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Study of biomechanical overload in urban gardeners of Barcelona: application of analytical models for risk exposure evaluation in annual working cycle

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Abstract. Occupational musculoskeletal disorders in the upper limbs and its consequences on the impact and prevalence in the work force are subject of many investigations in almost all the production fields. However, the exposure to this kind of risk factor on urban gardeners has not been well studied so far. The kind of plant varieties used in the parks, the tools that they use, as much as the necessary actions for the maintenance of the park, have an impact on the biomechanical overload of the upper limbs. Additionally, the analysis of the exposure to the biomechanical overload on upper limbs in gardening work is a complex task, mainly because it is an activity highly variable and of annual cycle. For this reason an analytical model for risk exposure evaluation is necessary. During this research the work activity of 29 gardeners in 3 urban parks of Barcelona has been analyzed. Each park has a specific acting plan, in relation with the quantity and the typology of vegetal species, its classification and the season of the year. Work and observation and video recording sessions on-site were conducted. The video-graphic registration was done on workers without any prior musculoskeletal disorder and with a minimum labour experience of 5 years. Moreover, the analysis of saturation time, considered as the relation of the repetitive working hours in reference with the hours of effective work was done. Using the registered tasks on video, the biomechanical overload on upper limbs applying the OCRA Checklist method was analyzed. **Results:** A methodological procedure to analyze the risk exposure in annual working cycle has been proposed. The results that we got allow us to get information that can help in the assignment of the tasks and in the training of staff, as well as in the recommendations of the urban landscape's design. All these aspects have the goal to decrease the risk to develop work-related musculoskeletal disorders

Keywords: Gardening, biomechanics, risk exposure, highly variable exposure, musculoskeletal disorders, annual cycle.

1. Introduction

The concept of garden as a space where to cultivate plants is probably as ancient as human settlements, even though for many centuries it was used more as a status symbol, in order to show ones power and wealth. We have clear examples of this in Europe, dating as far back as the Renaissance. The concept of garden as a place for the entertainment of senses is without any doubt more recent. Since the beginning of XX century gardens are an integrative part of the city.

The landscape gardening is a new discipline of the urban agriculture (an agricultural practice that is made inside or on the outskirts of an urban area). This kind of gardening is based on the cultivation of plants, as an ornamental function; the economic goal is not as important as in the traditional agriculture. Some examples of spaces used for the landscape gardening are public and private parks, courtyard and gardens.

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The urban gardening is a practice that grew significantly in the last couple of years, due to an increase in the quality of life and to a higher environmental consciousness. The International Health Organization recommendation for the cities is to dispose a minimum of 10 to 15 m2 of green space per habitant. In the last years, the surface of green areas in Barcelona has increased about 12%, and today it gets an actual ratio of 17,3 m2 per habitant of green and natural areas.

Gardeners take care of the grass and of the plantation of various kinds of plants annually (plants for garden) and of the plantation and the maintenance of bushes and trees [1]. This kind of tasks makes gardening an activity where the labour force is a real important and essential component.

The kind of works that gardening requires in a park can vary according to the period of the year and the vegetal status of the plants. In this research we present the characterization of the exposure to the biomechanical overload in upper limbs during the annual cycle of the gardeners that are in charge of the maintenance of three parks in the city of Barcelona.

2. Methodology

In this research we analyzed the activity of a total of 29 gardeners that are in charge of the maintenance of 3 urban parks of Barcelona (see Table 1), in a range of age between 20 and 55 years old (see Table 2).

The working day of the gardeners is 7 hours, from 8.00 to 15.00.

They have a break for half an hour, between 10.00 and 10.30. The time that they use to move through the park to get the working place is approximately 15 minutes at the beginning of the day, and 15 minutes at the end of the day.

They work 5 days per week, from Monday to Friday, for a total of 35 hours per week and 1549 hours per year.

Park A has a surface of 17,43 hectares and it has a large grass area and big walk paths; park B has a surface of 3,16 hectares and it is rich of parterres with rosebushes; park C has a surface of 1,65 hectares and is rich of big hedges, vegetables and bindweeds.

Table 1

Number of gardeners for sex

Gardeners per sex	Park A	Park B	Park C	Total
Number of men	11	4	7	22
Number of women	5	2	0	7
Total	16	6	7	29

Once the necessary administrative permissions to develop the research have been obtained, interview with people in charge of each park was contacted in order to explain the goal of this study and the content of the working sessions on-site. All of them accepted to collaborate and gave us their complete consent.

