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Prediction of Musculoskeletal Discomfort in a Pick and Place Task (A pilot study)

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A pilot study was conducted regarding the effects of working posture, handling frequency, and task duration on musculoskeletal discomfort. Participants rated their discomfort perceived while performing a repetitive task at 8 different combinations of manipulations. Pauses between the work periods lasted 15 min. Discomfort was rated according to Borg's category-ratio scale CR-10 and postures were recorded by an optoelectronic movement registration system. From linear multiple regression analysis equations for predicting discomfort at various body regions were obtained. Coefficients of determination especially point to trunk inclination and handling frequency as major determinants of musculoskeletal discomfort.

prediction musculoskeletal discomfort RSI repetitive task multiple regression

1. INTRODUCTION

Repetitive strain injuries (RSI), also known as cumulative trauma disorders (CTDs) or chronic upper limb musculoskeletal disorders, are

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considered as major work-related health problems for employees as well as for employers (MacLeod, 1995; Putz-Anderson, 1988; Putz-Anderson, 1990; Putz-Anderson & Galinsky, 1993; Silverstein & Hughes, 1996). Therefore, when (re-)designing a workplace one should be aware of the risk factors for RSI. Risk factors often mentioned in literature are working posture, handling frequency, work and rest schedules, exertion of external force, static load, velocity and acceleration of movements, psychosocial factors, skills, experience and learning capability, vibration, and temperature (Genaidy & Karwowski, 1993; Kilbom, 1994a, 1994b; McAtamney & Corlett, 1993; Putz-Anderson, 1988; Moore & Garg, 1993; Schoenmarklin, Marras, & Leurgans, 1994). Yet, little is known about the specific contribution of the risk factors to the development of RSI. Repetitive movements or sustained postures may overload the musculoskeletal system, which at first results in localized discomfort and fatigue. When rest periods between tasks are not adequate for recovery, the overload might even result in disorders. Fatigue and discomfort are considered as early symptoms of work-related soft tissue disorders (Putz-Anderson & Galinsky, 1993). The feelings of discomfort are related to physical load. When it is clear what the specific contribution of the various risk factors to the physical load is, workplaces can be (re-)designed in such a way that health problems and production losses could be reduced and even prevented.

The aim of this study was to design a model predicting the musculoskeletal discomfort during repetitive work. Because of the pilot character of this study, it was not possible to investigate more risk factors. The study concentrates on the effects of handling frequency, working posture, and task duration on localized musculoskeletal discomfort (LMD) in different body regions. Repetitive shoulder elevation may contribute to acute fatigue, neck-shoulder symptoms, or both (Hagberg, 1981; Kilbom, Persson, & Jonsson, 1986). According to Hagberg et al. (1995) frequency of movements might be a risk factor for work-related disorders. Prolonged or repetitive non-neutral spinal positions might increase pressure and strain on spinal discs, ligaments, and muscles, which may cause fatigue, discomfort, or microtraumata (Isernhagen, 1995). When head inclination increases, muscles have to work harder in order to compensate the biomechanical moment. The weight of the upper arm, lower arm, and the hand may lead to large biomechanical moments in the shoulder region, when elevating the upper arm. The biomechanical moments correlate high with discomfort and fatigue. Blood circulation and working capacity will diminish when elevating the arm above shoulder level (Hagberg et al., 1995). Task duration, working hours during a day, or the number of years in a job might influence the risk of developing work-related disorders (Kilbom, 1994a). Rest periods between contractions and between tasks are also important factors for recovery of the body.

By rating localized musculoskeletal discomfort, the internal musculoskeletal load can be estimated (Van der Grinten & Smitt, 1992). Localized musculoskeletal discomfort includes sensations like tension, fatigue, soreness, heat, tremor, pain, and so on. In this research, localized musculoskeletal discomfort was rated according to Borg's category-ratio scale CR-10 (1982) and a body map (modified after Corlett & Bishop, 1976). This method turned out to be feasible practical, reasonably sensible, and reliable for comparisons of relative low static loads (Van der Grinten & Smitt, 1992). Cameron (1996) reported that Borg's category-ratio scale CR-10 (1982) is a very precise measuring tool.

