Ergonomic analysis of grapevine pruning and wine harvesting to define work and hand tools design requirements

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Abstract. Knowledge of the stress-strain analysis while grapevines pruning and wine harvesting in vineyards will make a significant contribution towards reducing the risk of cumulative trauma disorders (CTD) in the upper limbs of vineyard workers. The stress-strain analysis in field and laboratory studies show that pruning grapevines and wine harvesting involves a combination of dynamic and sensorimotoric work, and also a high incidence of ergonomically undesirable postures of the trunk, the upper limbs and the head irrespective of cutting tools used. The information obtained can be applied in the ergonomic redesign of pruning tasks and pruning tools to reduce incidence of trauma.

Keywords: Pruning grapevines, wine harvesting, stress-strain analysis, pruning hand tools, CTD

1. Introduction

Pruning grapevines and wine harvesting causes high stresses on vineyard workers. The stress factors include repetitive movements combined with external forces acting on the finger-hand-wrist system (using non-powered pruning shears) and static work in the upper arm-shoulder system. A wide variety of prunes and cutting shears is used in vineyards in Germany daily during the 5 months from November to March for the manual pruning of grapevines and for grape picking during two months from September to November.

Anthropometric and physiological design deficits in some existing cutting hand tools, for example, high actuation forces and poor adaptation to the human hand-arm system may lead to undesirable body postures. Consequently considerable worker strain and financial losses occur from inefficient job performance.

There is an increasing awareness that good ergonomic design of hand tools used by manual workers is an important contributory factor in alleviating physical stress and reducing the risk of cumulative trauma disorders (CTD) in the upper limbs. It is, for example, a recognised fact that CTD like carpal tunnel syndrome and tenosynovitis are linked with work involving high levels of hand [3]. The nature of the work task and the work object and the design of the hand tools being used are all factors which can influence how the worker applies the tools and what postures will be adopted.

The conditions of the present field studies were the following:

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– The studies were performed at two vineyards differing from each other, for example, in soil quality and slope, a wine growing enterprise and a family enterprise.
– There were different types of branches to be cut:
  * 1–2 year-old branches: until 20 mm ("normally grapevine");
  * more than 2-years-old branches: above 20 mm ("thick grapevine");
  * cutting of old leaves and 1-year-old branches;
– Different climatic conditions such as air temperature, humidity and air movement had to be considered.

The objectives of the investigation are to: (1) analyse the stress-strain situation of grapevines pruning and wine harvesting in vineyards (especially for hand-arm-system), (2) find ways to reduce strain for wine growers and (3) help implement ergonomic improvements (especially for cutting hand tools).

2. Methods

2.1. Work analysis

The newly developed Hand Tools-oriented Work Analysis Method (HTWAM-Method, see PETERSON et al., this issue) was used in a field study to analyse the work system “pruning grapevines” (Fig. 1) and “wine harvesting”. The analysis covered task performance, work environment, tools used, actions forces and working postures adopted. This screening method is based on the K-AET- and ABBA-Methods [4]. The method includes more detailed analysis of items relating to positions of the hand-arm system during task performance and hand tool design features. For example, the factors involved are: weight and dimensions of tool, grip and surface characteristics (material and surface structure, friction arising at surfaces), possibility of using different grips, mechanical output, level and transmission of the forces involved.

Fig. 1. Description of the work system “pruning grapevines”.
2.2. Analysis of task performances and positions of hand-arm systems

The NOLDUS Observer system [9] was used to collect and statistically analyse observational data. The data used are: task performance (reach and cut, removing pruned branches, rest breaks), positions of the hand-arm system holding the tool and of the other hand-arm system (hand-arm below or above shoulder height), overall working posture (standing with straight back, standing with back bent, walking).

