Ergonomic Evaluation of Winegrape Trellis Systems Pruning Operation

A. E. Kato, F. A. Fathallah, J. A. Miles, J. M. Meyers,
J. Faucett, I. Janowitz, E. G. Garcia

Abstract. *The winegrape industry suffers from high incidence rates of work-related musculoskeletal disorders. Pruning of dormant vines is a significant task, requiring long periods of highly repetitive and physically demanding work. The purpose of this study is to quantitatively evaluate five commonly used winegrape trellis systems with regard to the risk of developing musculoskeletal injuries to the wrist and lower back while pruning. Eleven subjects participated in this study. Subjects performed a simulated pruning task as wrist and trunk postures were gathered using electrogoniometers. The results showed significant postural differences among the trellis systems. Compared to the other systems, the VSP was determined to be the optimal system in terms of decreasing relative MSD risk. These results will assist vineyards in the selection process of suitable trellis systems that will include the worker health aspect in conjunction with other trellis-related parameters such as grape quality and productivity.*

Keywords. *Ergonomics, Musculoskeletal disorders, Posture, Pruning, Vineyard trellis.*

Each year in the U.S., approximately one million people report injuries resulting from work-related musculoskeletal disorders (WRMSDs) leading to time away from work for the treatment and recovery of predominantly lower back and upper extremity injuries (NRC, 2001). Furthermore, the estimated worker compensation costs associated with WRMSDs range between $45 and $54 billion annually. The National Institute of Occupational Safety and Health (NIOSH) has determined that musculoskeletal injuries rank first in frequency among workers, with approximately half of the nation's workforce being affected (Bernard, 1997; NIOSH, 2004).

The agriculture industry has been recognized as one of the nation's most hazardous industries, along with mining and construction (BLS, 2004; McCurdy and Carroll, 2000; NIOSH, 2004), and California's agriculture industry is no exception. Many agricultural workers in California suffer from an excessive number of work-related injuries (NIOSH, 2004). The most commonly reported injuries within the California agricultural industry have been associated with musculoskeletal disorders (MSDs) (AgSafe, 1992; McCurdy et al., 2003; Villarejo, 1999).

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The authors are **Andrew E. Kato,** Former Graduate Student, **Fadi A. Fathallah, ASABE Member Engineer,** Associate Professor, **John A. Miles, ASABE Member Engineer,** Professor, and **Erica G. Garcia,** Development Engineer, Department of Biological and Agricultural Engineering, University of California, Davis, California; **James M. Meyers,** Extension Specialist, School of Public Health, University of California, Berkeley, California; **Julia Faucett,** Professor, Department of Community Health Systems, University of California, San Francisco, California; and **Ira Janowitz,** Senior Ergonomic Consultant, Ergonomics Program, University of California, San Francisco/Berkeley, California. **Corresponding author:** Fadi Fathallah, Department of Biological and Agricultural Engineering, One Shields Ave, Davis, CA 95616; phone: 530-752-1612; fax: 530-752-1612; e-mail: fathallah@ucdavis.edu.

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In the winegrape industry alone, a WRMSD prevalence of 80 per 1000 workers was reported (Meyers et al., 2000). The most commonly recorded injuries were attributed to MSDs of the lower back and the upper extremities. These are most likely due to the highly forceful and repetitive hand movements combined with frequent stooped postures commonly adopted for different tasks.

Grape vineyards utilized for the production of wine are prominent and extensive in northern California, with more than 400,000 acres situated primarily in the Sonoma and Napa valleys. In 1997, the production of winegrapes within California was estimated to account for over 95% of grapes crushed within the U.S. Approximately half of the existing commercial wineries in the U.S. are located in California, employing more than 31,000 workers per year, with an additional 40,000 to 50,000 workers hired specifically for the harvesting season (Meyers et al., 1999).

The hand-pruning of dormant vines requires considerable effort and time. Typically, this involves a six- to twelve-week period every year between the months of December and March. Among the various procedures involved in the production of wine, pruning is one of the most expensive and labor consuming, and is exceeded in both respects only by the harvest process (Smart and Robinson, 1991; Tassie and Freeman, 1992). Pruning has also been associated with increased risk of developing CTDs of the wrist among workers (Roquelaure et al., 2002). In general, vineyard rows (about 30 feet long each) are planted 8 to 12 feet apart, with about five vines per row. Pruning one vine takes about 60 seconds. Field visits by our group have shown, on average, that typical pruning work shifts are 8 hours, with approximately 2400 cuts per hour (i.e., about 60 vines per hour, or 480 vines per day).

