The Effect of Task Frequency on the Risk of Biomechanical Overloading of the Upper Limb During Tomato Binding

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Abstracts
Greenhouse tomato growing involves specific cultivation operations, such as green pruning, tying the plants and distribution of pesticides and fertilisers. Although they do not require particular effort they involve repetitive movements of the upper limbs and often they induce the operator to assume an incorrect posture. As regards the tying of tomato plants, this study shows how the task frequency influences the risk of biomechanical overloading of the upper limbs. It also deals both with the degree of saturation of the limbs and its effect on the daily productivity curve. It intends to enhance if there are any differences between the Ocra Index when this is calculated on the basis of the average daily frequency and when it is calculated on the basis of representative frequency values for different periods of time obtained from field observations. The data was obtained by observing the work carried out by operators standing on a mobile platform. The data regarded the tying of the plants to vertical wire supports and the removal of side-growths next to the apex, operations that may be performed at the same time. All the details of the work were recorded as were the execution times and methods. The action frequency was calculated with an analytical counting of the technical actions examining a video film of the work in slow motion.
A statistical analysis of the frequency carried out with publicly available software, was performed on the data collected in two work sites, each composed of two operators responsible for the manual tying of tomato plants. The operators were on a mobile platform. Analyses of the saturation of the limbs and the exposure indices were carried out using the software "midaOCRAmulticompiti". The analyses confirm the high level of saturation of the limbs. From the numerous data obtained it can be seen that the work productivity of the operators depends on the characteristics of the site and the tiredness of the operator, which was found to be variable during the day. To reduce the risk arising from the high levels of repetitiveness and obtain a suitable action frequency it would be necessary to reduce the work rhythm with a consequent increase in cycle time and reduction in productivity, a solution farms are reluctant to accept. Facilitating machines, such as the mobile platform, increase productivity and they should be designed in such a way as to permit more correct posture.

Keywords: OCRA, greenhouse, frequency, productivity

Introduction
One of the main aspects of ergonomics concerns the so-called WMSDs (Work related muscle-skeletal disorders), a generic definition of muscle-skeletal disorders that affect workers subject to incorrect postures and who do repetitive work. Among these pathologies, generally of a multifactorial origin, we may mention some that concern professional illnesses: tendinitis, epicondilitis (tennis elbow), and the carpal tunnel syndrome (*Colombini et al*., 2005).

The cultivation of tomatoes in greenhouses is carried out with specific cultivating operations, such as green pruning, tying the plants and the distribution of pesticides and fertilizers. They do not require particular effort, but repeated movements of the upper limbs often induce workers to assume postures that are not correct (*Schillaci et al*., 2009).
Regarding tying tomatoes, this research aims to ascertain:
a) the extent to which the frequency of the work affects the risk of biomechanical overloading of the upper limbs,
b) if there are any differences between the OCRA Index calculated on the basis of the average daily frequency and that calculated on the basis of the average frequency for each hourly time slot,
c) the daily productivity curve and, if this is positive, highlight the progression.

Materials and methods
The trials were carried out in a greenhouse situated in the south east of Sicily (province of Ragusa). It has a surface area of about 5,000 m^2 and the metallic structure, covered with a plastic film, is subdivided into 10 sections, each 70 m long and 9 m wide. The highest point is 5.8 m, and the tomato plants cultivated there during the tests were on average 2.70 m high. The distance between the double rows is 1.80 m, while the distance between single rows is 0.85; the distance between the plants on each row is 0.75 m. Considering the double structure form of cultivation there were about 180 plants for each row.
The investigations involved tying the plants on vertical support wires, and green pruning that can be done at the same time. (*Fig. 1*).

Fig. 1- Tying the tomatoes

The tying consists in manually twisting the stem of the tomato plant around a vertical support wire. The work of two sites was timed, each comprising 2 workers positioned on a mobile caterpillar platform (*Schillaci et al.*, 2009); the working day begins at 7.00 a.m. and finishes at 4.00 p.m. and was broken down into time slots of an hour.
All the details of the work and the times and ways of carrying out the work were recorded according to the C.I.O.S.T.A. - A.I.G.R. methodology.

The movements were assessed and counted re-examining the technical actions in the field and subsequently through films shown in slow motion. The strength value was obtained by the assessment of the pruners
The exposure indices were calculated using the software "midaOCRAmulticompiti", using both the average daily frequency and the average frequency of each timeslot.
Beginning with the real capacity (plant/h), the frequency was deduced (cycles/min), which represents one of the main parameters of calculations in the OCRA index.