2. METHODS

2.1. Participants

Ten healthy right-handed participants (5 males, 5 females) participated in this study. Their mean age was 23.6 years (range 22–26). Participants had no relevant signs of musculoskeletal problems in shoulders, neck, back, or right arm. The participants were nontrained and nonindustrial workers.

2.2. Experimental Task

The experiment was taking place in a laboratory setting. Pieces of Lego™ had to be picked up out of a box and had to be stuck on a Lego™ plate one by one. When the plate was full, the pieces had to be pulled off again, and were placed back into the box one by one. The plate and the box were standing in front of the sitting participant. The task was performed with the preferred (right) hand.

2.3. The Independent Variables

The independent variables in this study are handling frequency, working postures, and task duration.

2.3.1. Handling frequency

Participants performed the task at two frequencies (10 pieces/min and 20 pieces/min). The handling frequency was indicated by a metronome.

2.3.2. Working posture

The working posture was manipulated by varying the reach height (shoulder and elbow height) and the reach distance to the box (0.8 and 1.2 maximal reach distance). The maximal reach distance was defined as the horizontal distance between the acromion-clavicular joint and the top of the distal phalangeal III, when the arm was positioned horizontally forward. Elbow height was the vertical distance between the floor and the elbow when the sitting participant kept his or her forearm horizontally forward, whereas the upper arms hung down along the body. Shoulder height was defined as the vertical distance between the acromion-clavicular joint and the floor. The Lego™ plate was placed on the table, which was adjusted to the elbow height of each participant keeping the trunk upright.

Postures were recorded by an optoelectronic movement registration system (VICON™), containing four synchronized video cameras. These cameras are able to identify retroreflective markers, which were put on selected body joints (Table 1). Based on the three-dimensional positions of the markers, head angle, head inclination, trunk angle, trunk inclination, arm angle, and arm elevation were calculated (Table 2). These angles were determined from the data while participants were picking up a piece out of the box. Reference postures were measured before the experimental task started. In the reference postures, participants had to sit straight and had to look straight ahead. Their arms were hanging relaxed down along their body.

2.3.3. Task duration

The participants performed every task during 20 min. Pauses between the work periods lasted 15 min. At the start of the task, after 10-min and after 20-min task performance the participant had to rate his or her discomfort. In this way two levels of task duration were obtained.

2.3.4. Combinations of levels of variables

Handling frequency, reach height, and reach distance were manipulated in such a way that combinations of levels of these variables led to eight different tasks. In this way each task was carried out under a combination of one level of handling frequency, arm elevation, head inclination, and trunk inclination.

TABLE 1. Names and Locations of Markers Placed on Selected Body Joints

Marker	Name	Location
M1	hip	upper edge of the left greater trochanter*
M2	eye	near the lateral corner of the eye
M3	ear	just centrally in the lobe
M4	neck	intervertebral disc C7-T1
M5	right shoulder	acromion-clavicular joint
M6	right elbow	humero-radial joint

Notes. *—A virtual marker, calculated from the location of a marker placed above the greater trochanter.

TABLE 2. Names and Definitions of Postures and Angles

Name	Definition
Head inclination	Difference in head angle during task execution and during the reference posture.
Head angle	Angle between the vertical and the line between the eye and the ear, projected in the sagittal geometry plane.
Trunk inclination	Difference in trunk angle during the reference posture and during task execution.
Trunk angle	Angle between the vertical and the line between the trochanter mayor and C7/T1, projected in the sagittal geometry plane.
Upper arm elevation	Difference in arm angle during the reference posture and during task execution.
Arm angle	Absolute angle between the vertical and the line between the humero-radial joint and the acromion-clavicular joint.