There are several vineyard trellis systems used throughout California and other part of the country. In order to help workers who perform hand-pruning tasks in California vineyards, it is important to know which trellis systems are most often installed. However, no extensive data are available that categorize trellis systems by vineyard acreage. Consequently, a survey questionnaire was sent out to all viticulture and enology farm advisors in the UC Davis Cooperative Extension program to obtain estimates of the most commonly used trellis systems. Several large sellers of trellis system equipment were also interviewed to determine which trellises had the highest sales throughout California. Using the interviews information coupled with the initial results of the survey and the existing limited literature, seven trellis systems were identified that encompass the majority of winegrape acreage in California. These systems are: traditional single curtain (California sprawl), vertical shoot positioned (VSP), wye, lyre, Scott-Henry, Smart-Henry, and Smart-Dyson. Of these systems, the VSP system seems to be the most widely used throughout California (>50,000 acres) for recent and new vineyards, followed by the lyre (~10,000 acres) and the wye and Scott-Henry systems (~3,000 to 5,000 acres). Although the California sprawl system covers a large area (>100,000 acres), mainly in the California Central Valley, this system is rarely used for new vineyards or for replanting existing ones, and is mostly machine-pruned. There was also an indication that the Smart-Dyson system is gaining popularity in certain areas, especially in new vineyards. Another newly introduced system that also is gaining popularity was a lower version of the typical VSP systems, commonly referred to as the “VSP 4×4.”

The observational/survey study described above revealed that a wide variety of trellis systems is used throughout the winegrape industry. However, five trellis systems seem to represent the majority of hand-pruned trellises used throughout California. In general, the design characteristics of these systems vary significantly (Dokoozlian et al., 2000), which is 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 purpose of this study is to quantify the five commonly used trellis systems with regard to the relative risk of developing MSDs to the wrist and lower back while pruning.

Safety Emphasis

This article focuses on improving the health of the vineyard worker by selecting a trellis system that minimizes relative MSD risk while pruning.

Materials and Methods

Participants

Eleven healthy volunteers (10 males and 1 female), each with a minimum pruning experience of two years, participated in this study. The volunteers were compensated workers at the UC Davis vineyards, which is administered by the Department of Viticulture and Enology. 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: VSP 4×4, Smart-Dyson, Scott-Henry, VSP, and lyre. The cutting heights were based on average vineyard standards and are as follows: 61.0 cm VSP 4×4, 86.4 cm Smart-Dyson, 99.1 cm Scott-Henry, 106.7 cm VSP, and 122 cm lyre. The row length for all trellis systems was approximately 9.1 m.

The WristSystem (Greenleaf Medical Systems, Inc., Palo Alto, Cal.) was used to capture the workers' wrist joint motion. The WristSystem is a two-dimensional electrogoniometer that provides kinematic data of the wrist in the flexion/extension and radial/ulnar planes. Note that flexion/extension of the wrist indicates motion towards the palmer/dorsal side of the hand, whereas ulnar/radial wrist deviation indicates hand motion towards the ulna/radius bones of the forearm. The device consists of two gloves (one per hand) with cutouts for the digits and compartments for the transducers (fig. 1). The WristSystem stores continuous data on a portable data logger equipped with an SRAM card. Data collection frequency was set at 20 Hz. The device's accompanying Motion Analysis System (MAS) software was used to download the raw data from the portable data logger and to convert the signals into angular positions.

Figure 1. The WristSystem for monitoring wrist joint movement.

The Lumbar Motion Monitor (LMM) (Chattecx Corp., Hixon, Tenn.) is an electrogoniometric device used to track the motion of the trunk in the three principal anatomical planes (sagittal, transverse, and coronal). The device is secured on the volunteer's upper body through flexible harnesses. A wireless transmitter sends continuous data from the LMM to a laptop computer, enabling the researcher to collect data without hindering the performance of the subject. Figure 2 shows a subject equipped with the LMM and WristSystem while performing a pruning trial.