The analyses performed with the Observer system were based on time-coded video records of pruning work at different vineyards and data collection on 3 levels (Fig. 2). As “classes” were defined the cutting hand-arm-system (C.1) with the “elements” (task performance, hand position); non cutting hand-arm-system (C.2) with the same “elements” as by C.1; back and head (C.3) with such “elements” as head and back positions and type of cute grapevines (C.4) with such “elements” as cut of young grapevines or cut of old one or cut of leaves.

As “modifier1” of C.4 was defined by the positions of the wrist in the time of cutting of old or young grapevines and as “modifier2” how long was the cutting performance – from 0,5 sec. to more as 9 sec divided into 10 time classes.

2.3. Evaluation of working postures

The Ovako working Posture Analysis System (OWAS) [2] was used at the beginning of study to analyse and evaluate overall working postures. As the results obtainable with this method are not applicable to hand tool design, a method based on ISO 11226 and prEN 1005-4 was also used for detailed analysis and evaluation of working positions of upper arm and shoulder – upper arm [7].

2.4. Strain analysis

Electrophysiological methods [6] were used to evaluate the effects of the stresses on the vineyard workers. Effects on the cardiovascular system were assessed by heart rate measurement and the workload

Fig. 2. Structure of categories used for classification of data collected with Observer system.
on selected muscles by measurement of electrical activity in the:

- musculus (m.) flexor digitorum superficialis, m. bizeps brachii and the m. deltoideus pars spinalis while pruning grapevines
- m. bizeps and m. deltoideus while wine harvesting.

The data were digitally recorded with a portable system from Par Electronics and analysed by means PC.

3. Results

3.1. Stress-strain analysis grapevines pruning in field study

3.1.1. Analysis of work system

The results contained in this report relate only to pruning work performed in level-ground vineyards in the Rheingau wine-growing region in Germany. The vines were of the Riesling and Spätburgunder variety growing on the wire trellis structures widely used in this type of German vineyard. Two different methods of vine pruning are used in the Rheingau region. In the first, the branches are cut off and pulled out of the trellis in one work sequence (Fig. 3). In the second method, pruning is the first work sequence and removal from the trellis the second work sequence. As the second work sequence can be performed by unskilled workers, this method reduces labour costs.

The present study analysed pruning grapevines with five non-power shears from different manufacturers (Fig. 4) and 2 power tools (electrical and pneumatic) operated by a total of eight workers. Table 1 includes technical data of hand tools for grapevines pruning used in region Rheingau.

Fig. 3. Pruning grapevine in the Rheingau.
3.1.2. Results from analysis of task performances and positions of hand-arm systems

A detailed analysis of the cutting performances was done with the help of video analysis PC-tool “Observer”. Results of cutting frequencies and heights of hand-arm positions are illustrated in Table 2. Grapevines of the type Riesling were analysed. The results reveal that cutting with pneumatic tool is up to 30% more effective (according to productivity) than cutting with non-powered hand tools. The dominant position of height of the cutting hand-arm is in non-stressive areas, i.e. from hip to shoulder and under hip. The non cutting hand-arm rested more than 1/3 of the analysed time.

Table 3 shows the pruning rates achieved with different types of tool and vine as example. The pruning work is analysed by effort required (for example age of grapevine). The analysis covers 10 work cycles (each individual cycle involving 3 vines and lasting approximately 3 minutes). The vines were of the Riesling variety.
Table 2
Results of workloads analysis while grapevines pruning (based on PC-tool Observer)

<table>
<thead>
<tr>
<th>Stress factors</th>
<th>Shears</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F7</td>
</tr>
<tr>
<td></td>
<td>29 ± 5</td>
</tr>
<tr>
<td>Frequency of cutting performances and hand position</td>
<td>Hand normal</td>
</tr>
<tr>
<td></td>
<td>Hand flexion / extension</td>
</tr>
<tr>
<td></td>
<td>Hand ulnar / radial</td>
</tr>
<tr>
<td>Frequency of cutting performances and type of grapevine</td>
<td>normally grapevine</td>
</tr>
<tr>
<td></td>
<td>Thick grapevine</td>
</tr>
<tr>
<td></td>
<td>Cut of leaves</td>
</tr>
<tr>
<td>Cutting hand-arm above shoulder</td>
<td>7% ± 2</td>
</tr>
<tr>
<td>Non-cutting hand-arm above shoulder</td>
<td>5% ± 2</td>
</tr>
</tbody>
</table>