2.4. The Dependent Variable: Localized Musculoskeletal Discomfort

Localized musculoskeletal discomfort (LMD) was rated (Van der Grinten & Smitt, 1992). Prior to the first task, an instruction on LMD rating was given. The participant was told to rate his or her discomfort in the different regions shown in Figure 1. The degree of discomfort was rated according to Borg's (1982) category-ratio scale CR-10 shown in Table 3. Prior to each task (t_0), after 10 min (t_1), and immediately after each

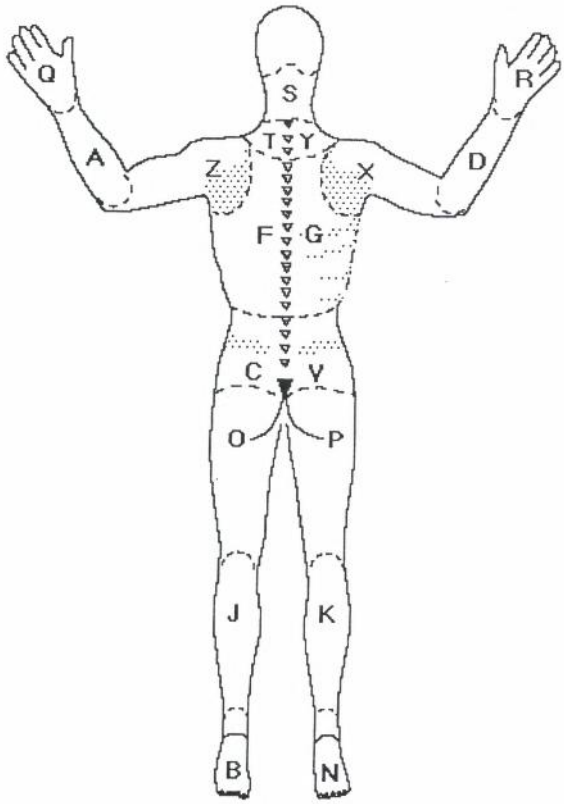

Figure 1. Body map for rating discomfort. *Notes.* — — — — boundaries between body regions, ▒ bone.

TABLE 3. Category-Ratio Scale CR-10 (Borg, 1982)

.	=	maximal
10	=	extremely strong (almost maximal)
9	=	
8	=	
7	=	very strong
6	=	
5	=	strong
4	=	somewhat strong
3	=	moderate
2	=	weak (light)
1	=	very weak
½	=	extremely weak (just noticeable)
0	=	nothing at all

work period (t_2) the participant was asked in which region and to what degree he or she perceived localized discomfort. As far as possible, the physical load of a task was unchanged during verbal rating.

2.5. Data Analysis

The LMD data obtained from the experiment were analyzed with LMD-software. Scores on t_0 were subtracted from scores on t_1 and t_2 to correct for any discomfort after rest. Only the maximum scores for t_1 and t_2 were analyzed. The maximum ratings were chosen to detect the highest discomfort. The LMD-software composed functional units out of the body regions (Van der Grinten & Smitt, 1992). The reason for using the maximal scores in the clustering operation was that they represented the weakest link within a cluster and would be decisive for the whole cluster. These scores would determine eventually the subsequent postural endurance time (Van der Grinten & Smitt, 1992).

The working postures were derived from the angles computed from the VICON™ recordings. Equations for predicting localized musculoskeletal discomfort from working postures, handling frequency, and task duration were obtained from multiple regression analyses. Test results were statistically significant if $p \leqslant .10$.

3. RESULTS

The discomfort ratings concentrated especially in the regions G, X, Y, and in the clusters wb (whole body), bn (back-neck), and rt (right side of the trunk, Figure 1). Because participants scored mostly in these regions and clusters, only the relation between the LMD scores of the regions G, X, and Y and of the clusters wb, bn, and rt as dependent variables and arm elevation, trunk inclination, head inclination, handling frequency, and task duration as dependent variables were analyzed in a linear multiple regression. The clusters wb, bn, rt are functional units, constructed from several regions. Table 4 shows the three clusters where participants perceived LMD and the regions in these clusters. The resulting models derived from the linear multiple regression analyses are summarized in Table 5. The models show the equations for the prediction of localized musculoskeletal discomfort, when only using the significant independent variables at $p \leqslant .10$ (Table 6).

