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COMFORT AND ERGONOMICS EVALUATION OF A CHECKOUT WORKSTATION

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ABSTRACT

The ergonomic principles to the design processes, workplace and organization, has to be applied not only to respond to legal requirements, but also for answer to the companies' needs for pursuing a business logic. This paper shows a cheap and effective method to acquire workplaces, work-cycles and workers-postures, in a supermarket, in order to analyze how cashiers move them-selves into their workspace, with their own tools and devices and do their jobs. Photo and video acquisition has been done to acquire postures and movements by DARTFISH® software; DELMIA® software was used to model humans postures, workstation and interactions. Simulation results were processed by CaMAN® software for evaluating comfort indexes both for each task and globally. Lastly, results have been correlated to subjective perceptions through experimental tests, in order to validate the comfort model.

Keywords: comfort evaluation, digital human modelling, ergonomics, non-invasive postural analysis, cashier.

INTRODUCTION

Products are designed to incorporate specific functions that benefit users. However, successful function is dependent on people being able to use the products correctly. In the past, the principles of user-centered design were 1) methods for creating products, 2) environments, and 3) systems fit for human use [2]. Ergonomics, meanwhile, studies the 1) interfaces between people, 2) activities they perform, 3) products they use, and 4) environments in which they work, travel, or play. As stated in [3], ergonomic principles allow us to develop guidelines for improving and redesigning both old and new products. As required in several ergonomics assessment methods-including RULA [4], REBA [5], LUBA [6], Strain Index [7]; OCRA [8-11], OREGE [12], NIOSH [13-15], and others-the physical ergonomics and the physical comfort assessment is required to overcome by-law specifications. For this reason, a wide range of research has been done on physical comfort and discomfort in the workplace. Most studies have discussed the relationships among environmental factors that can affect perceived levels of comfort/discomfort, such as temperature [16], humidity [17], applied forces [18], and others [19]. Several papers adhered to the assumption that a relationship exists between self-reported discomfort and musculoskeletal injuries, with these injuries affecting perceived comfort [20, 21]. However, theories relating comfort to products and product design characteristics have been rather underdeveloped. The last 15 years have seen only five "comprehensive models" that considered every aspect of human perception: the Helander model [22], the Moes model [23], the Vink-Hallbeck model [24], the Naddeo-Cappetti model [25], and the Vink model [26]. In the Naddeo-Cappetti model (see Figure-1), the internal body and perceived effects play a fundamental role in comfort/discomfort perception and evaluation.

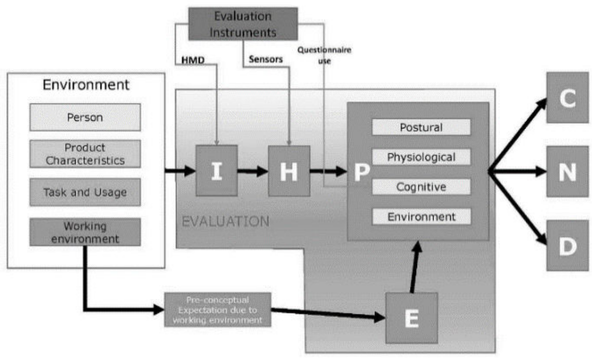


Figure-1. The Naddeo-Cappetti model of comfort/discomfort perception.

In this model, the internal body (B) and perceived effects (P) play a fundamental role in comfort(C)/discomfort (D) perception and evaluation during the Interaction (I), without forgetting the effects of Expectation [27] and of evaluation instruments. Each model underlines the importance of body posture in comfort analysis since it considers body effects and perceived effects that are useful in evaluating the Maximum Level of Comfort (MLC) positions in human postures. In MLC identification, it is useful to perform a comfort evaluation based on measurement of the angular Range of Motion (ROM) of each joint [1, 28-30] as the limits of variability and mobility. "Comfort' can be defined as the level of well-being perceived by humans when interacting with a working environment; thus, "postural comfort" can be defined as the well-being due to body posture, which is difficult to detect and measure because it is affected by individual judgment that is analyzed using quantitative/qualitative methods. Certain medical studies have shown that each joint has its own natural Rest Posture (RP) [30–31] when the muscles are completely relaxed or at minimum strain level: When this occurs, the geometrical configuration corresponds to the natural position of the resting arms, legs, neck, and so forth. Naddeo *et al.* [32] demonstrated that the positions of human body joints are useful to evaluate users' postural comfort, building curves that represent comfort values along the entire range of postures for the considered joints. In that study, only upper limb joints were considered, starting from their rest posture evaluated in [1]. These curves show the maximum comfort in RRP; therefore, extending the curves to the whole human body, one must evaluate the Rest Postures for all joints. Trapanese *et al.* [33] and D'ambrosio *et al.* [18] demonstrated that less muscular activation has the outcome of higher perceived postural comfort. In Cappetti [34], the curves of comfort have been directly related to overall muscular activation for upper limbs and some lower-body joints.