Results and discussion

Organization of the work

Each operator works standing up on the platform and uses his upper right and left limbs in a different way. Both workers are right-handed and carry out the main action with their right hand. The operator holds the stem of the plant with his left hand while he twists the stem around the vertical support wire with his right hand. Given the kind of work, the exposure indices are calculated only for the right hand that is subjected to greater strain. The activity is the same for the entire work cycle and does not require particular effort, but a repetitive movement of the upper limbs; besides, the posture is punishing because the arms are often held above the shoulders. The activity is characterized by the same set of movements kept up for more than 2/3 of the time of the cycle.
The average time taken to work a row is 1024 s, with a standard deviation of 116, and a variation coefficient (%) of 11.34% (Tab 1).

Tab. 1 – Average times of timeslots

Tomato tying	s/row
Timeslot	**s**
7÷8	1151
8÷9	985
9÷10	840
10÷11	872
11÷12	1080
12÷13	pause
13÷14	1080
14÷15	998
15÷16	1186
Average	1024

Beginning with the average times per row and the number of plants per row, the capacity of the work site (plant/h), the productivity (plant/h·op.), the frequency (cycles/min·op.), and the time unit (s/plant) are obtained. The average productivity is 588 plants per hour per worker, with a standard deviation of 69.66 and a CV% of 11.85% (Tab. 2).

Tab. 2 – Productivity and frequency

	Productivity plants/h·op.	**Frequency** cycles/min·op.	s/plant
7÷8	516	8.6	7.0
8÷9	603	10.1	6.0
9÷10	707	11.8	5.1
10÷11	681	11.4	5.3
11÷12	550	9.2	6.5
12÷13	Pause		
13÷14	550	9.2	6.5
14÷15	595	9.9	6.0
15÷16	501	8.3	7.2
media	588	10	6
Σ	69.66	1.16	0.70
CV%	11.85%	11.85%	11.34%

Productivity tendency

The productivity indices were calculated by using the ratio between the daily productivity and the average hourly one, relative to the work (Tab. 3).

Tab. 3 – Work productivity of tying tomatoes in the green house

Tying tomatoes	Productivity	Average productivity	Productivity Index	Difference
Timeslots	Plants/h·Op.	Plants/h·Op.	%	%
7÷8	516	588	87.77	-12.23
8÷9	603		102.56	2.56
9÷10	707		120.26	20.26
10÷11	681		115.85	15.85
11÷12	550		93.54	-6.46
12÷13	PAUSE		-	-
13÷14	550	588	93.54	-6.46
14÷15	595		101.22	1.22
15÷16	501		85.18	-14.82

The maximum values of productivity are reached in the timeslot 9÷10 (+ 20.26%). The lowest productivity level takes place during the first hour (-12.23%), the last hour of work (-14.82%) and the one close to the lunch break (-6.46%). We made the work productivity curve from the values we obtained. (*Fig. 2*).