TABLE 4. The Three Clusters and the Regions in These Clusters in Which Participants Perceived Localized Musculoskeletal Discomfort (LMD)

Abbreviation	Clusters	Regions
wb	whole body	all
bn	back-neck	C F G S T V Y
rt	right side of trunk	G V Y S

TABLE 5. Equations for Predicting Significantly Localized Musculoskeletal Discomfort ($p \leqslant .10$)

LMD region or cluster	Equation
wb	$-1.363 + .020$ AE $+ .064$ TD $+ .127$ HF $- .024$ HI $+ .021$ TI $+$ e
bn	$-1.006 + .016$ AE $+ .066$ TD $+ .044$ HF $+ .019$ TI $+$ e
rt	$-.313 + .011$ AE $+ .055$ TD $+ .020$ TI $+$ e
G	$-.070 + .011$ AE $+ .034$ TD $- .028$ HF $+ .007$ TI $+$ e
X	$-1.082 + .013$ AE $+ .084$ HF $+ .022$ TI $+$ e
Y	$-.202 + .054$ HF $+ .013$ TI $+$ e

Notes. When the outcome of an equation is negative, the LMD score is to be set to 0 (no discomfort); LMD—localized musculoskeletal discomfort; AE—arm elevation (degrees); TD—task duration (min); HF—handling frequency (number of pieces per minute); HI—head inclination (degrees); TI—trunk inclination (degrees); e—error; wb—whole body cluster; bn—back-neck cluster; rt—right side of trunk; G, X, Y—regions.

The statistical significances of the regression coefficients when all statistically significant variables are taken into the equations are summarized in Table 7. *F*-values and *p*-values are shown resulting from analyses on various significance levels ($p \leqslant 1.00$, $p \leqslant .05$, $p \leqslant .10$) and separately for men and women ($p \leqslant .10$). The upper part of Table 8 shows the coefficients of determination (R^2) of the separated independent variables in the regression analyses ($p \leqslant .10$). The lower part summarizes the R^2 under different inclusion criteria of the regression model for all the participants together ($p \leqslant 1.00$, $p \leqslant .05$, $p \leqslant .10$) and separately for men and women ($p \leqslant .10$). The prediction is relevant to practice when $R^2 \geqslant .05$.

The variables arm elevation, trunk inclination, and handling frequency are both statistically and practically significant to LMD wb (Tables 6 and 8). The variables task duration and head inclination are only statistically significant to LMD wb. Almost all independent variables, except head inclination, have a statistically significant effect on LMD G when $p \leqslant .10$ (Table 6). Task duration, arm elevation, and trunk

TABLE 6. ***T*-Values and *p*-Values of Regression Coefficients of Independent Variables ($p \leqslant .10$)**

Variable	LMD wb		LMD bn		LMD rt		LMD X		LMD G		LMD Y	
	T	*p*	*T*	*p*	*T*	*p*	*T*	*p*	*T*	*p*	*T*	*p*
HF	6.64	.000*	2.30	.023*	1.510	.132	4.10	.000*	−1.73	.086**	2.89	.005*
TD	3.41	.001*	3.49	.001*	2.740	.007*	1.61	.111	2.11	.036*	1.47	.144
AE	2.82	.005*	2.49	.014*	1.750	.083**	1.89	.060**	2.14	.034*	−.38	.701
TI	4.26	.000*	3.84	.000*	3.870	.000*	4.23	.000*	1.78	.077**	2.76	.007*
HI	−2.23	.027*	−.19	.850	.035	.972	−.24	.808	.27	.788	−.63	.530

Notes. *—statistically significant at $p \leqslant .05$; **—statistically significant at $p \leqslant .10$; LMD—localized musculoskeletal discomfort; HF—handling frequency; TD—task duration; AE—arm elevation; TI—trunk inclination; HI—head inclination; wb—whole body cluster; bn—back-neck cluster; rt—right side of trunk; X, G, Y—regions.