When developing and designing of checkout workstations, the respect of ergonomics' criteria in the national law was set by EU Directives (89/392/CEE - 93/44/CEE - 93/68/CEE e 2006/42/CE). In particular, the Directive 2006/42/CE, states that, in the terms of use, discomfort, fatigue and psycho-physical stress must be minimized, in accordance with the following criteria: 1) avoid control that requires high concentration; 2) set human-machine interface considering worker's features; 3) considering variability of physical dimensions, force and resistance of the workers. Analyzed workstation, in particular, reflects imposed directives:

- For design: EN ISO 12100-1, EN ISO 12100-2, EN ISO 14121;
- For ergonomics law: EN 547-1-2-3, EN 614-1, EN 14738, EN 1335-1-2-3;
- For safety law: EN ISO 12100-1-2, EN ISO 14121, EN ISO 60204, EN ISO 60439-1.

This paper focuses its attention on the workers' postures, because they are the basis of the growth of muscular-skeletal disease. This work analyses dynamic positions as a sequence of static positions, thanks to the low speed of actions, without considering relations with environmental temperature and interface temperature between human body and objects [16]. In this study, analysis of workers' work-cycle was done because the literature [35-38] about supermarkets' workers says that they suffer from physical problems related to the neck, arms, shoulders and low back due to the job positions assumed and their duration.

TEST CASE AND METHODS

Photographic and video acquisition was made from 7:00 AM to 9:00 AM of two consecutive weekly days. The work-environment being analyzed is a payment station, in which the cashier can work only seated. The workstation (Figure-2) is composed by: a sliding belt/carpet on which the customer can place his/her items; a bar-code reader and a touch-screen monitor by which the cashier can acquire and verify the price of each item; the "collective desk", often divided in two, in which the cashier can put the items after the prize reading; a normal fully configurable seat for the cashier; a small payment system in which the credit card reader, the pin-code system; a cash for money storage; a receipt laser printer, located on the right of the cashier, on a secondary desk perpendicular to the sliding belt/carpet axis.

Figure-2. Real checkout workstation.

Twenty-one people (12 males and 9 females), all volunteers, participated in the experiment. Eleven of them are professional cashiers. None had a history of musculoskeletal diseases. The main characteristics of the subjects are summarized in Table-1. All subjects were informed of the nature of the tests, and written consent was obtained. The Ethical Guidelines of both the University of Salerno and Italian Law were respected while performing the tests.

Table-1. Descriptive statistics of selected variables for the participant population.

	Age (years)	**Weight** (kg)	**Height** (cm)	**Body Mass Index**
Mean	24.37	69.56	170.19	23.77
Std. Deviation	2.35	13.90	8.68	2.95
Minimum	21	45	154	18.3
Maximum	44	96	186	28,4