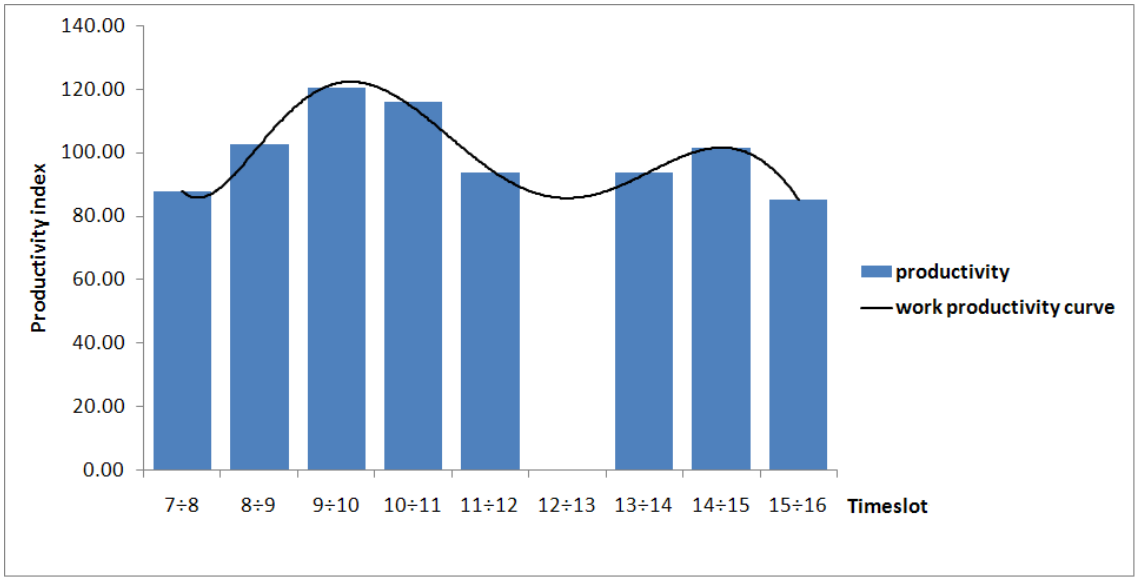

Fig. 2 – Indices and work productivity curve

The OCRA indices

The data for the calculation of the exposure index are listed below (Tab. 4). The effort required is almost zero (FF = 1); the posture is punishing (FP = 0.5); the activity is characterized by repetitive mechanized movements (FS = 0.85); no complementary factors were noted (FC= 1); and a "recuperation" adequate for each hour of work was assigned (FR = 1).

Tab. 4 – Data for the calculation of the exposure index

	Tying of tomatoes
Duration of shift (min)	480
Average duration of cycle (s)	5
CF (constant of frequency)	30
FF (strength factor)	1
FP (posture factor)	0.50
FS (stereotype factor)	0.85
FC (complementary factors)	1
Du (duration factor)	1
FR (recuperation factor)	1
D (duration repetitive task) (min)	440

Beginning with the average frequency of each timeslot (cycles min^{-1}), the number of technical actions per minute was obtained and the OCRA indices were calculated (Tab. 5).

Tab. 5 – Calculation OCRA Index

Timeslot	actions / min	OCRA Index
7÷8	43	3.4
8÷9	50	3.9
9÷10	59	4.6
10÷11	57	4.5
11÷12	46	3.6
13÷14	46	3.6
14÷15	50	3.9
15÷16	42	3.3
Daily	49	**3.8**

The daily index of exposure is 3.8, and can be relegated to the slot of light red risk, in which the risk is slight.
The recording of the frequency for separate hourly timeslots has highlighted that for 50% of the time of daily work, the OCRA Index stays above the OCRA Index calculated by resorting to the average daily frequency (3.8). The greatest exposure to risk is between 9 and 10 (equal to 12.5% of the working day), in which the index is set in the slot of highest risk (medium risk, 4.6). In the time slots 7÷8 and 15÷16 (25% of the working day) there is lower exposure to risk that is relegated to the yellow slot or borderline (*Fig. 3*).

