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Ergonomic Evaluation of Pruning and Harvesting Tasks of Winegrape Trellis Systems

Fadi A. Fathallah, John A. Miles, Julia Faucett, James M. Meyers, Ira Janowitz, Andrew E. Kato, Erica Garcia, David A. Reiter, Brandon J. Miller, and Diana G. Tejeda
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There is high prevalence of work related musculoskeletal disorders (MSDs) in the winegrape industry. Manual pruning of dormant vines and harvesting are highly repetitive and physically demanding jobs that are expected to expose workers to an increased risk for MSDs. The purpose of this study is to quantify risk factors associated with the development of musculoskeletal injuries to the wrist and lower back while pruning and harvesting five commonly used winegrape trellis systems. Twenty three subjects participated in two separate pruning and harvesting simulations. Subjects performed either a simulated pruning or harvesting task as wrist and trunk postures data were gathered. The results revealed significant differences among the trellis systems. Compared to the other systems, the vertical shoot positioned (VSP) was determined to be most optimal in terms of decreasing relative MSD risk, for both pruning and harvesting.

INTRODUCTION

It has been well known that the agriculture industry is one of the Nation's most hazardous industries (Meyers, 1999). The most commonly reported injuries within the California agriculture were musculoskeletal disorders (MSDs) (Villarejo, 1999). In the winegrape industry alone, a work related MSD incidence rate of 80 per 1000 workers (Meyers, 2000) was reported. The most commonly recorded injuries were attributed to MSDs of the lower back and the upper extremities.

Manual pruning of dormant vines, among the various procedures involved in the production of wine, is one of the most expensive and labor consuming, and is exceeded in both respects only by the harvest process (Tassie, 1992).

trellis system with regards to minimizir to the employee.

Subjects

Twenty three healthy subjects (22 r each with pruning and harvesting exper this study. Pruning experience across st 5-15 years. The mean age was 39 years mean stature was 169.5 cm (10.1 std. d were screened with regard to any curre of the back and upper extremities.

Apparatus

Field visits have shown on average that typical pruning work shifts are 8 hours, at a rate of approximately 40 cuts per minute. The major tasks involved in manual harvesting of wingrape consist of cutting grapes (at a rate of 25-50 cuts per minute) from the vine and dropping them into a tub, and carrying the filled tub to be emptied into trailer-mounted bins for transport (each worker performs about 150-200 tubs per day).

The design characteristics of the vine trellis system vary significantly (Dokoozlian, 2000). These differences are expected to result in differences in workers exposure to MSD risk. Finding a trellis system that minimizes MSD risk factors would be beneficial in reducing the prevalence of MSDs in the winegrape industry. Therefore, the objectives of this study is to quantitatively evaluate five commonly used trellis systems throughout the Northern California winegrape vineyard industry. This evaluation will be based on the relative risks of developing MSDs to the wrist and the lower back while pruning. It is hoped that the results of this study will assist vineyard proprietors to select an optimal

Five simulation trellis systems were study: Lyre, Scott Henry, Smart Dyson, The cutting heights were based on aver standards and are as follows: 61.0 cm-V Scott Henry, 99.1 cm-Smart Dyson, 10 cm-Lyre. The row length for all trellis s approximately 9.1 m. To simulate the p previously cut (pruned) vine branches v Styrofoam blocks at the appropriate hei task was simulated using 1-lb bags or ri vine wires at the appropriate cutting hei

The Motion Analysis System (MA Systems, Palo Alto, CA) and the Biom goniometers (Biometrics Ltd., UK) wer position and kinematic data of the wrist flexion/extension and radial/ulnar plane harvesting, respectively.

The Lumbar Motion Monitor (LM Hixon, TN) was used to track the motic three principal anatomical planes (sagit

---

coronal). Figure 1 shows a subject equipped with the LMM and MAS while performing a pruning trial, and Figure 2 during harvesting, on one of the simulated trellis systems.

Figure 1. A subject performs a pruning trial on a simulation trellis.

simulation, each subject was instructed row per trellis system and to perform th they would normally. Similarly, during simulation the subjects were asked to c clusters (rice bags) of half a row, and p placed on the ground.