Experimental Design

The study was a one-way within-subject design, with five levels (trellis systems, discussed above). The dependent variables were classified into two categories: (1) right and left wrist postures (flexion/extension, and radial/ulnar deviation), and (2) trunk postures (coronal, transverse, and sagittal angles). The pruning sequence for the trellis systems was randomly presented across all subjects.

Experimental Procedure

An informed consent form approved by the UC Davis Internal Review Board was presented to each subject prior to data collection. Only participants who consented to volunteer participated in the study. The experiment lasted about one hour per subject, and data were collected on two subjects per day.

For each subject, baseline readings from the LMM and WristSystem devices were obtained prior to data collection. Each subject was instructed to prune half of each row per trellis system and to perform the pruning task as they would normally. This length was determined to be sufficient due to the repetitive nature of the task.

A subjective rating instrument was administered at the completion of the last trellis system to capture subject's trellis preference. The subjects were asked to rank (1 through 5) the trellis systems in terms of difficulty pertaining to bodily discomfort from least difficult (1) to most difficult (5). The subjects were told to respond assuming a typical 8-hour work shift.

Data Analysis

For the wrist posture analyses, descriptive statistics were obtained for each trellis system for the right and left flexion/extension and radial/ulnar deviations. Similarly, for trunk postures, descriptive statistics were obtained for left/right lateral, flexion/extension

Figure 2. A study participant performing the pruning task on the simulation trellis.

sagittal, and left/right twisting angles. Analysis of variance (ANOVA) was also performed to determine statistical differences in wrist and trunk postures among trellis systems.

A frequency distribution of time spent, centered on different ranges of motion of the trunk in the sagittal plane, was created. This analysis was conducted because this plane exhibited the most postural difference across trellis systems. The posture-specific ranges of the trunk were based on parameters established by Fathallah et al. (1998). The four ranges for the wrist flexion/extension angle (θ) are defined as follows:

$$1 = \theta < 0^\circ,\ 2 = 0^\circ \leq \theta < 15^\circ,\ 3 = 15^\circ \leq \theta < 30^\circ, \text{ and } 4 = 30^\circ \leq \theta$$

An average percent of time was obtained by taking the ratio of the number of data points that fell within the specified range and the overall number of collected data points per subject. The obtained ratios were collapsed across all participants, resulting in average values per trellis system. ANOVA was performed to determine statistical differences among the trellis systems.

A Friedman ANOVA was conducted with the rankings from nine out of the eleven subjects. The responses from two subjects were not complete.

Results and Discussion

Table 1 shows the descriptive statistics and statistical significance for the left and right hand wrist postures within each trellis system. Only the "left hand extension" and the "left hand radial" angles were statistically significant among the trellis systems ($p < 0.05$ and

Table 1. Wrist deviations in different directions.

		Left Hand[a]		Right Hand	
Direction	System	Mean (°)	Std. Dev.	Mean (°)	Std. Dev.
Flexion	Lyre	−12.61	10.07	−11.73	6.70
	VSP	−7.17	4.26	−8.44	5.15
	Smart-Dyson	−4.49	3.47	−9.92	7.95
	Scott-Henry	−7.06	6.25	−9.74	7.69
	VSP 4×4	−12.04	6.87	−12.42	6.42
Extension[a]	Lyre	18.69	10.55	13.52	7.69
	VSP	22.97	14.56	12.87	8.35
	Smart-Dyson	19.73	14.28	13.28	7.24
	Scott-Henry	21.61	12.03	17.35	8.25
	VSP 4×4	29.68	7.91	13.01	5.62
Radial	Lyre	−7.84	5.22	−7.60	5.62
	VSP	−8.68	6.53	−5.10	3.47
	Smart-Dyson	−9.71	6.50	−8.69	6.32
	Scott-Henry	−9.16	5.57	−7.46	7.19
	VSP 4×4	−17.88	13.16	−5.39	3.03
Ulnar[b]	Lyre	27.65	17.84	7.00	6.50
	VSP	14.71	12.96	7.29	5.98
	Smart-Dyson	28.77	18.92	7.82	6.20
	Scott-Henry	27.63	18.38	7.16	7.03
	VSP 4×4	17.38	17.35	6.40	4.12

[a] Significant at $p < 0.05$.
[b] Significant at $p < 0.1$.