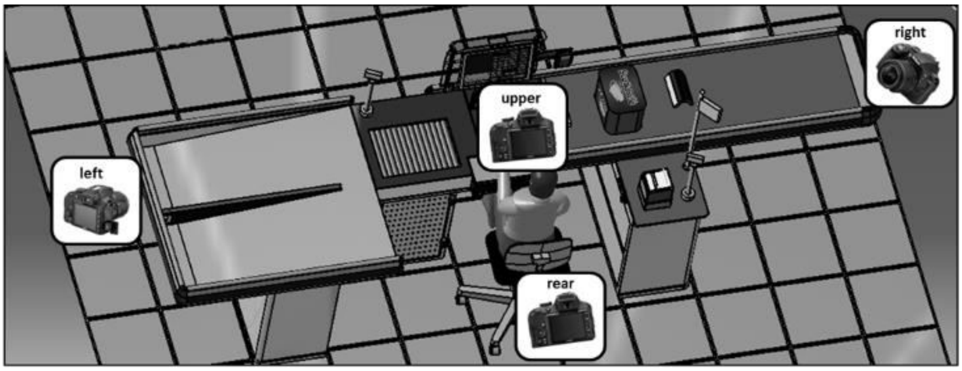
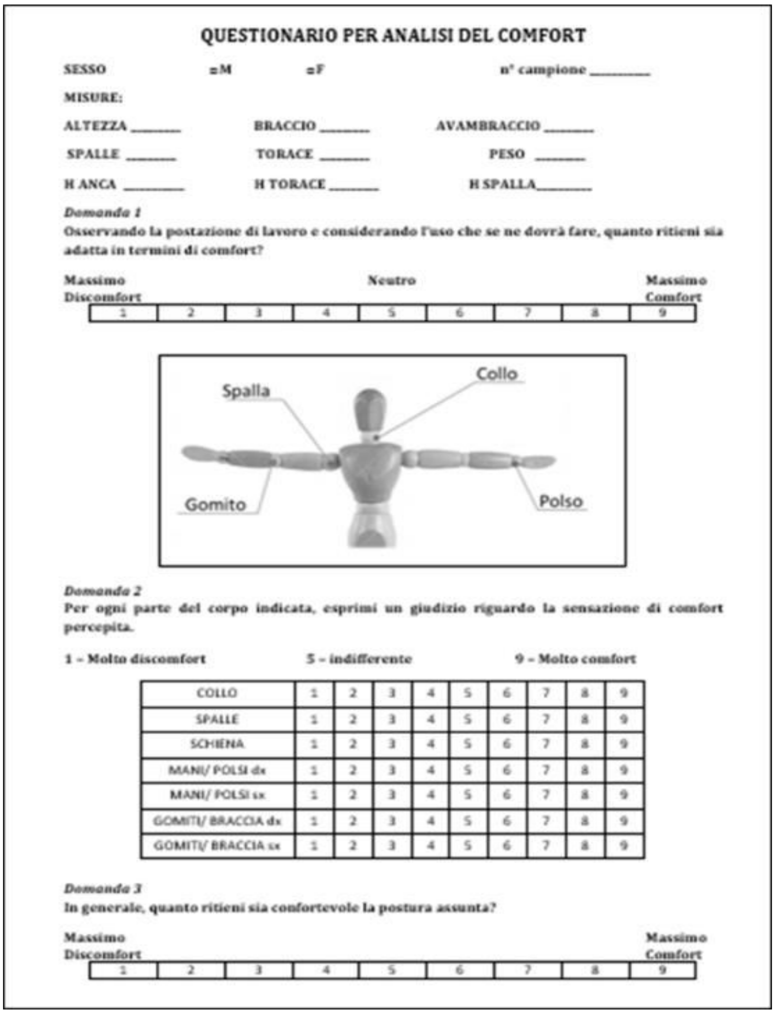


Figure-3. Video-camera position.

The test case has been prepared as shown in Figure-3, using four video camera (one rear, one upper and two laterals, on the right side and left side). People are asked to handle two kinds of item: a toothpaste container and a toilet paper box (8 units) that have been positioned on the sliding belt/carpet, about 30 cm from the scanner and 10 cm from each other. Whereas this analysis has not the purpose to evaluate the influence of the weight of the items on the operator comfort, the choice of these items was dictated firstly by the difference of their size that, in our opinion, has a big influence on the handling and actions carried out by the cashier during payment transitions. After the manual operations, each subject has been asked to fill the questionnaire in Figure-4.



QUESTIONARIO PER ANALISI DEL COMFORT

SESSO □M □F n° campione ________

MISURE:

ALTEZZA _______ BRACCIO _______ AVAMBRACCIO _______

SPALLE _______ TORACE _______ PESO _______

H ANCA ________ H TORACE _______ H SPALLA________

Domanda 1

Osservando la postazione di lavoro e considerando l'uso che se ne dovrà fare, quanto ritieni sia adatta in termini di comfort?