TABLE 7. Statistical Significance of Regression Coefficients for all Participants ($p \leqslant 1.00$, $p \leqslant .05$, $p \leqslant .10$) and Separately for Men and Women ($p \leqslant .10$). *F*-Values and *p*-Values Are Summarized

Variable	LMD wb		LMD bn		LMD rt		LMD X		LMD G		LMD Y	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
All variables in equation $p \leqslant 1.00$ (♂♀)	18.91	.000*	7.78	.000*	5.49	.000*	8.62	.000*	2.89	.016*	4.03	.002*
All significant variables in equation $p \leqslant .05$ (♂♀)	18.91	.000*	9.79	.000*	10.85	.000*	18.05	.000*	4.24	.016*	8.53	.000*
All significant variables in equation $p \leqslant .10$ (♂♀)	18.91	.000*	9.79	.000*	8.35	.000*	13.44	.000*	3.62	.008*	8.53	.000*
All significant variables in equation $p \leqslant .10$ (♂♂)	14.77	.000*	8.81	.000*	6.79	.000*	12.17	.001*	2.92	.092**	3.85	.013*
All significant variables in equation $p \leqslant .10$ (♀♀)	13.43	.000*	7.51	.000*	7.94	.000*	14.60	.000*			8.18	.000*

Notes. *—statistically significant at $p \leqslant .05$; **—statistically significant at $p \leqslant .10$; .—no variable was statistically significant at $p \leqslant .10$, so no variable was taken into the equations; LMD—localized musculoskeletal discomfort; wb—whole body cluster; bn—back-neck cluster; rt—right side of trunk; X, G, Y—regions.

TABLE 8. Coefficients of Determination of Separated Independent Variables in Regression Analyses ($p \leqslant .10$); Coefficients of Determination for all Participants Under Different Inclusion Criteria ($p \leqslant 1.00$, $p \leqslant .05$, $p \leqslant .10$) and Separately for Men and Women ($p \leqslant .10$)

Variable	LMD wb	LMD bn	LMD rt	LMD X	LMD Y	LMD G
HF	.188^{P}	.036	.019	.104^{P}	.058^{P}	.016
TD	.049	.066^{P}	.044	.014	.013	.026
AE	.075^{P}	.031	.015	.017	.001	.027
TI	.076^{P}	.083^{P}	.085^{P}	.106^{P}	.053^{P}	.016
HI	.023	.001	.000	.000	.000	.003
All variables in equation $p \leqslant 1.00$ (♂♀)	.396^{P}	.213^{P}	.160^{P}	.230^{P}	.123^{P}	.091^{P}
Significant variables in equation at $p \leqslant .05$ (♂♀)	.396^{P}	.213^{P}	.129^{P}	.197^{P}	.104^{P}	.055^{P}
Significant variables in equation at $p \leqslant .10$ (♂♀)	.396^{P}	.213^{P}	.146^{P}	.216^{P}	.104^{P}	.091^{P}
Significant variables in equation at $p \leqslant .10$ (♂♂)	.447^{P}	.263^{P}	.216^{P}	.138^{P}	.135^{P}	.037
Significant variables in equation at $p \leqslant .10$ (♀♀)	.504^{P}	.363^{P}	.260^{P}	.297^{P}	.328^{P}	.