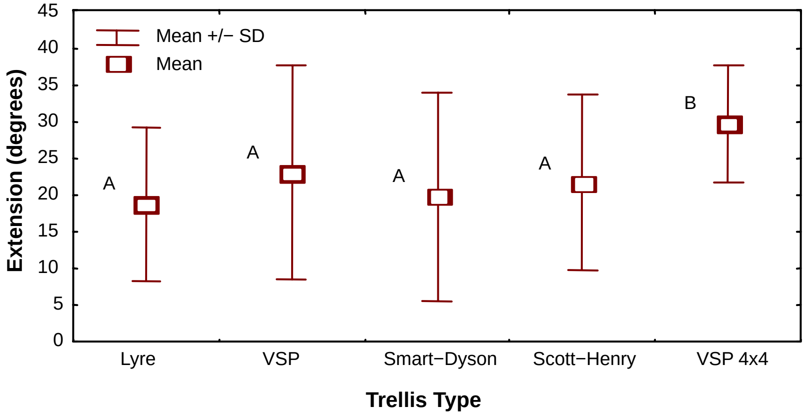

Figure 3. Average extension of left wrist. Means labeled with different letters are significantly different from each other.

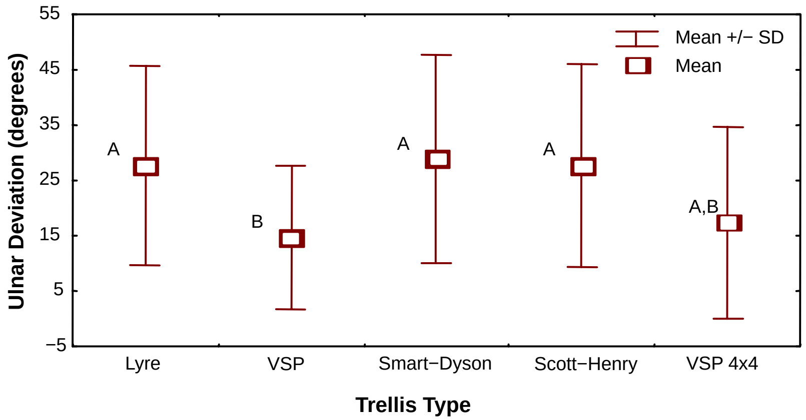

Figure 4. Average ulnar deviation of left wrist. Means labeled with different letters are significantly different from each other.

0.1, respectively). Figures 3 and 4 depict these two angles and show the *post hoc* analysis (LSD, $p < 0.05$). Extension of the left wrist for the VSP 4×4 was significantly the largest among all systems (fig. 3). Radial deviation for the VSP system was significantly lower than all systems except the VSP 4×4 (fig. 4).

Table 2 shows the descriptive statistics and statistical significance for the trunk postures within each trellis system. The ANOVA results revealed a significant difference among the five trellis systems for the trunk flexion and left lateral motion of the trunk ($p < 0.05$) (table 2). Figures 5 and 6 depict these two angles and show the *post hoc* analysis (LSD, $p < 0.05$). Each trellis system was significantly different from all other systems with, as expected, the VSP 4×4 exhibiting the largest flexion angle and the lyre system the lowest angle (fig. 5). Left lateral motion for the Scott-Henry and Smart-Dyson systems were significantly higher than for the other three systems (fig. 6).

Figures 7, 8, and 9 depict the average percent of time spent in a sagittal angle (θ) of less than 0° (extension), between 0° and 15° (neutral range), and greater than 30°(extreme flexion), respectively. From figure 7, the lyre system resulted in the largest

Table 2. Trunk postures for different plane of motion and direction.