Massimo Discomfort — Neutro — Massimo Comfort

1	2	3	4	5	6	7	8	9

Domanda 2

Per ogni parte del corpo indicata, esprimi un giudizio riguardo la sensazione di comfort percepita.

1 - Molto discomfort 5 - indifferente 9 - Molto comfort

COLLO	1	2	3	4	5	6	7	8	9
SPALLE	1	2	3	4	5	6	7	8	9
SCHIENA	1	2	3	4	5	6	7	8	9
MANI/ POLSI dx	1	2	3	4	5	6	7	8	9
MANI/ POLSI sx	1	2	3	4	5	6	7	8	9
GOMITI/ BRACCIA dx	1	2	3	4	5	6	7	8	9
GOMITI/ BRACCIA sx	1	2	3	4	5	6	7	8	9

Domanda 3

In generale, quanto ritieni sia confortevole la postura assunta?

Massimo Discomfort — Massimo Comfort

1	2	3	4	5	6	7	8	9

Figure-4. Subjective questionnaire.

The operations sequence carried out by the cashier is reported in the following scheme: 1) Expecting the positioning of objects on the conveyor belt by the customer; 2) Taking of the first item positioned on the

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belt; 3) Bar-code reading on the scanner - the bar code was already in the right position -; 4) Placing of the item on the "collective desk" on the left; 5) Taking of the second item positioned on the belt; 6) Bar-code reading on the scanner - the bar code was already in the right position -; 7) Placing of the item on the "collective desk" on the left; 8) Typing on the frontal touch-screen monitor to request the bill; 9) Taking of the money deposited from the customer on the frontal Plexiglas support; 10) Counting of the money; 11) Taking of the receipt from the printer with right hand; 12) Change and receipt delivery. Indeed, whereas the workstation analyzed are provided by automatic payment system, it is considered also the work-cycle without the tasks 9), 10), 11), 12).

MODELLING OF WORKSTATION AND WORKER

Delmia® was used for 3D modelling of the cashier workstation and the worker. The manikin instead was modelled according the anthropometric measurement of each operator. The cashier workstation was modelled from the technical specifications [39] of the manufacturer that was verified directly on site. In Figure-4, it is possible to observe the virtual model realized, while in Figure-5 the real one.

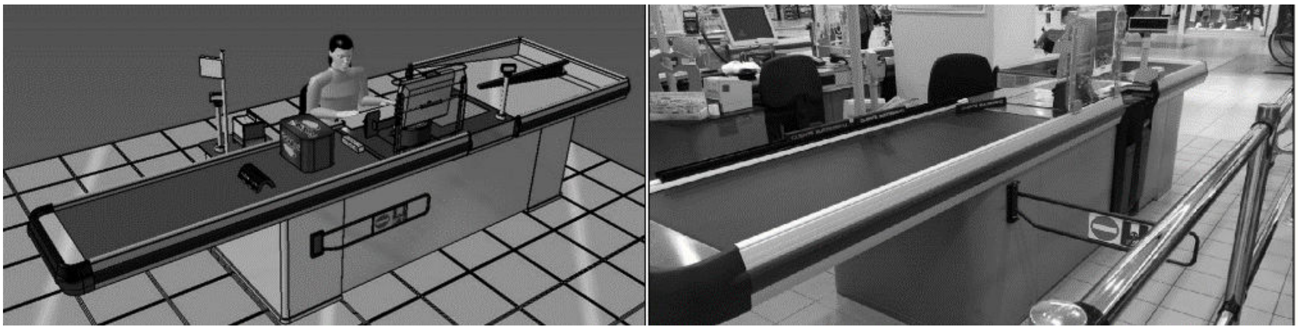

Figure-5. Modeled (left) and real (right) workstation.

Delmia® was used also to simulate the work-cycle and for checking the postures of operators during the work-cycle itself. Postures have been acquired through photos and videos and have been processed by DartFish® software, as reported in Figure-6. After modelling every task for each manikin, using function "Data read" it was possible to continuously (in time) store angles in an Excel™ spreadsheet in order to obtain a mean comfort curve for each manikin. The acquired angles are: Head (rotation, frontal flexion, lateral flexion); Forearm (flexion-extension, pronation-supination); Arm (frontal flexion, abduction-adduction); Hand (flexion, radial-ulnar deviation).