Analysis

Frequency distributions centered or the wrists and trunk in each respective p created. The percent of time spent with was established for each principal plan posture specific ranges of the wrist wer software. The ranges for the wrist flexi (θ) are defined as follows:

$1 = \theta \leq -15^\circ$; $2 = -15^\circ < \theta < 15^\circ$; $3 = 30^\circ \leq \theta$

The posture specific ranges of the t parameters established by Fathallah et a

Figure 2. A subject performs a harvesting trial on a simulation trellis.

Design

The study consisted of two one-way within-subject designs (one for pruning, one for harvesting) with five levels (trellis systems, discussed above). Several dependent variables were collected in this study. However, this paper focuses on the percent of time spent in specified ranges of the wrist (flexion/extension) and trunk (sagittal plane). The pruning and harvesting order for the trellis systems was randomly presented across all subjects.

Procedure

Each subject agreed to participate in the study and signed an informed consent form. For both simulations, data were collected on two subjects per day. Baseline readings from the LMM and MAS/Biometrics systems were collected for each subject prior to data collection. During the pruning

ranges for the trunk sagittal plane are d

$1 = \theta < 0\ ^\circ$; $2 = 0\ ^\circ \le \theta < 15\ ^\circ$; $3 = 1$
and $4 = 30\ ^\circ \le \theta$

Analyses of variances (ANOVAs)
determine statistical differences among

RESULTS AND DISC

Figures 3 and 4 show the average p
during pruning within the specified ran
flexion/extension of the left wrist and t
sagittal plane, respectively. ANOVAs v
compare the average percent of time wi
(i.e., range 1) among all trellis systems
From Figure 3, significance was notice
flexion/extension of the left hand for ra
The VSP 4x4 resulted in the lowest per
the neutral range (range 2) with an aver
VSP resulted in the highest percent of t
of 51.2% in this range. The large percer
the VSP suggests that the left hand is w
for at least 50% of the time.

The VSP 4x4 (left wrist) resulted ir
of time in extreme extension (range 4)
42.1% compared with the other system
prevalent range for the VSP 4x4 was ra
average of 35.1%. Therefore, 75% of tc
spent in extension postures exceeding 1

Results form the flexion/extension
during harvesting demonstrated that the
percentage spent in semi-neutral postur
(Figure 5).

60

50

$\theta <= -15$

$-15 < \theta < 15$

$15 <= \theta < 30$

Figure 3. Percent of time spent in flexion/extension of the left wrist during pruning.

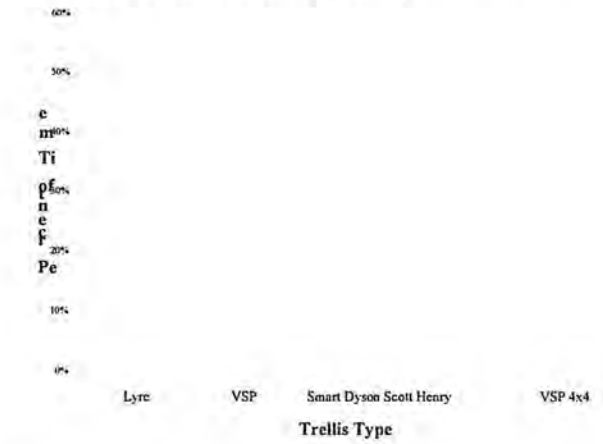

Figure 4. Percent of time spent in flexion/extension of the right wrist during harvesting.

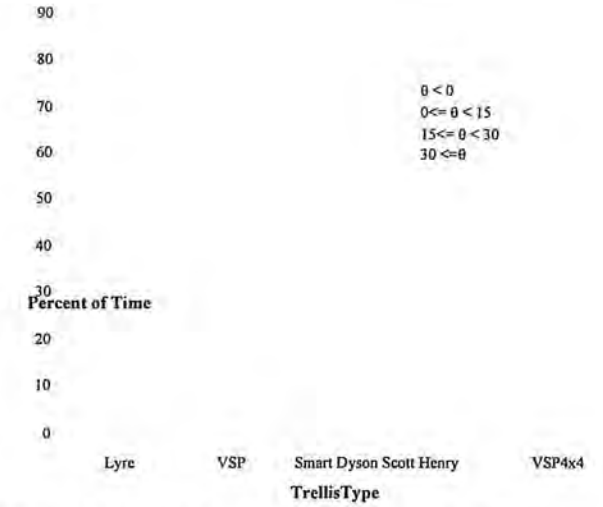

Figure 5. Percent of time spent in the sagittal plane during pruning.