Plane	System	Flexion (Sagittal) or Left[a]		Extension (Sagittal) or Right	
		Mean (°)	Std. Dev.	Mean (°)	Std. Dev.
Sagittal[a]	Lyre	3.94	5.10	−5.67	4.70
	VSP	9.71	7.08	−1.21	1.07
	Smart-Dyson	16.19	7.41	−1.95	1.48
	Scott-Henry	24.24	7.96	−1.95	1.43
	VSP 4×4	44.62	14.15	−0.47	0.30
Lateral[a]	Lyre	−5.24	1.98	2.93	2.03
	VSP	−3.98	1.62	4.63	2.96
	Smart-Dyson	−7.90	2.17	4.67	2.22
	Scott-Henry	−8.02	3.63	3.50	2.46
	VSP 4×4	−4.06	2.33	5.54	4.55
Twisting	Lyre	−4.03	2.29	3.57	1.74
	VSP	−3.14	1.72	2.87	0.99
	Smart-Dyson	−3.56	2.69	2.89	1.51
	Scott-Henry	−3.50	2.64	3.47	2.04
	VSP 4×4	−2.69	1.91	2.26	1.91

[a] Significant at $p < 0.05$.

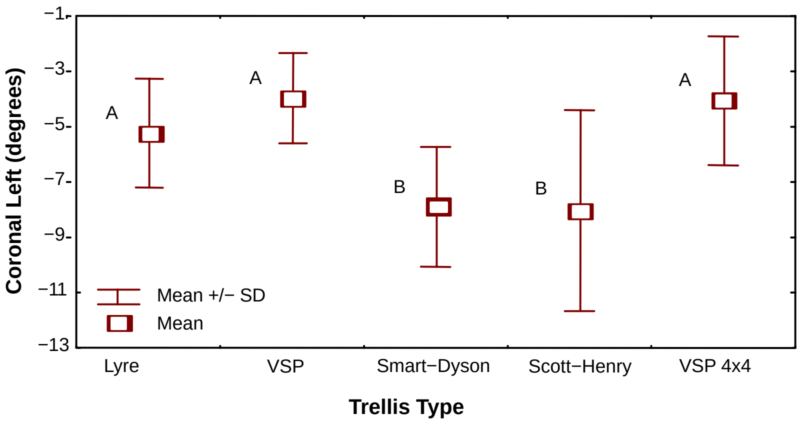

Figure 5. Average left lateral (coronal) motion of the trunk. Means labeled with different letters are significantly different from each other.

percent of time spent in sagittal extension compared with the other systems. The average percent of time spent in extension was 67.3% compared with 17.1% for the Scott-Henry, which resulted in the second highest percentage. The extension of the trunk may be harmful to the posterior elements of the lumbar spine (Adams et al., 2000). In addition, from observing the workers, 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 and Andersen (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, despite the fact that the lyre system resulted in the least flexion of the trunk, this system would not be an ideal choice.

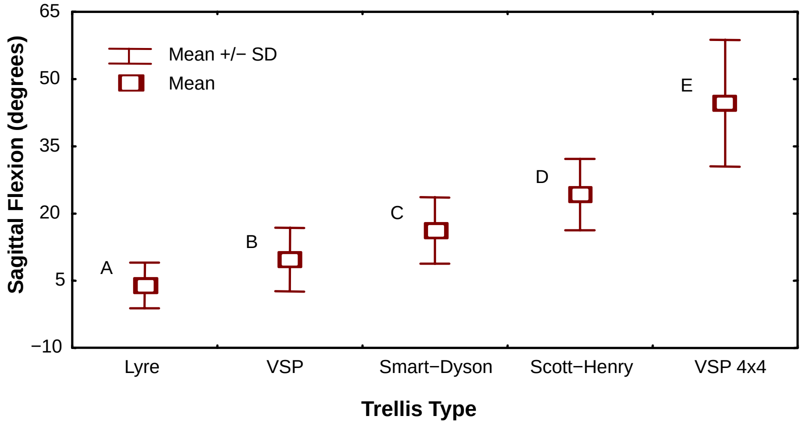

Figure 6. Average sagittal flexion of the trunk. Means labeled with different letters are significantly different from each other.