Table 3
Specimen pruning rates (mean values based on 10 work cycles, test person no. 2)

<table>
<thead>
<tr>
<th>Type of Shears</th>
<th>Number of cuts performed</th>
<th>Percentage of normal young vines (1–2 years old) %</th>
<th>Percentage of old vines (&gt; 2 years old) %</th>
<th>Trimming only %</th>
</tr>
</thead>
<tbody>
<tr>
<td>“F7”</td>
<td>106</td>
<td>60</td>
<td>3</td>
<td>37</td>
</tr>
<tr>
<td>“LÖ”</td>
<td>91</td>
<td>63</td>
<td>10</td>
<td>27</td>
</tr>
<tr>
<td>“Ni”</td>
<td>160</td>
<td>58</td>
<td>3</td>
<td>39</td>
</tr>
</tbody>
</table>

The average cutting rate is 23 to 30 cuts per minute, of which roughly 60% are on young (1–2 year old) vines. These cuts are not spread evenly across the total working time. Their frequency is higher during work sequences in which cutting predominates and lower in those in which the removal of cut branches predominates. The interval between two cuts can in some cases be less than 0.5 seconds.

3.1.3. Results from working-postures analysis

Table 4 lists the frequencies of “not recommended” (definition from ISO 11226 and EN 1005-4) working positions while pruning grapevines by 6 test persons using the same hand tool (F7). The results show that approximately 50% of the trunk positions observed in four test persons (P 5, 6, 3 and 2) can be classified as “not recommended”. There is also a high incidence of “not recommended” positions of the head and neck, ranging from 31% in test person no. 2 to 69% in test person no. 1. Between one quarter and one third of the shoulder and upper arm positions can also be classified as “not recommended”.

Possible influences of non-power and power tools on the working postures were analysed (Table 5). These reveal only minor differences (up to 5%) in the frequencies of “not recommended” working positions of the shoulder-upper arm and the forearm-hand systems, but rather wider differences (15%–23%) in “not recommended” trunk and head positions with different non-powered tools. Comparison of non-powered and powered tools revealed only minor differences (up to 10%) in frequencies of “not recommended” working positions for all parts of the body.

3.1.4. Results from climatic conditions analysis:
– air temperature changed from 0°C in the morning to 9°C afternoon;
– humidity ranging from 44% to 86%;
– air movement achieved often 9 m/sec.
Table 4
Results of posture analysis for 7 wine growers used non-power cutting tool F7

<table>
<thead>
<tr>
<th>Part of body</th>
<th>Frequencies of not recommended working positions (% of all analysed postures)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P1</td>
</tr>
<tr>
<td>Trunk</td>
<td>32.0</td>
</tr>
<tr>
<td>Shoulder and upper arm</td>
<td>40.7</td>
</tr>
<tr>
<td>Forearm and hand</td>
<td>29.0</td>
</tr>
<tr>
<td>Head and neck</td>
<td>69.3</td>
</tr>
<tr>
<td>No. of postures analysed</td>
<td>300</td>
</tr>
</tbody>
</table>

*female; P = working person.