Figure 6. Percent of time spent in t during harvesting.

From Figure 5, the Lyre system dur in the largest percent of time spent in se compared with the other systems. The a time spent in extension (range 1) was 6 17.1% for the Scott Henry, which resul highest percentage. Similar trends were harvesting (Figure 6). The extension of harmful to the posterior elements of the (Adams et al., 2000). In addition, much performed with the arms above the sho posture assumed was similar to that of above the shoulders, causing extension al. (1999) defined occupational tasks th above the acromion as harmful to the sl hand position causes impingement of th structures leading to MSDs of the soft t the shoulder. Therefore, the Lyre trellis ideal choice.

The VSP resulted in the largest per the neutral range (range 2) during pruni of 73.2%. In contrast, the VSP 4x4 resu of 4.5%. Excluding the Lyre, a downwa for the percent of time spent in range 2 decreased. This clearly showed the dire between trunk flexion and cutting heigh decreased, the amount of time spent in decreased as flexion of the trunk was in accommodate the lower cutting height. trends were observed during harvesting

During both pruning and harvesting spent in trunk flexion angles that excee significantly higher for the VSP 4x4 co other systems. The VSP 4x4 averaged that range compared to less than 5% an system during pruning and harvesting,

The Lyre and VSP 4x4, both of which encompass relatively extreme trunk postures, result in the largest wrist flexion angles compared with the other trellises. Therefore, the implication from this result emphasizes the interaction effect of risk factors. The relatively large trunk flexion and extension angles in combination with increased wrist flexion increase the risk of developing MSDs of both the wrist and the back. The increased trunk flexion and increased wrist flexion angles make the VSP 4x4 system the least desirable from a MSD risk standpoint. The Lyre system would also be undesirable due to the combination of increased trunk extension, increased wrist flexion and shoulder increased abduction angles (observed during the experiment).

CONCLUSION

This study was able to demonstrate the relative risk of developing MSDs during pruning and harvesting among five of the common trellis systems used in the winegrape industry. The significance of these findings may have important implications to vineyards that are currently considering to plant or re-plant new vines. On average, the VSP system showed the lowest levels of risk to the wrist and the back during both pruning and harvesting. Hence, the use of this system should be advocated especially if there are no substantial differences with respect to grape quality or vine productivity among the variety of trellis systems.

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INTRODUCTION

It has been well known that the agriculture industry is one of the Nation's most hazardous industries (Meyers, 1999). The most commonly reported injuries within the California agriculture were musculoskeletal disorders (MSDs) (Villarejo, 1999). In the winegrape industry alone, a work related MSD incidence rate of 80 per 1000 workers (Meyers, 2000) was reported. The most commonly recorded injuries were attributed to MSDs of the lower back and the upper extremities.

Manual pruning of dormant vines, among the various procedures involved in the production of wine, is one of the most expensive and labor consuming, and is exceeded in both respects only by the harvest process (Tassie, 1992). Field visits have shown on average that typical pruning work shifts are 8 hours, at a rate of approximately 40 cuts per minute. The major tasks involved in manual harvesting of wingrape consist of cutting grapes (at a rate of 25-50 cuts per minute) from the vine and dropping them into a tub, and carrying the filled tub to be emptied into trailer-mounted bins for transport (each worker performs about 150-200 tubs per day).

The design characteristics of the vine trellis system vary significantly (Dokoozlian, 2000). These differences are expected to result in differences in workers exposure to MSD risk. Finding a trellis system that minimizes MSD risk factors would be beneficial in reducing the prevalence of MSDs in the winegrape industry. Therefore, the objectives of this study is to quantitatively evaluate five commonly used trellis systems throughout the Northern California winegrape vineyard industry. This evaluation will be based on the relative risks of developing MSDs to the wrist and the lower back while pruning. It is hoped that the results of this study will assist vineyard proprietors to select an optimal trellis system with regards to minimizing MSD risk exposure to the employee.