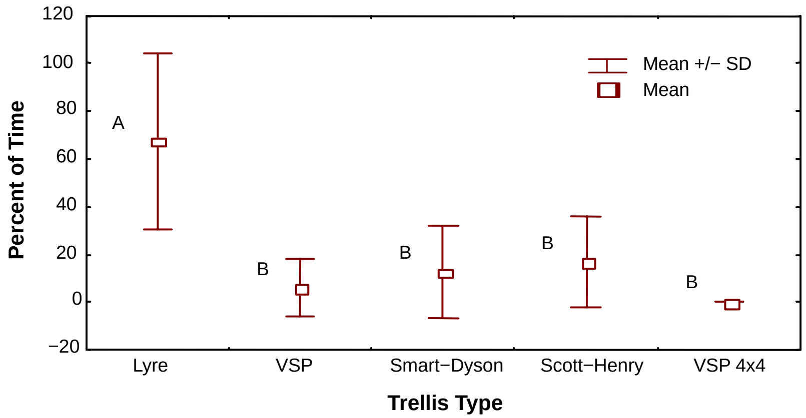

Figure 7. Average percent of time spent in sagittal plane ($\theta < 0^\circ$, extension). Means labeled with different letters are significantly different from each other.

The VSP resulted in the largest percent of time spent in the neutral range, with an average of 73.2%. In contrast, the VSP 4×4 resulted in an average of 4.5%. Excluding the lyre, a downward trend was noticed for the percent of time spent in the neutral range as cutting height decreased. This clearly showed a 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 (fig. 8). The percent of time spent in trunk flexion angles that exceeded 30° was significantly higher for the VSP 4×4 compared with the other systems (fig. 9). The VSP 4×4 averaged 81% compared with the second highest percentage of 31% for the Scott-Henry. Extreme sagittal flexion of the back has been consistently linked to low back disorders (Marras et al., 1995).

Figure 10 shows the averages (±std. dev.) for the subjective rankings for each trellis. The trellis systems were ranked from 1 (easiest) to 5 (hardest). There was a significant difference among the trellis systems ($p < 0.05$). It was apparent that the VSP was the most desirable system, and both the VSP 4×4 and lyre systems were the least desirable among

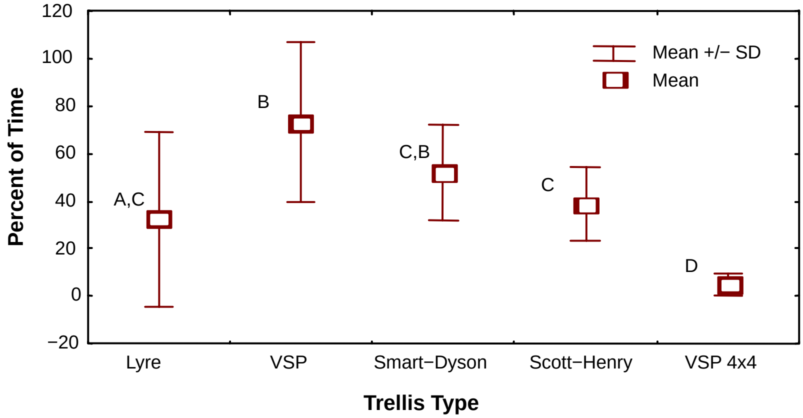

Figure 8. Average percent of time spent in sagittal plane ($0 \leq \theta < 15^\circ$, neutral range). Means labeled with different letters are significantly different from each other.

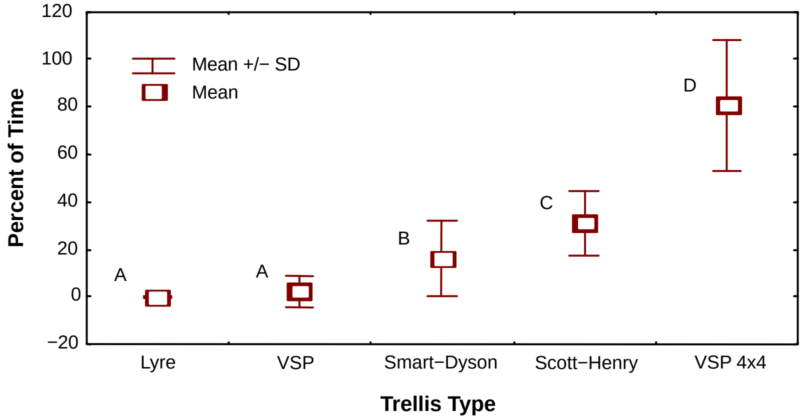

Figure 9. Average percent of time spent in sagittal plane ($\theta > 30^\circ$, flexion). Means labeled with different letters are significantly different from each other.