Table 5
Frequencies of not recommended working positions while grapevines were cut used different tools

<table>
<thead>
<tr>
<th>Hand tool part of body</th>
<th>Person 1</th>
<th>Person 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&quot;F7&quot;</td>
<td>&quot;Lo&quot;</td>
</tr>
<tr>
<td>trunk</td>
<td>32.0</td>
<td>47.0</td>
</tr>
<tr>
<td>shoulder/upper arm</td>
<td>40.7</td>
<td>44.2</td>
</tr>
<tr>
<td>forearm and hand</td>
<td>29.0</td>
<td>35.4</td>
</tr>
<tr>
<td>head and neck</td>
<td>69.3</td>
<td>46.4</td>
</tr>
<tr>
<td>No. of postures analysed</td>
<td>300</td>
<td>181</td>
</tr>
</tbody>
</table>

3.1.5. Example results from strain analysis

Figure 5 shows a specimen strain curve over a full working day for test person no. 2 using F7 shears. This test person was not only cutting but also removing the cut branches with the other hand. This is a heavy dynamic work and consequently led to a slight rise in heart rate during the course of the working day. The overall strain can be rated as tolerable for cutting grapevines by different shears (Fig. 6) because the working heart rate remained below the upper limit for strain [6].

For local strains (muscle activity) it was found that the musculus biceps brachii provided the greater part of the support to the musculus flexor digitorum superficialis during the pruning work. The minor rises in electrical activity indicate a very low degree of muscular fatigue. In contrast, the electrical activity in the musculus deltoideus pars spinalis showed less strong fluctuations.

![Strain curve](image.png)

Fig. 5. Strain (including regression line) registered in test person no. 2 using F7 tool.
3.2. Results of stress-strain analysis of cutting performances in laboratory study

3.2.1. Background

A detailed stress-strain analysis was carried out in laboratory [8]. In the analysis, four different types of non-powered tools F7, Fi-Erg, L0 and W RS22, were used. Two hand-arm postures, hand-upper arm neutral position and forearm in supination (position 90°) as well as different cutting tasks and hand grips were analysed.

The load was evaluated by means of the EMGs of two muscles (m. flexor digitorum superficialis and m. extensor digitorum) and through subjective ratings. Eleven persons (2 winegrowers and 9 students) took part in the study.

3.2.2. Results

In general, tools based on the “shearing” principle (for example F7, Fi-Erg.; Fig. 4) resulted in lower strain situations compared to those operating in an “hammer/amboss” principle (e.g. L0). Results show that in the closing/opening process, the type “F7” was to some extent preferred to the type “Fi-Erg”. Cutting of grapevines produced a different ranking. In this case, the type “F7” was substantially preferred against the type “W-RS22” and the type “L0”. Prunes operated in neutral wrist position resulted less fatigue than those position if wrist was supinated. These results are based on the strain situation of two muscles, namely the m. flexor digitorum superficialis and the m. extensor digitorum.

The strain analysis of m. flexor digitorum superficialis during the first cycle of the experiment (close and open shears) revealed increased strain of the muscle in the position “hand supinated” compared with the position “hand neutral”. Looking on strain of the m. flexor digitorum superficialis while shears will close /open of the (hand and arm neutral), the mean values have the following ranking order: 1) type “W-RS22”, 2) type “Fi-Erg”, 3) type “L0” and 4) type “F7”. The same ranking was maintained in the experiments with hands in a supinated position. Cutting of grapevines resulted in a strain which was 2 to 4 times higher than during the closing and opening process. These results show that the use of the “F7” and “Fi-Erg” shears resulted in lower strain levels compared to the use of “L0” and “W-RS22” prunes.

While looking into the subjective rating of prunes, it was found that lay people took into consideration the results of the experiment only, whereas professional users included also the working experience in their rating. The brand of prunes currently used by the worker in his or her job also influenced the subjective rating.

For local strains (muscle activity) it was found that the musculus biceps brachii provided the greater part of the support to the musculus flexor digitorum superficialis during the pruning work. The minor
rises in electrical activity indicate a very low degree of muscular fatigue. In contrast, the electrical activity in the musculus deltoideus pars spinalis showed less strong fluctuations.

3.3. Results of stress-strain analysis during wine harvesting

Data on the stress-strain situation during wine harvesting was gathered in a field study at two vineyards in autumn (September–October). This data included:

- analysis of different types of shears to be used in wine harvesting (Figs 7 and 8, Table 6),
- analysis of the working process, performances and working postures (especially of upper extremities),
- analysis of the strain data as a base for evaluation of the stress factors. The data included heart rates and EMGs of two muscles (m. bizeps and m. deltoideus).