Table 2

Distribution of gardeners per parks, according to age range

Gardeners per age	Park A	Park B	Park C	Total
20-30 years	1	0	1	2
> 30 - 45 years	9	3	4	16
> 45 -55 years	6	3	2	11
> 55 years	0	0	0	0
Total	16	6	7	29

Thanks to interviews conducted on the participants in charge of the organization of each park, information about working organization, assignment of tasks amongst the group of gardeners and temporal planning were collected.

Working sessions on-site were made: an industrial engineer with a previous training observed and registered the labour activities on video. Workers with no musculoskeletal disorders and with a minimum working experience of 5 years were selected for video registering.

A video registration of a minimum of 10 minutes with non-stop was made for each task, even if the work was really repetitive, in order to be sure to represent a high number of postures and movements that they require during their job. For each task, a minimum of three different workers were registered with the goal to identify the more frequent working habits.

Planning of the working sessions on-site was organized with the person in charge of the work of each park with the main goal to observe different tasks or conditions. The planning was altered in many occasions, due to meteorological reasons, to machines or tools' availability and to the change of organizational requirements.

In fact, the bad meteorological conditions can cause the change of some programmed tasks. For example, when it rains, they work on tools' cleaning task; when there is strong wind, they remove fallen trees and when it snows, they remove the snow from the points of access to the park. In our research we did not take in consideration these unplanned tasks.

Once the tasks were defined, the filming files were edited in order to finally get video-archives that could represent each activity with duration of approximately 1 minute.

Using these videos, the analysis of the biomechanical overload in upper limbs, applying the OCRA Checklist method [2] was done. The

Checklist method [2] was done. The application of this method to similar activities as agriculture has been published in some papers [3, 4].

In reference to the information related with the time of exposure to each one of the tasks, we extracted them from the daily register that the manager of each park prepares. In order to characterize the exposure of a whole year, we used the register of the year 2009.

3. Results

Each park is associated with a specific action plan, according to the quantity and the typologies of vegetal species, its classification and the year season.

In tables 3, 4, 5 the hours per month that the gardeners dedicate to each task for every park are shown.

Due to the variability of the work planning, it was not possible to shoot all the tasks, which have been accomplished during the year. However, the tasks that we analyzed represent the 80% of the working time during the year (See Table 6).

Table 3
Monthly hours dedicated to each task in park A, year 2009.

Park A	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Total
To provide compost and substrates		22			18					12	35		87
To bring bark of pine													0
To change and collocate earth													0
To hoe manually					3		4	2		6	12		27
To hoe mechanically		4	48		22	20	10	5		6	17		132
To plant trees in areas				5				18	8	2			33
To plant trees in lining up		23		1		4				5			33
To plant flowers' plant	5	24	24	44	188			35	106	4	122		552
To plant other vegetables		60	24		28	5	44		9	24	4		198
Grass: to cut	8	92	134,5	199,5	129	119	186	150	135	88	116	38	1395
Grass: to sow			15				1			3			19
Grass: to fill holes										9	5		14
Grass: to scarify			202										202
Grass: to remove garbage and vegetation	45,5	54		82	61	50	82	76	71	46	49	101	717,5
To clean green surfaces	80	80	87	111	103	112	126	138	113	118	152	142	1362
To clean sand and pavement	216	130,5	131,5	92	107	99	106	95	116	124	188	149	1554
To clean lakes	3	12	2	2,5	128		1		3,5	4,5	2,5	1,5	160,5
To clean hut		2	9,5	11,5	3	1	8,5	6	2	2	1	10	56,5
To clean tree wells		26											26
To prone trees in areas	10			15	3			4					32
To prone trees lining up			8			3							11
To prone hedges, bushes...	364	308,5	22		96	142	362	198	40	100	166	225,5	2024
To pull up trees				1				2					3
To pull up other vegetables	2	4		101				73		42	9		231
Mounting irrigation system													0
Irrigation by sprinkler		6	66	12	4	6,5	11	48	30	4			187,5
Irrigation by hose	23	55	73,5	17	68	159	81	161	39	36	55	14	781,5
Light digging	68	172	137	173	115	151,5	76	27	49	119	48	3	1138,5
To remove weeds	4	42	222	33	82	19	87	5	118	44	28	23,5	707,5
To ring out	14	1			24	3							42
To polish and to put in order the sand	18		88		8		18		65		29	10	236
Weedkiller treatment and to fence			12	6	18						16		52
To pick up and to transport garbage	273	165	168	123	169	135,5	196	138	176	152	192	156,5	2044
To move from one place to another							0,5						0,5
Supervision and control	117	114	114,5	63	65,5	71	67	64	29	27	23,5	20	775,5
Different repairs	50,5	29	57,5	56	36,5	110	64	57	40,5	9,5	13,5	32,5	556,5
Specific: to open the park		32		13	10	11,5	11	16	12	3	13	19	140,5
Specific: to dismount manger	44,5												44,5
Specific: to place sward			283										283
Specific: greenhouse										37		105	142
Others	11		21	36			23	3	16	62	15,5		187,5
TOTAL Hours of work	1357	1458	1950	1198	1489	1222	1565	1321	1178	1089	1312	1051	16188,5
TOTAL Other hours	463,5	648	559	1052	831,5	955,5	1080,5	999,5	973,5	1100,5	765,5	1134	10562
TOTAL Hours per month	1820	2106	2509	2249	2320,5	2177,5	2645,5	2320,5	2151,5	2189,5	2077,5	2184	26750,5