the participants. The increased trunk flexion and increased wrist flexion/extension angles (table 1) make the VSP 4×4 system the least desirable from an MSD risk standpoint. As shown in figure 10, the subjective rankings of the trellis systems further validate this claim. The elicited subjective responses were unfavorable for the VSP 4×4 system. A major complaint was the relatively low height of the system. The lyre system would also be undesirable due to the combination of increased trunk extension, increased wrist flexion/extension, and increased arm flexion angles (observed). The majority of the subjects complained about the effects of fatigue due to the excessive arm flexion required for reaching the higher branch height. The average trunk flexion values for the Smart-Dyson and Scott-Henry systems were significantly higher than for the VSP. It must be noted that the overall body posture for pruning these systems consisted of squat/stoop postures.

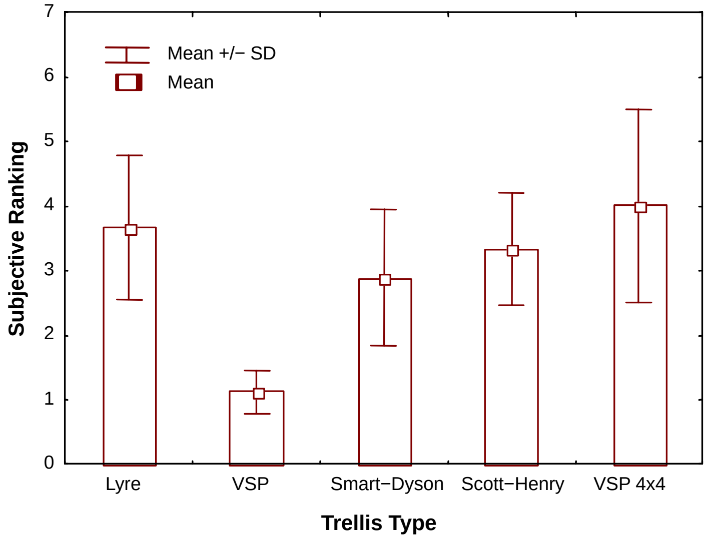

Figure 10. Subjective ranking of trellis systems: 0 = easiest, 5 = hardest.

Limitations

The study has several limitations. Firstly, the study focused on five simulated trellis systems that reflected the average design characteristics of each corresponding system. In other words, since there is variability within a given system, it is conceivable, for example, that a lower-height lyre system would be better than a high VSP system. However, the information presented should provide general guidelines for a preferred cutting height. Secondly, the study did not evaluate the forces applied during pruning. Elevated and repetitive cutting force, combined with even moderate wrist postures, could lead to increased risk of CTDs of the wrist (Silverstein et al., 1986). The assumption was that, since the participants were cutting similar material in each system, the forces were expected to be rather similar. Furthermore, the workers were provided with identical pruning shears; however, this was necessary to avoid the potential confounding effect of shears design. Thirdly, the subjective responses were obtained under conditions in which the subjects assumed an 8-hour use of these systems, rather than the shorter pruning times during the experiment, which is a commonly adopted approach in psychophysical research (e.g., Snook and Ciriello, 1991). Lastly, this study did not evaluate the effect of trellis system on MSD risk to the wrist and back during harvesting (cutting of grape clusters).

Conclusion

This study was able to demonstrate the relative risk of developing MSDs among five of the common trellis systems used in the winegrape industry. The study has shown that the lyre and VSP 4×4, both of which encompass relatively extreme trunk postures, result in the largest wrist flexion angles compared with the other trellis systems. 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/extension observed in these systems increase the risk of developing MSDs of both the wrist and the back. On the other hand, it was observed that the VSP system resulted in both the most time spent in a neutral trunk posture combined with acceptable wrist postures. The significance of these findings may have important implications to vineyards that are currently considering to plant or re-plant new vines. Because the trellis height does not substantially affect grape quality or vine productivity for a given grape variety (J. Wolpert, 2002, personal communication), the findings of this study will be disseminated to propagate the benefits of the VSP system (around 106 cm), and to avoid the VSP 4×4 (around 61 cm) and the higher (above 106 cm) lyre systems.