During wine harvesting, make working person perform about 4–5 cutting actions per minute. The quantity depended on the type of wine, vineyard, working person and some other factors. The force needed for performing the cutting actions was small. The dominant position of the cutting hand-arm was in non-stressive areas (from hip to shoulder and under hip). The non-cutting hand-arm does not have much time for resting (less than 10% of the analysed time).

Quantitative results of the frequency of the not recommended positions of trunk, shoulder and upper arm, forearm, hand and head during cutting with different hand tools were obtained. The results show that there are very small differences (up to 10%) between the frequencies of not recommended working positions of shoulder-upper arm – forearm – hand system during cutting with different shears. More differences (15%–23%) can be found in the trunk and head positions. The mean heart rate of 5 test

![Fig. 7. Cutting tools used for wine harvesting (products from Germany and Japan).](image)

![Fig. 8. Cutting tools for wine harvesting (Products from Finland).](image)
persons during wine harvesting was nearly 30/minute above of the level before the measurement. This means that this cutting work is less stressful than cutting of grapevines. The type of Fi-Erg shears on the right in Fig. 8 was regarded the best in the subjective ratings given by the eight working persons.

4. Conclusions

The results obtained in this study indicate that, from the ergonomics viewpoint, grapevine pruning involves mainly muscular work. The level of the workload varies according to the work method used (i.e. cutting only or cutting and simultaneous removal of the cut branches), the work rate and the vineyard. Vine pruning in level-ground vineyards and at normal working rates involves mainly dynamic muscular work. In vineyards situated on slopes the height differences that the worker has to negotiate invariably necessitate heavy dynamic muscular work. In terms of muscular effort, pruning without subsequent removal of the cut branches involves a slightly higher degree of total strain. This is mainly due to the higher cutting rate and the increase in the incidence of undesirable postures involving high static stress in the dorsal region. In cases where trimming (the removal of shoots from the vine branches) was delayed until the second work sequence, there was an increase of around 40% in cutting rate with a higher proportion of cuts on young (1–2 year old) vines. This was clearly reflected in both total and local strain on the m. flexor digitorum superficialis of the arm performing the pruning. If one adds the stresses and strains arising in the second work sequence, vine pruning with non-powered shears without simultaneous removal of the cut branches gives rise to a higher total strain. Thus, when working with non-powered pruning tools, the work method involving pruning and simultaneous removal of the cut branch is ergonomically preferable to pruning only.

This study shows that vine pruning entails a number of working positions of the upper limbs and shoulders that constitute a direct risk of musculoskeletal disorders and diseases. The results vary from person to person and vineyard to vineyard (for example sloping or flat, method of cultivating and training the vines, age of the vines). The most critical positions are those affecting the upper arm and especially the wrist.

The high frequency of repetitive movements during vine pruning imposes a high strain on the hand-arm system. The intervals during which the cut branches are removed allow the hand operating the prunes to rest and these obviously do not occur in the “cutting only” procedure.

Comparisons of different types of prunes were only performed intraindividually, i.e. in individual workers using various types of prunes. Primary design differences between the prunes had already been established in the work system analysis. The power-driven tools are approximately three times heavier than the non-powered pruning tools. This means that static holding work accounts for a substantially higher proportion of total muscular work involved.

No differences were observed in the total strain caused by the various types of non-powered pruning shears. Design suggestions were formulated from the data obtained on stresses and strains observed
during the field and laboratory studies [7,8] and from reference to the literature. They indicate possible
directions and improvements in the design of pruning prunes but their exact effects still need to be tested.

Acknowledgement

This study was supported by the European Community under the Industrial and Materials Technologies
Programme (Brite Euram III), “Eurohandtool” Project (Contract no BRPR-CT96-0350).

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