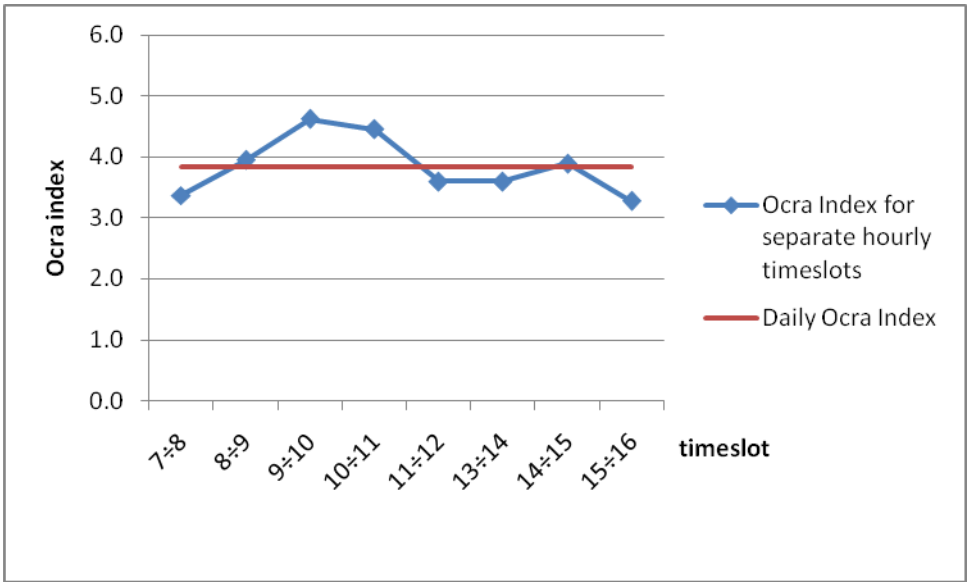

Fig. 3 – Comparison of OCRA indices

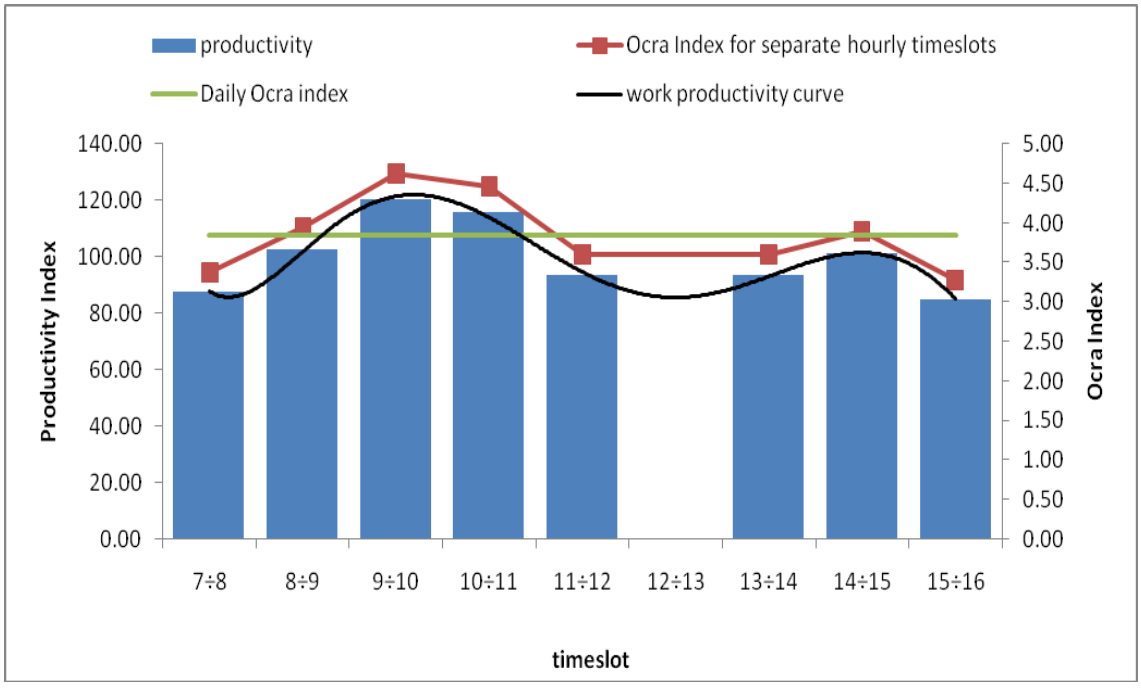

Fig. 4

The productivity curves and the OCRA index on an hourly basis can overlap and show an elevated affinity and confirm how much the index depends on productivity; the line parallel to the axis of the abscissa represents the OCRA index calculated on a daily basis (*Fig. 4*).

Conclusions and recommendations

The survey leads us to state that the presence of potentially repetitive tasks, like pruning fruit crops, the high visibility of the objective (the shoots to be eliminated), and the closeness between one objective and another, can be considered indicators of exposure to risk. These conditions appear to be satisfied in the winter pruning of vines too.

For this work, the productivity (number of worker divided by real work capacity) and the frequency (according to OCRA equal to the number of movements per minute) are closely correlated, because of the high incidence of repetitiveness of movements and the reduced instances of pauses between one movement and the next. Over the course of the working day, the productivity follows an undulating tendency and may be represented by a curve that presents two peaks, corresponding to the central hours of the morning and afternoon, and a minimum, near the lunch break, which corresponds to results of other studies (*CNR*, 1981; *Bonsignore et al.*, 2010). This is indicative of how the tiredness of the worker affects the frequency of the work.

The importance of the frequency can be seen also by consulting the OCRA Indices calculated with the average frequency of each timeslot with that calculated on the basis of the average daily frequency. A decrease of the index of exposure corresponds to a reduction of the frequency, and consequently there is a reduced risk of biomechanical overloading of the upper limbs.

We can state that the OCRA index calculated on the basis of average daily frequency provides an underestimation of risk for 50% of work and disguises the increase to a higher level of risk for 12.5 % of the time.

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