3 to 5 Yr	6 to 10 Yr	> 10 Yr	Total
No	16	17	22	21	29	105
Yes	8	8	4	4	3	27
Total	24	25	26	25	32	132 ‡

* By Wilcoxon-Mann-Whitney nonparametric Test, the distribution of number of years of past raking differs for those who reported hand pain and those who did not (p = 0.01).
† "1 year" means that 1993 was the first year of raking.
‡ Some participants did not answer all questions.

Discussion

Unlike the scheduled laboratory studies, field investigations of seasonal or migrant workers are usually subject to a variety of limitations and difficulties, e.g., pressure for production, worker's suspicion of the investigation. This study was no exception and suffered a low participation rate. Nonetheless, our findings if interpreted with caution, can provide some useful information on the ergonomics of blueberry raking and its potential health effects among seasonal workers, which have not heretofore been available.

Ergonomic Assessment

Although rakes were made of both steel and aluminum and in different sizes, it appeared that most workers desired the biggest rake that they could handle. If they had recently switched from steel to aluminum, they usually had also switched to a bigger size for more harvest. Therefore, use of a lighter tool did not necessarily result in the reduction of raking force. The handle length was 102 to 114 mm; a minimum length of 100 mm has been recommended by Kodak (1983) and a minimum of 125 has been recommended by Konz (1983). The handle diameter was 32 mm. Using an average male adult inside grip diameter of 48 mm (female and child grip diameters are not available) (NASA, 1978), handle diameters in the range of 50 to 60 mm are recommended from most of the published literature (Mital and Kilbom, 1992). People with small hands, however, should not be expected to use tools with grip diameters greater than 60 mm.

The average cycle time for the task of raking blueberries was 2 s (32 lifts/min). Silverstein et al. categorized any job with a cycle time of less than 30 s as highly repetitive (Silverstein et al., 1987). They found that high repetition jobs in manufacturing had a 2.7 times greater chance of the workers having carpal tunnel syndrome. Silverstein also defined a high force job as one with an adjusted hand

force requirement greater than 6 kg. For this study, the amount of hand force cannot be extracted from the 9 kg (87 N) maximum force required to pull the rake through the berries. It is known, however, that the worker must maintain a continuous static power grip on the handle of the rake during the raking task. This continuous grip would have to be strong enough to counter-act the weight of the rake (1.7 kg) and the weight of the berries (up to 1 kg). In addition to this continuous static grip, there is an added manual exertion of a dynamic nature approximately every 2 s.

The design of the rake requires that the wrist be moved from an ulnar deviation in the radial direction (or that the wrist be held stationary and resist the force from the ulnar direction) with up to 87 N of force. At the same time, the worker must control for the rotation of the rake. One side of the rake often moves through easier than another side causing the rake to twist. The forearm muscles must be used to counter-act this rotation. Over half of the rakers overcome the rotation of the rake by using their second hand; however, the second hand must maintain a pinch grip because there is no second handle. Many workers did not appear to have the strength to rake with only one hand over the entire day at such a high repetition rate. Possibly for this reason, most workers used two hands to rake. 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 combined with the force are consistent with the musculoskeletal disorders observed in the medical screening. 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 shoulder and elbow joints, respectively. Some workers were observed using mostly elbow and shoulder motions rather than wrist deviations, although those workers were the minority.

Continuous raking in a bent-over posture is likely to cause static and postural fatigue, discomfort, and pain in the low back. The compression at the L_5/S_1 disc during the maximum force of the lift was estimated to be 249 kg. Hence, the main problem is not the magnitude of the force but the prolonged static trunk flexion. Some blueberry rakers, who could rake with one hand, rested one elbow on their knee, possibly to combat this fatigue. 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.

The “roller-rake” was particularly heavy because it was made of steel and two locking pliers were used to hold the rake and the handle together. If this rake was mass produced, the pieces could be welded together, reducing its weight. It’s use reduced the worker’s risk of developing lower back pain when compared to using the traditional rake because the stooped posture and the lifting motion were eliminated. The rake appeared to require a significant amount of force to use which may cause added stress to other joints. Hand raking is only done on uneven terrain, therefore, the ground is very uneven, and the roller-rake does not roll easily through the bushes. Some of the workers were concerned that the use of the roller rake might squash the blueberries. The other problem with this rake was that the entire rake had to be lifted and turned to dump the rake’s contents into the bucket. The rake’s weight and bulk made this job difficult.