Table 4
Monthly hours dedicated to each task in park B, year 2009.

Park B	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Total
To provide compost and substrates	15												15
To bring Bark of Pine	46,5	67,5	44	32,5								9	199,5
To change and collocate earth			98	16									114
To hoe manually													0
To hoe mechanically	4	10									12		26
To plant trees in areas		11	5		4								20
To plant trees in lining up						12							12
To plant flowers' plant		59	25	6							9,5		99,5
To plant other vegetables	11		63		13		9						96
Grass: to cut	4	4	78	76	112	115	105	120	81	67	38,5		800,5
Grass: to sow													0
Grass: to fill holes		28,5											28,5
Grass: to scarify													0
Grass: to remove garbage and vegetation	2	7,5	24,5	48,5	39	21	58	22	26	18			266,5
To clean green surfaces	33	29	26	21	30	22	27	25	22	26	36	32	329
To clean sand and pavement	28	25	25	29	46	23	32	25	28	26,5	30,5	28	346
To clean lakes													0
To clean hut	8	8	8	10	6	8	10	8	8	10	9	10	103
To clean tree wells													0
To prone trees in areas		4											4
To prone trees lining up		5											5
To prone hedges, bushes...	264,5	186,5	21	83,5	75	131	151	39	47	214,5	227,5	324,5	1765
To pull up trees													0
To pull up other vegetables													0
Mounting irrigation system													0
Irrigation by sprinkler													0
Irrigation by hose			23	3	8	13	13	2	4				66
Light digging	35	102,5	45,5	4								60,5	247,5
To remove weeds	4,5		196,5	70	173,5	137,5	95,5	153,5	177	166,5	86,5	5	1266
To ring out													0
To polish and to put in order the sand	4	10		3	50		3		4	18	15,5		107,5
Weedkiller treatment and to fence				27									27
To pick up and to transport garbage	67	61,5	63	41,5	60	42	46	47	41	48,5	51	41	609,5
To move from one place to another													0
Supervision and control	40	58,5	74,5	44	72	46	51	44	40	43	40	41	594
Different repairs	6	13			47	18	7,5	8	12		1		112,5
Specific: to open the park			66,5										66,5
Specific: to dismount manger	60,5												60,5
Others	51,5	6	6			4,5				10	18	25	121
TOTAL Hours of work	684,5	696,5	892,5	515	735,5	593	608	493,5	490	648	575	576	7507,5
TOTAL Other hours	95,5	116	108,5	275	64	187	289	324,5	290	171	244	243	2407,5
TOTAL Hours per month	780	812,5	1001	790	799,5	780	897	818	780	819	819	819	9915

Table 5
Monthly hours dedicated to each task in park C, year 2009.