Notes. ^{P}—practically significant ($R^2 \geqslant .05$); .—no variable significant and entered; LMD—localized musculoskeletal discomfort; HF—handling frequency; TD—task duration; AE—arm elevation; TI—trunk inclination; HI—head inclination; wb—whole body cluster; bn—back-neck cluster; rt—right side of trunk; X, Y, G—regions.

inclination contribute statistically significantly ($p \leqslant .10$) to LMD rt. The latter two and handling frequency have a statistical significant effect on LMD X. The two variables that contribute to LMD Y are handling frequency and trunk inclination. Handling frequency leads to a practical significant contribution to LMD wb, X, and Y. Task duration contributes only practically to LMD bn and the upper arm elevation only to LMD wb. Trunk inclination has a practically significant effect on almost every LMD region or cluster except for region G. When all significant ($p \leqslant .05$) variables are taken into the equations, these variables explain 40% of the variance of LMD wb, 21% of LMD bn, and 10% of LMD Y. All statistically significant ($p \leqslant .10$) variables in the equations explain 15% of the variance of LMD rt, 22% of LMD X, 9% of LMD G (Table 8).

A linear multiple regression analysis separate for men and women shows a difference in coefficients of determination between these groups, especially in the back-neck regions. The regression analyses show that significant variables ($p \leqslant .10$) explain 26% of the variance of the LMD score in the bn cluster of men and 36% of LMD bn of women. Major differences between men and women are found for the LMD scores in

X and Y; the R^2 of these regions are respectively 14% in men and 30% in women, and 14% in men and 33% in women. Remarkable also is the fact that the separate R^2 for men and women are larger than for men and women together.

Concluding, both handling frequency, arm elevation, and trunk inclination have a statistical and practically significant effect on LMD wb. Handling frequency also has both effects on LMD X and Y. Trunk inclination has also a statistically and practically significant effect on LMD X, Y, bn, and rt. Task duration is only statistically and practically significant to LMD bn. Arm elevation only to LMD wb. Head inclination never contributes either practically or statistically significant to LMD.

4. DISCUSSION

4.1. General

The predictive value of equations obtained in this study is not very high. Yet, the equations and their coefficients of determination do give some information about the contribution of the risk factors concerning localized musculoskeletal discomfort. The equations show that when all variables have a minimal value, the LMD scores will be minimal, too, because the constant values in the equations are negative. Most variables have an unfavourable effect on the LMD perceived. However, head inclination does have a negative contribution to the overall LMD score (LMD wb), which is propitious for the degree of LMD perceived. This is remarkable, because enlarging the head inclination leads to a greater impact of gravity on the antigravitational muscles, so that fatigue will be present earlier and LMD scores are expected to be higher. The neck angle (head inclination-trunk inclination) becomes larger when the head inclines and the trunk inclines slightly or not. The neck flexes when the neck angle-value is positive and the neck is in extension when the value is negative. Neck flexion might cause less discomfort than neck extension. This might be an explanation for the negative contribution to LMD wb of the head inclination.

4.2. Handling Frequency

In the regions X, Y, and cluster wb, handling frequency contributes unfavourably to LMD, as was expected. Tasks requiring high rates of repetition require more muscle effort, and consequently more time for recovery, than less repetitive tasks. In this manner, tasks with high repetition rates may cause traumata even when the required forces are minimal and normally safe (Putz-Anderson, 1988). The pathophysical mechanism of tendon disorders appears to be linked to the frequency of movements, yet the epidemiological evidence for an increase in risk above certain rates of movements is incomplete (Kilbom, 1994a). Muscle disorders also appear to be associated with repetitive work. The pathophysical mechanisms of muscle disorders appear to be linked to muscle fatigue and lack of recovery, which suggests that it is important that short contraction periods are followed by sufficient periods for recovery (Kilbom, 1994a).

In further studies on this subject, one should be aware that when the frequency of movements has been controlled, velocity and accelerations of movements are not controlled per definition, either. High speed of motion and possibly acceleration appear to increase the risk of disorders according to epidemiological studies (Kilbom, 1994a). According to Schoenmarklin et al. (1994) the epidemiological association between flexion/extension acceleration and incidence rate of CTDs is compatible with results from empirical studies and theoretical models in the physiologic and biomechanical literature. In their study on wrist motions and incidence of CTDs it was found that acceleration in the flexion/extension plane discriminated the best between groups of low and high incidence rates.