Incentive pay systems of work have several disadvantages. Brisson et al. (1989) found a risk ratio of 4 to 11 for musculoskeletal diseases of female garment workers depending on the number of years they had been working in the piece rate system (compared to garment workers with 0 to 4 years experience). Another study found that workers on a piece work system had the highest incidence of severe “Vibration White Finger” than those on a salary system (Wasserman, 1982). Besides being at increased risk for musculoskeletal diseases, piece rate workers are often unwilling to

take the time to change gloves or perform other safety precautions (Jolanki et al., 1987). Although incentive systems in general may put the workers at an increased risk of musculoskeletal disease, the incentive system was not quantitatively evaluated during this study.

Medical Questionnaire and Evaluation

Since this was a cross-sectional survey based on a convenience sample, the results should be interpreted with caution. Also, since it was difficult to study a reference population of non-rakers, with which to compare our results, respondent's own assessment that the pain started after he/she had begun raking were used. This method may have caused some over-estimation of pain experience. Nonetheless, the above results seem to indicate in general that: first, there were at least 15% of rakers with back pain, hand/wrist pain, or elbow pain; second, raking work caused moderate to extreme musculoskeletal stress/strains on these parts of the body; and third, medical findings were consistent with the ergonomic hazards identified. Further, it was possible that some rakers who had developed serious hand or back pains might have left the field; hence our study might underestimate the prevalence of morbidity.

In 1994, as a supplement to this survey, 905 questionnaires were distributed to the students of three high schools in the same blueberry growing region of Maine (72% responded) (Millard, 1996). 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. The risk ratio of hand pain was 3.7 when comparing rakers with non-rakers. It is notable that the non-raker's incidence of hand and wrist pain is similar to the incidence of the raking population in this study. The differences could be attributed to two reasons: workers with previous injury were excluded from this study, and Millard's study did not use a physical exam to determine hand and wrist pain, it relied on self-reported data.

The ergonomics survey documents that raking work involves repetitive and forceful movements of the hand/wrist, which frequently occurred in the plane of radial and ulnar deviation. Motions such as these have been reported to be related to DeQuervain's tendinitis (Finkelstein, 1930; Loomis, 1951). Therefore, these 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.

This survey data failed to prove that raking slowly at the beginning of the season would result in less hand pain. If the incidence of pain found in this study was a result of unaccustomed work, then a difference would be expected between those who consciously decided to begin the season by raking slowly. Also, it is likely that workers develop these types of injuries in a short period of time. Tichauer (1976) showed that trainees in a wire assembly plant developed tenosynovitis and epicondylitis within the first two weeks of work. Tichauer also showed that those working with a bent wrist were more likely to develop those disorders. However, in Tichauer's study no carpal tunnel syndrome was seen until the tenth week of work. It does appear likely that during the 4 to 6 weeks of raking blueberries, the workers could have developed these types of injuries considering that the worker performed the same hand and wrist motion over 15,000 times per day.

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.

Moderate to severe back pain which began 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 (Guo et al., 1995). Since the definitions of these back pains are different, comparison of these numbers is difficult.

Recommendations

Engineering Controls

An improvement of the raking tool should be considered. To avoid stooping posture, repetitive motions, and high forces at the hand/wrist, the long-handled "roller rake" may be a logical improvement. At present, this type of rake is home-made, used sporadically, and it's future popularity is still uncertain. There is much room for improvement of this rake. If this rake were made professionally, it could be made lighter and connected together with welded joints. Attachment of two wheels to the rake instead of a cylindrical roller may be less damaging to blueberry plants and may be easier for rolling through the blueberry bushes. Also, the impact of the roller-rake on the blueberry plants, if its use becomes widespread, is unclear. At any rate, the use of this type of rake needs to be further researched from the aspects of ergonomics and productivity. The other item that needs to be addressed is an easy method to dump the collected berries into the buckets. A plastic liner that holds the berries while raking and can be easily removed to dump the collected berries may be practical.

Aluminum rakes are naturally much lighter than the steel rakes of the similar size and, therefore, should be ergonomically the safer of the two. 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.

Many rakers used two hands to rake; the second hand held the side of the rake with a pinch grip. This pinch grip could be eliminated by including additional handles at either side. The use of two hands would stabilize the rake so that it would not have a tendency to turn when raked through the plants. In addition, having a handle on either side would allow the worker to switch the primary raking hand and still have another handle for support. The diameter of the rake handle should be enlarged to 50 mm. The handle diameter should be large enough that the fingers and thumb do not meet and yet small enough that the fingers and thumb surround more than half of the circumference (Mital and Kilbom, 1992). A rubber or plastic grip could be added to enlarge the handle and also provide a non-slip surface.

Administrative Controls

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, the incentive for increasing the amount of harvest may override the incentive to work safely.

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 21 kg, two buckets full of blueberries weighed 26 kg. Therefore, to reduce the weight carried at one time, the buckets should not be filled to the top.

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