Park C	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Total
To provide compost and substrates													0
To bring Bark of Pine			66	22,5									88,5
To change and collocate earth													0
To hoe manually													0
To hoe mechanically													0
To plant trees in areas						12							12
To plant trees in lining up	6			26						2	18		52
To plant flowers' plant								20	24				44
To plant other vegetables		20	10			24,5			11	12			77,5
Grass: to cut		24	40	52	78,5	54,5	28	41	54	27,5		26	425,5
Grass: to sow													0
Grass: to fill holes													0
Grass: to scarify													0
Grass: to remove garbage and vegetation	3	2	4	16	48	10,5	17	27,5	6				134
To clean green surfaces	70,5	78	73	62,5	68	62	48	8	52	78	149	58,5	807,5
To clean sand and pavement	71	53,5	55	65	66	96,5	82	31	49	73	73	43	758
To clean lakes													0
To clean hut	8	3	2			2	3	1	2	6	4	11	42
To clean tree wells													0
To prone trees in areas								2					2
To prone trees lining up													0

To prone hedges, bushes...	227	180,5	285	152	306,5	84,5			166,5	245	305,5	191,5	2144
To pull up trees													0
To pull up other vegetables	13							14,5					27,5
Mounting irrigation system		72											72
Irrigation by sprinkler		2	2		12	14	45,5	62,5	15	12	15	4	184
Irrigation by hose		13,5	36		21	30,5	152,5	160	53	15	11	2	494,5
Light digging			47	47	24	43,5	93,5		90,5	19		2,5	367
To remove weeds		28		52	4				2	15,5		25	126,5
To ring out													0
To polish and to put in order the sand										16			16
Weedkiller treatment and to fence													0
To pick up and to transport garbage	136	116	126	94,5	115	107	112,5	56	102	11,5	122	98	1196,5
To move from one place to another	21	21	22	17	19,5	18,5	21	8	18	19	20	16,5	221,5
Supervision and control		10	8			9		7		52	85	58	229
Different repairs			8	4		110	6	15		7	9	6	165
Specific: emergencies with trees	85	24	6				5			2			122
Others	10			5		16	28		3	32			94
TOTAL Hours of work	650,5	647,5	790	615,5	762,5	695	642	453,5	648	644,5	811,5	542	7902,5
TOTAL Other hours	129,5	262,5	211	294,5	186,5	241	398,5	502	372,5	233	144	413,5	3388,5
TOTAL Hours per month	780	910	1001	910	949	936	1040,5	955,5	1020,5	877,5	955,5	955,5	11291

Table 6
Working hours and percentage of representation

Representation		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	In the whole year
Park A	Net time of repetitive work (h)	861	1118	1589	907	1208	894	1204	1043	905	836	1055	823	12443
	Working time studied (h)	770	932	942	722	934	814	1033	816	814	645	916	643	9981
	% representation	89,43	83,36	59,28	79,60	77,32	91,05	85,80	78,24	89,94	77,15	86,82	78,13	80,21
Park B	Net time of repetitive work (h)	520	558	749	430	557	483	504	395	397	547	465	469	6074
	Working time studied (h)	414	492	503	371	526	456	476	381	384	527	445	446	5421
	% representation	79,62	88,17	67,16	86,28	94,43	94,41	94,44	96,46	96,73	96,34	95,70	95,10	89,25
Park C	Net time of repetitive work (h)	484	501	626	495	628	435	475	368	525	523	576	364	6000
	Working time studied (h)	347	354	580	447	588	362	408	285	477	462	491	328	5129
	% representation	71,69	70,66	92,65	90,30	93,63	83,22	85,89	77,45	90,86	88,34	85,24	90,11	85,48

In Table 7, the temporal representation of the tasks analyzed over the time of exposure to repetitive work by each month is shown.

Moreover, we also did the analysis of saturation time, considered as the relation of the repetitive working hours in reference to the effective working hours (see Table 8). The un-saturation is due mainly to the time of training, sick leaves, permits, union activities and rain. In the same table the net time of repetitive work is shown, which corresponds to the time of effective work minor the dedication at no repetitive tasks [5], such as to pick up or to transport sacks, supervision, planning, moving from one place to the other, etc.

For each task the intrinsic risk level, considered as the risk level that a worker would have if he/she was exposed to the task for 420 minutes per day, for the duration of all working days was determined (see Table 9).