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Figure-6. Angles from lateral, rear and upper side.

ERGONOMIC AND COMFORT EVALUATION

Acquired angles have been used to calculate global and local comfort index through the Software CaMAN® [32] in accordance with listed actions. These indexes were organized in the table as shown in the Figure-7.

Local Comfort Index Matrix													
	Tasks												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean Value
Neck: FF+R	9,986	7,365	9,986	5,376	5,286	9,985	9,007	9,986	9,395	9,884	1,000	9,395	
Neck: FL	9,900	9,900	9,900	9,900	9,900	9,900	9,900	9,900	9,900	9,900	9,900	9,900	6,554
Shoulder L: FF	9,484	9,484	7,280	6,833	7,140	6,781	8,754	6,855	6,855	9,484	9,484	6,855	
Shoulder L: ad-ab	10,000	10,000	10,000	5,800	6,780	8,795	5,100	9,935	9,935	10,000	10,000	9,935	
Shoulder R: FF	8,306	7,135	6,776	6,776	5,738	6,423	6,423	5,534	1,196	9,055	8,559	1,196	
Shoulder R: ad-ab	10,000	9,946	10,000	10,000	6,004	10,000	10,000	10,000	10,000	10,000	5,100	10,000	6,390
Elbow L: ps	6,000	6,000	6,000	5,994	9,262	5,857	1,000	6,227	6,227	6,000	6,000	6,227	
Elbow L: F-E	5,743	5,743	6,908	10,000	7,100	7,100	7,100	7,100	7,100	5,608	5,608	7,100	5,764
Elbow R: ps	6,000	6,000	6,000	6,000	6,425	6,425	6,425	6,425	6,425	6,000	8,900	6,425	
Elbow R: F-E	6,152	7,023	7,100	7,100	10,000	7,107	7,107	10,000	10,000	5,814	10,000	10,000	6,650
Hand L: dev RU	10,000	10,000	4,300	9,971	10,000	10,000	10,000	10,000	10,000	4,300	4,300	10,000	
Hand L: FE	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	7,368
Hand R: dev RU	10,000	3,824	4,300	4,300	2,019	4,447	4,447	4,447	4,447	4,300	4,300	4,447	
Hand R: FE	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	4,994
Global	7,310	6,563	6,413	6,448	5,952	6,881	5,410	6,868	5,684	6,176	5,094	5,684	**6,207**

Figure-7. Global and local comfort indexes.

In order to calculate global comfort index, comfort indexes related to the following bodyparts have been weighted and averaged with a weighted average: shoulders, right arm and right hand; these were chosen because they are the most used in the whole work-cycle. A sensitivity analysis was carried out in order to establish the right weight for each contribution for obtaining the higher correlation between global comfort index and subjective perceptions.

Pearson index has been used to check statistical correlations among evaluated parameters and factors. Figure-8 shows the obtained results: the sensitivity analyses allowed choosing the first criterion of weighting the comfort contributions, because it shows the best

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correlation between subjective analyses and objective comfort rating.

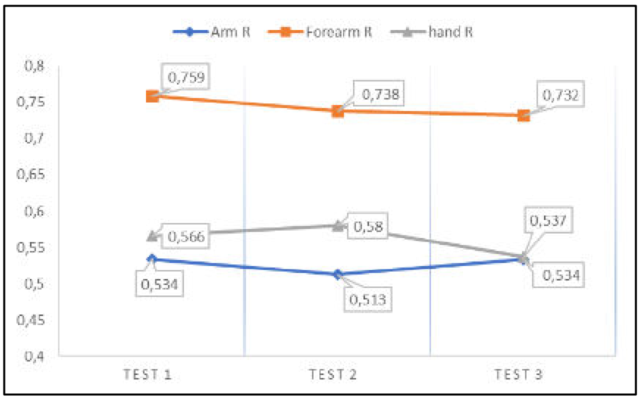

Figure-8. Results of sensitivity analysis.

RESULTS AND CONCLUSIONS

The first relevant result is a good correlation among subjective evaluations and calculated comfort indexes. In particular, high correlations have been found for neck, shoulders and hand, as shown in Figure-9.