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References

Adams, M. A., S. May, B. J. Freeman, H. P. Morrison, and P. Dolan. 2000. Effects of backward bending on lumbar intervertebral discs: Relevance to physical therapy treatments for low back pain. *Spine* 25(4): 431-438.

AgSafe. 1992. Occupational injuries in California agriculture: 1981-1990. Oakland, Cal.: University of California, Division of Agricultural and Natural Resources.

Bernard, B. P., ed. 1997. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati, Ohio: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health.

BLS. 2004. Survey of occupational injuries and illnesses. Detailed statistics. Occupational injuries and illnesses: Industry data. 2001. Washington, D.C.: U.S. Department of Labor, Bureau of Labor Statistics. Available at: www.bls.gov/iif/.

Dokoozlian, N., E. Gladstone, and N. Ebisuda. 2000. Wine grape trellising trends in California. Davis, Cal.: University of California.

Fathallah, F. A., W. S. Marras, and M. Parnianpour. 1998. The role of complex simultaneous trunk motions in the risk of occupationally related low back disorders. *Spine* 23(9): 1035-1042.

Frost, P., and J. H. Andersen. 1999. Shoulder impingement syndrome in relation to shoulder intensive work. *Occup. and Environ. Medicine* 56(7): 494-498.

Marras, W. S., S. A. Lavender, S. E. Leurgans, F. A. Fathallah, S. A. Ferguson, W. G. Allread, and S. L. Rajula. 1995. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics* 38(2): 377-410.

McCurdy, S. A., and D. J. Carroll. 2000. Agricultural injury (Review). *American J. Industrial Medicine* 38(4): 463-480.

McCurdy, S. A., S. J. Samuels, D. J. Carroll, J. J. Beaumont, and L. A. Morrin. 2003. Agricultural injury in California migrant Hispanic farm workers. *American J. Industrial Medicine* 44(3): 225-235.

Meyers, J., J. Faucett, J. Miles, I. Janowitz, D. Tejeda, V. Duraj, R. Smith, and E. Weber. 1999. Effect of reduced load weights on musculoskeletal disorder symptoms in wine grape harvest work. In *Proc. 127th Meeting of APHA*. Washington, D.C.: American Public Health Association.

Meyers, J., J. Miles, J. Faucett, I. Janowitz, D. Tejeda, V. Duraj, J. Kabashima, R. Smith, and E. Weber. 2000. High-risk tasks for musculoskeletal disorders in agricultural field work. In *Proc. IEA 2000/HFES 2000 Congress*, 616-619. Santa Monica, Cal.: Human Factors Engineering Society.

NIOSH. 2004. *Worker Health Chartbook, 2004*. Cincinnati, Ohio: National Institute for Occupational Safety and Health.

NRC. 2001. Musculoskeletal disorders and the workplace: Low back and upper extremities. Washington, D.C.: National Academy Press, National Research Council.
Roquelaure, Y., C. Dano, G. Dusolier, S. Fanello, and D. Penneau-Fontbonne. 2002. Biomechanical strains on the hand-wrist system during grapevine pruning. *Int. Arch. Occup. Environ. Health* 75(8): 591-595.
Silverstein, B. A., L. J. Fine, and T. J. Armstrong. 1986. Hand wrist cumulative trauma disorders in industry. *British J. Industrial Medicine* 43(11): 779-784.
Smart, R., and M. Robinson. 1991. *Sunlight into Wine: A Handbook for Winegrape Canopy Management*. Goodwood, South Australia: Winetitles.
Snook, S. H., and V. M. Ciriello. 1991. The design of manual handling tasks: Revised tables of maximum acceptable weights and forces. *Ergonomics* 34(9): 1197-1213.
Tassie, E., and B. M. Freeman. 1992. Pruning. In *Viticulture*, 66-84. B. G. Coombe and P. R. Dry, eds. Goodwood, South Australia: Winetitles.
Villarejo, D. B. 1999. The occupational health status of hired farm workers. *Occup. Med.: State of the Art Reviews* 14(3): 613-635.