4.3. Arm Elevation

Arm elevation contributes statistically to LMD in the neck-back clusters and regions. This might be due to the fact that it is not possible to use the arm or hand without stabilizing the shoulder girdle. Work tasks demanding continuous arm movements generate a static load component. The load on the gleno-humeral joint is transmitted to the scapula and further on to the upper trapezius muscle, which thereby acts as the principal antigravitational muscle for the arm (Winkel & Westgaard, 1992). The static load caused by the stabilization of the arm by the proximal part of the shoulder, seems to be a common cause for shoulder disorders (Kilbom, 1994a). The static components of electromyographic activity, which is mostly responsible for the muscle fatigue, decreased when working at a lower speed (Kluth, Böhlemann, & Strasser, 1994).

Hagberg (1981) also states that in work postures demanding elevated arms, the localized load on the shoulder muscles produces fatigue. By means of electromyographic analysis shoulder muscular fatigue has been found to depend on the working posture of the arm (Herberts, Kadefors, & Broman, 1980). Striking in this context is the fact that arm elevation does not play a major role in LMD Y neither statistically nor practically. It is also remarkable that arm elevation is only practically significant in LMD wb. It might be possible that the static load component is not present. The task duration might be too short and the handling frequency might be too slow to notice an effect of arm elevation on LMD. It might also be possible that the elbow of the participant performing the task in the "high reach task" did not reach the shoulder level. So this did not lead to high LMD-values.

4.4. Trunk Inclination

An important risk factor seems to be trunk inclination. This factor contributes to LMD in almost all clusters and region. Keyserling, Punnett, and Fine (1988) reported that the use of non-neutral trunk postures, such as forward flexion, lateral bending, and axial twisting, was associated with reports of back pain. Awkward postures, if not controlled, would contribute to localized fatigue and musculoskeletal disorders and non-neutral trunk postures could significantly increase biomechanical strain indices in the lower back, such as the forces exerted by the erector spinae muscles, intradiscal pressure, compression forces on the spinal discs, and the trapezius muscle.

4.5. Task Duration

The fact that task duration, arm elevation, and head inclination show hardly any practically significant effect, might be due to the length of the task duration, which was 20 min for each task. This might be too short for evoking statistically and practically significant discomfort.

4.6. Load Capacity

The difference in R^2 between men and women is remarkable. The R^2 for women is in all LMD regions and clusters higher than the R^2 for men. This might be due to a greater impact of the factors under study on women than on men. A difference in load capacity might be the explanation for this finding. This finding has to be taken with caution. When designing workplaces, this should not be done either for men or for women.

5. CONCLUSIONS

When performing the task, right-sided discomfort occurred in the back-neck and shoulder regions. Trunk inclination and handling frequency played a major role in developing this discomfort. The coefficients of determination of the other variables might not be very large, yet all variables together contribute significantly to localized musculoskeletal discomfort.

In this study not all factors characterized as a risk factor of RSI have been taken into account. So the equations are not yet complete. The relatively low R^2-values, might be due to this incomplete character of the study. In further studies on this subject, individual, psychosocial conditions at work, the velocity and acceleration of movement, the exertion of force, and the temperature should also be taken into account (Kilbom, 1994a, 1994b; Moore, 1993). More levels of handling frequency and task duration might have enlarged the coefficients of determination. It is possible that the tasks did not last long enough to produce a greater impact in localized musculoskeletal discomfort. The equations presented in this pilot study are far from complete and have to be developed and extended. One has to be careful with extrapolation and applications of the equations.

LIST OF SYMBOLS

AE — arm elevation (degrees)
bn — back-neck cluster, regions: C F G S T V Y
HF — handling frequency (number of pieces per minute)
HI — head inclination (degrees)
LMD — localized musculoskeletal discomfort
rt — right side of trunk, regions: G V Y S
TI — trunk inclination (degrees)
TD — task duration (min)
wb — whole body cluster, regions: all

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