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Table 7
Coverage of the study

Coverage (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Park A	85,4	82,7	90,3	96,4	92,7	88,4	88,4	81,6	93,4	91,9	81,5	81,4
Park B	91,7	87,7	88,2	86,2	89,8	86,4	96,6	89,4	90,4	83,3	85,2	93,4
Park C	99,1	95,6	99,3	87,6	87,6	84,1	96,6	98,6	88,9	89,9	97,8	98,6

Table 8
Working and saturation time

Work and saturation		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Park A	Total working time (h)	1820	2106	2509	2249	2321	2178	2646	2321	2152	2170	2078	2184
	Effective working time (h)	1357	1458	1950	1198	1489	1222	1565	1321	1178	1089	1312	1051
	Net time of repetitive work (h)	861	1118	1589	907	1208	894	1204	1043	905	836	1055	823
	Saturation (%)	63,4	76,7	81,5	75,7	81,1	73,2	76,9	79	76,8	76,7	80,4	78,3
Park B	Total working time (h)	780	812,5	1001	790	799,5	780	897	818	780	819	819	819
	Effective working time (h)	684,5	696,5	892,5	515	735,5	593	608	493,5	490	648	575	576
	Net time of repetitive work (h)	520	558	749	430	557	483	504	395	397	547	465	469
	Saturation (%)	76	80	83,9	83,4	75,7	81,4	82,8	79,9	81	84,3	80,9	81,4
Park C	Total working time (h)	780	910	1001	910	949	936	1041	955,5	1021	877,5	955,5	955,5
	Effective working time (h)	650,5	647,5	790	615,5	762,5	695	642	453,5	648	644,5	811,5	542
	Net time of repetitive work (h)	484	501	626	495	628	435	475	368	525	523	576	364
	Saturation (%)	74,3	77,3	79,2	80,4	82,4	62,5	73,9	81	81	81,1	70,9	67,1

Table 9
Intrinsic risk for repetitive movements for each task

TASK		DX	IX
Plantation of flower groups			
To delimitate groups		19,1	14,6
		22,7	16,4
To plant		15,5	15,8
		17	12,5
Maintenance of flower groups			
To remove flowers or dried leaves		21,5	14
Maintenance of the grass			
To reap (automotive reaper)		11,5	11,5
To reap (self-propelled reaper)		11,4	11,1
To clean	group of plants	15	10,5
	isolated plants	14,5	10,5
	edges	14	18,5
Maintenance of path			
To complete with sand	Close Area.	16,5	21
	Far Area	17,5	17,5
To clean with the blower		11,5	6
To remove weeds		22	11,5
Pruning of trees and bushes			
To prune trunk	eight <1m	21,5	17
	eight >1m	19,7	13,2
To shape trunk		17,9	17,4
Several			
Light digging	Little vegetables	16,5	7
	Big plants	16,5	13
To irrigate with hose		21,5	10,5
To sweep		16	20

As demonstrated in this table, for some tasks, some variants were defined. These variants are conditions that had different effects on the upper limbs, depending from the kind of requirements. For example, the requirement to clear a group of plants is really different from clearing the edges of a parterre.

After this, the monthly risk value was calculated as the arithmetic average of the intrinsic risk values of each task, weighted by the exposure time to each of them.

As the exposure time information for each of the identified variants was not available, the monthly risk value was enclosed in the value ranges. The maximum value matches the arithmetic average, weighted by the time, considering the variants with maximum intrinsic risk values. The minimum value matches the arithmetic average weighted by the time considering the variants of each task with minimum intrinsic risk values.

The range of monthly risk values obtained in each park for the left and right upper limb are shown in the Figures 1, 2 and 3.