Correlazioni

		Com_collo	Com_Spalle	Com_Manodx	Com_Manosx	Com_Bracciadx	Com_Bracciasx	Com_Generale	Aspettativa	Caman_collo	Caman_braccia	Caman_avambracciosx	Caman_avambracciodx	Caman-polsosx	Caman_polsodx	Caman_glob
Com_Collo	Correlazione di	1	,156	-,082	,016	-,221	-,152	-,147	-,073	,294	,199	,253	,095	,045	,065	,198
	Sig. (2-code)		,511	,732	,945	,349	,523	,535	,760	,209	,401	,281	,690	,851	,785	,403
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Spalle	Correlazione di	,156	1	,224	,105	-,283	-,374	,105	,466*	,206	,577**	-,081	,411	-,040	-,021	,369
	Sig. (2-code)	,511		,342	,660	,227	,105	,660	,038	,384	,008	,735	,072	,868	,930	,110
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Manodx	Correlazione di	-,082	,224	1	-,212	,423	,229	,415	,383	-,103	,183	,114	,802**	-,076	,297	,693**
	Sig. (2-code)	,732	,342		,371	,063	,331	,069	,095	,666	,439	,632	,000	,749	,203	,001
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Manosx	Correlazione di	,016	,105	-,212	1	-,445*	-,259	-,099	,244	,352	-,176	,019	-,158	,757**	-,199	-,008
	Sig. (2-code)	,945	,660	,371		,049	,271	,678	,299	,128	,457	,936	,506	,000	,401	,973
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Bracciadx	Correlazione di	-,221	-,283	,423	-,445*	1	,634**	,296	0,000	-,101	-,212	,095	,120	-,083	,448*	,240
	Sig. (2-code)	,349	,227	,063	,049		,003	,204	1,000	,673	,369	,689	,614	,727	,048	,307
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Bracciasx	Correlazione di	-,152	-,374	,229	-,259	,634**	1	,212	,035	,259	-,147	,205	-,102	-,212	,726**	,262
	Sig. (2-code)	,523	,105	,331	,271	,003		,371	,884	,270	,535	,387	,669	,371	,000	,264
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Com_Generale	Correlazione di	-,147	,105	,415	-,099	,296	,212	1	,635**	-,028	,279	,322	,391	,227	,102	,497*
	Sig. (2-code)	,535	,660	,069	,678	,204	,371		,003	,905	,234	,166	,088	,336	,668	,026
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Aspettativa	Correlazione di	-,073	,466*	,383	,244	0,000	,035	,635**	1	,110	,538*	,159	,453*	,221	,285	,595**
	Sig. (2-code)	,760	,038	,095	,299	1,000	,884	,003		,644	,014	,504	,045	,350	,223	,006
	N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

Figure-9. Pearson indexes for correlation.

The statistical correlations show how the CaMAN software works very well in this kind of simulations. Among the analyzed factors, only arms' perceived comfort did not show a good correlation because it is not hanging, as CaMAN® was developed for, but it is usually hold on the main plane of the workstation.

Another limitation that can justify the lack of some correlations is due to the low number of subjects that performed the tests. This is also evident by the calculation of the variance of subjective judgments that is equal $\sigma=1.38$.

The first output of this work is the evaluation of the mean comfort values referred to the 12 main operations. Figure 10 shows the comfort curve for the subject n ° 20, where the average value is also reported in the case of manual payment to the cashier and in the case of automatic payment. Obviously, in the second case, as the number of actions performed by the operator is lower (actions, however, which in some cases are characterized by lower comfort indices); the average global comfort index is greater than in the first case. Thus, the first output is that the number of actions in a simple work-cycle affects the global comfort perception: the lower are the actions, the higher is the perceived comfort.

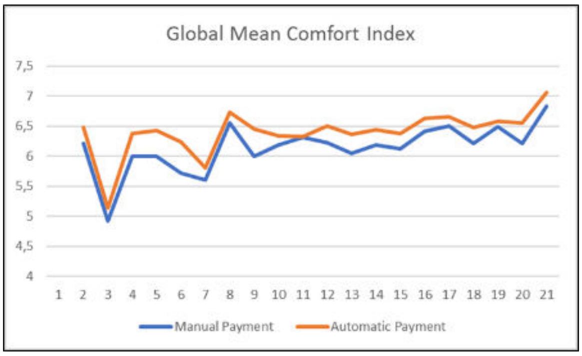

Figure-10. Global mean comfort index.