Subjects

Twenty three healthy subjects (22 males and 1 female) each with pruning and harvesting experience participated in this study. Pruning experience across subjects ranged from 5-15 years. The mean age was 39 years (10.3 std. dev.), and mean stature was 169.5 cm (10.1 std. dev.). All subjects were screened with regard to any current or previous MSD

of the back and upper extremities.

Apparatus

Five simulation trellis systems were constructed for this study: Lyre, Scott Henry, Smart Dyson, VSP 4x4 and VSP. The cutting heights were based on average vineyard standards and are as follows: 61.0 cm-VSP 4x4, 86.4 cm-Scott Henry, 99.1 cm-Smart Dyson, 106.7 cm-VSP and 122 cm-Lyre. The row length for all trellis systems was approximately 9.1 m. To simulate the pruning task, previously cut (pruned) vine branches were inserted into Styrofoam blocks at the appropriate height. The harvesting task was simulated using 1-lb bags or rice attached to the vine wires at the appropriate cutting height.

The Motion Analysis System (MAS) (Greenleaf Medical Systems, Palo Alto, CA) and the Biometrics wrist goniometers (Biometrics Ltd., UK) were used to capture position and kinematic data of the wrist in the flexion/extension and radial/ulnar planes during pruning and harvesting, respectively.

The Lumbar Motion Monitor (LMM) (Chattecx Corp., Hixon, TN) was used to track the motion of the trunk in the three principal anatomical planes (sagittal, transverse and

coronal). Figure 1 shows a subject equipped with the LMM and MAS while performing a pruning trial, and Figure 2 during harvesting, on one of the simulated trellis systems.

Figure 1. A subject performs a pruning trial on a simulation trellis.

Figure 2. A subject performs a harvesting trial on a simulation trellis.

Design

The study consisted of two one-way within-subject designs (one for pruning, one for harvesting) with five levels (trellis systems, discussed above). Several dependent variables were collected in this study. However, this paper focuses on the percent of time spent in specified ranges of the wrist (flexion/extension) and trunk (sagittal plane). The pruning and harvesting order for the trellis systems was randomly presented across all subjects.

Procedure

Each subject agreed to participate in the study and signed an informed consent form. For both simulations, data were collected on two subjects per day. Baseline readings from the LMM and MAS/Biometrics systems were collected for each subject prior to data collection. During the pruning simulation, each subject was instructed to prune half of each row per trellis system and to perform the pruning task as they would normally. Similarly, during the harvesting simulation the subjects were asked to cut the simulated grape clusters (rice bags) of half a row, and place those into bins placed on the ground.

Analysis

Frequency distributions centered on ranges of motion for the wrists and trunk in each respective plane of motion were created. The percent of time spent within a specified range was established for each principal plane of motion. The posture specific ranges of the wrist were based on the MAS software. The ranges for the wrist flexion/extension angle (θ) are defined as follows:

$1 = \theta \leq -15$

°
; 2 = -15
°
< θ < 15
°
; 3 = 15
°
≤ θ < 30
°
; and 4 =
30
°
≤ θ
The posture specific ranges of the trunk were based on parameters established by Fathallah et al. (1998). The ranges for the trunk sagittal plane are defined as follows:
1 = θ < 0
°
; 2 = 0
°
≤ θ < 15
°
; 3 = 15
°
≤ θ < 30
°
;
and 4 = 30
°
≤ θ
Analyses of variances (ANOVAs) were performed to determine statistical differences among the trellis systems.

RESULTS AND DISCUSSION

Figures 3 and 4 show the average percent of time spent during pruning within the specified ranges for the flexion/extension of the left wrist and trunk position in the sagittal plane, respectively. ANOVAs were completed to compare the average percent of time within a specific range (i.e., range 1) among all trellis systems during pruning. From Figure 3, significance was noticed for the flexion/extension of the left hand for ranges 2 and 4 only. The VSP 4x4 resulted in the lowest percent of time spent in the neutral range (range 2) with an average of 13.7%. The VSP resulted in the highest percent of time with an average of 51.2% in this range. The large percentage observed for the VSP suggests that the left hand is within a neutral range for at least 50% of the time.