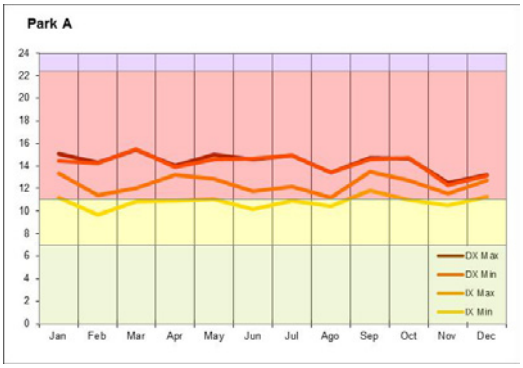

Figure 1 - Intrinsic risk level evolution of park A, year 2009

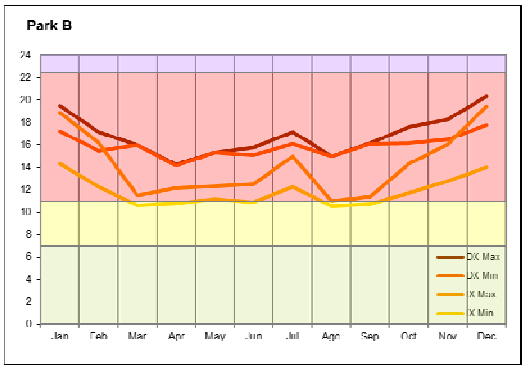

Figure 2 - Intrinsic risk level evolution of park B, year 2009

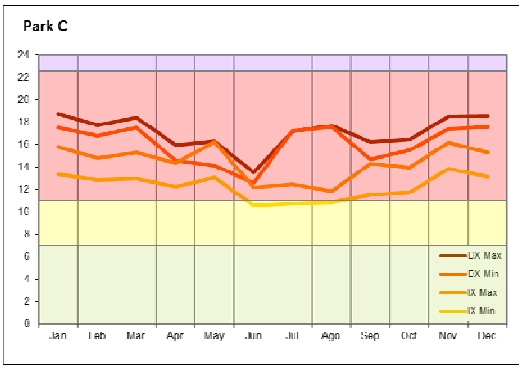

Figure 3 - Intrinsic risk level evolution of park C, year 2009

The right upper limb is the limb with greatest exposure in all parks. In Figure 4 the comparison between the maximum values obtained in the three parks is shown.

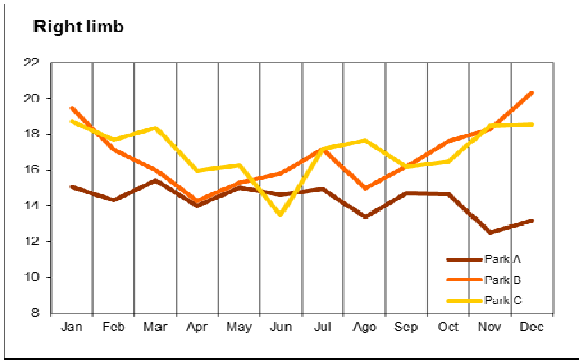

Figure 4 - Comparison of the evolution of real risk level evolution, year 2009

4. Discussion

The work of urban gardening is an activity that, even though it is accomplished in many cases with the support of machines and tools, it is intensively manual and characterized for repetitive tasks.

The kind of tasks that they have to accomplish and the necessary time that they dedicate to them follow an annual cycle pattern, marked by the vegetal cycle, similar to the major part of agriculture jobs in warm geographical areas, where the climate is distinguished by four seasons.

The major part of the tasks accomplished during the year requires a high biomechanical overload in the upper limbs; this causes significant risk to develop work-related musculoskeletal disorders.

In spite of the fact that all the kinds of gardening tasks are similar in all the parks, the features of the landscape design create differences in the necessary time of dedication to each task.

These differences in the temporal exposure pattern create the differences between the exposure risk levels between each park (see Figure 4). As noted in this figure, park A requires less requirements in the right upper limb than park C. The main reason of this is that in park A they dedicate a high percentage of time on grass maintenance, which is a task with less requirements, as they use machines that help to keep adequate postures. In park C, on the other hand, they use a higher percentage of time on the maintenance of hedges and bushes, a task where they need a higher movement frequency and more unnatural postures.

5. Conclusions

From this pilot study conducted in three urban parks in Barcelona, it can be concluded that urban gardening tasks have a high level of requirements in the upper limbs. For this reason it is highly possible that a significant part of the working population will develop musculoskeletal disorders.

The analysis of the exposure to the biomechanical overload on upper limbs in gardening works is a complex task, mainly because it is an activity with a high percentage of variability and with annual cycle.

In this research we presented a methodology of analysis that allows us to get interesting information with the aim to create organizational measures related to the assignment of tasks, to the training of staff and to the recommendations of urban landscape design.

It is possible that if this research is extended to a higher number of parks with different design features, an analysis and simulation frame can be obtained, which can be useful to orientate organization and landscape design decisions in order for its maintenance.

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