This advantage can be seen also as a method to increase productivity and improve psychophysical aspect, as the operator needs to pay less attention and concentration (less stress), while respecting the Directive 2006/42/ EC. The analyses of available data gave us information about the average comfort index for each person along the time. The use of DARTFISH completely integrated in the CaMAN software allow to investigate and rate the global comfort (using the weighted average as stated in previous paragraphs), and to understand which movement causes the less comfort perception or an uncomfortable situation. Simply putting in the graph the actual value and the mean values, as in Figure-11, allow understanding what the actions to improve are or change in order to improve the workstation and the work-cycle by a comfort-driven design.

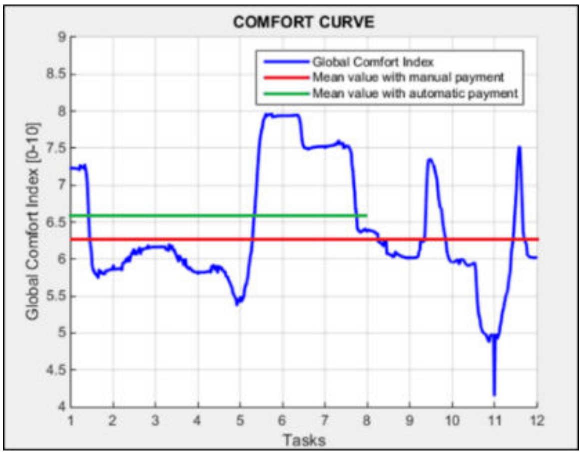

Figure-11. Comfort curve for subject n°20.

Finally, in order to complete the analysis as suggested by the NC-model of comfort, the influence of expectation on the subjective evaluation of global comfort has been investigated. This relationship has been identified by the presence of a strong index of correlation between the two variables. In order to deepen this functional bond, a second order polynomial regression has been done among them. This is shown in the Figure-12.

The slope of the curve of comfort towards the expected one decreases as the expectation increases; this means that for higher values of the latter variable, the difference between it and the perceived subjective comfort increases. In other words, expectation affects the perception of comfort more when it is elevated. This supports the theory of the influence of expectation on perceived comfort [25], which states that subjective perceived comfort could be represented as the following function:

$$C_i = Mod_C * P_C (h(Pe, Pr, T\&U, We, G\&E)) - E$$

In which:

- **Mod** = Modifier of P (Perception) of the **h** = Human body effect due to:
- **Pe** = Personal characteristics
- **Pr** = Product characteristics
- **T&U** = Task and usage
- **We** = Working environment (environment where activity is performed)
- **G&E** = Gratification level and emotions
- **E** = Expectations
- **Ci** is one of the four kinds of Comfort: Postural, Physiologic, Cognitive & Psychologic, Environmental & Organization

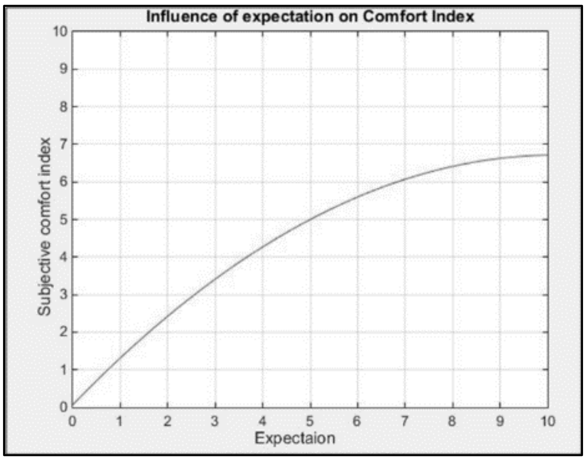

Figure-12. Expectation influence.

In this paper an easy methodology for determining comfort conditions as well as delivering solutions for improving the user experience, that are entirely consistent with reality, is shown. The methodology is also very cheap (photo and video acquisition of posture, off-line post-processing and by-software analyses) and can be used during the shift without affecting operators in terms of productivity and quality of their service, because is completely not-invasive.

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