The VSP 4x4 (left wrist) resulted in the highest percent of time in extreme extension (range 4) with an average of 42.1% compared with the other systems. The second prevalent range for the VSP 4x4 was range 3 with an average of 35.1%. Therefore, 75% of total pruning time is spent in extension postures exceeding 15
°
for the VSP 4x4.

Results form the flexion/extension of the right wrist during harvesting demonstrated that the VSP had the highest percentage spent in semi-neutral postures (-15 to 15 degrees) (Figure 5).

Figure 3. Percent of time spent in flexion/extension of the left wrist during pruning.

Figure 4. Percent of time spent in flexion/extension of the right wrist during harvesting.

Figure 5. Percent of time spent in the sagittal plane during pruning.

Figure 6. Percent of time spent in the sagittal plane duing harvesting.

From Figure 5, the Lyre system during pruning resulted in the largest percent of time spent in sagittal extension compared with the other systems. The average percent of time spent in extension (range 1) was 67.3% compared with 17.1% for the Scott Henry, which resulted in the second highest percentage. Similar trends were observed during harvesting (Figure 6). The extension of the trunk may be harmful to the posterior elements of the lumbar spine (Adams et al., 2000). In addition, much of the cutting was performed with the arms above the shoulder. The body posture assumed was similar to that of reaching for an object above the shoulders, causing extension of the trunk. Frost et al. (1999) defined occupational tasks that position the hands above the acromion as harmful to the shoulder. The elevated hand position causes impingement of the subacromial structures leading to MSDs of the soft tissues that comprise the shoulder. Therefore, the Lyre trellis would not be an ideal choice.

The VSP resulted in the largest percent of time spent in the neutral range (range 2) during pruning with an average of 73.2%. In contrast, the VSP 4x4 resulted with an average of 4.5%. Excluding the Lyre, a downward trend was noticed for the percent of time spent in range 2 as cutting height decreased. This clearly showed the direct relationship between trunk flexion and cutting height. As cutting height decreased, the amount of time spent in neutral postures decreased as flexion of the trunk was increased to accommodate the lower cutting height. Again, similar trends were observed during harvesting (Figure 6). During both pruning and harvesting, the percent of time spent in trunk flexion angles that exceeded 30 ^{o} were significantly higher for the VSP 4x4 compared with the

other systems. The VSP 4x4 averaged 81% of the time in that range compared to less than 5% and 30% for the VSP system during pruning and harvesting, respectively.

0
10
20
30
40
50
60
70
80
90
Lyre
VSP
Smart Dyson Scott Henry
VSP4x4
TrellisType
Percent of Time
θ < 0
0<= θ < 15
15<= θ < 30
30 <=θ
0
10
20
30
40
50
60
Lyre
VSP
Smart Dyson Scott Henry
VSP 4x4
TrellisType
Percent of Time
θ < = − 15
− 15 < θ < 15
15 < = θ < 30
30 < = θ

The Lyre and VSP 4x4, both of which encompass relatively extreme trunk postures, result in the largest wrist flexion angles compared with the other trellises. Therefore, the implication from this result emphasizes the interaction effect of risk factors. The relatively large trunk flexion and extension angles in combination with increased wrist flexion increase the risk of developing MSDs of both the wrist and the back. The increased trunk flexion and increased wrist flexion angles make the VSP 4x4 system the least desirable from a MSD risk standpoint. The Lyre system would also be undesirable due to the combination of increased trunk extension, increased wrist flexion and shoulder increased abduction angles (observed during the experiment).

CONCLUSION

This study was able to demonstrate the relative risk of developing MSDs during pruning and harvesting among five of the common trellis systems used in the winegrape industry. The significance of these findings may have important implications to vineyards that are currently considering to plant or re-plant new vines. On average, the VSP system showed the lowest levels of risk to the wrist and the back during both pruning and harvesting. Hence, the use of this system should be advocated especially if there are no substantial differences with respect to grape quality or vine productivity among the variety of trellis systems.

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