Improving performance and working conditions in Industry
with a focus on reduction of exposure to risk factors concerning musculoskeletal disorders

Gu van Rhijn, Tim Bosch
gu.vanrhijn@tno.nl
TNO, The Netherlands

Introduction

In various parts of the world the manufacturing companies are under a lot of pressure. Generally, customers demand a larger variety of products to be delivered at shorter time intervals than before, which may certainly not be at the cost of a lower quality or a higher price. In addition the recent financial and economic crises put extra pressure on manufacturing industry.
This all force manufacturers of (complex) products to improve the flow of production orders together with a more efficient employment. The pressure on the organization is likely to increase the mental and physical stresses on the individual workers. At the same time, it is increasingly important to keep the workforce healthy and well, as there will be fewer people in the workforce due to the ageing population (e.g. de Beer and van Wissen 1999).
In addition to the need for more efficiency, there is a need for flexibility. Automation can reduce manufacturing costs (Stahre and Vink, 2006). However, automation is most suitable for moderate or large batch sizes, and may have negative consequences for the remaining tasks. Jobs will show fewer opportunities for variation and recovery through discretionary breaks, and a larger occurrence of short-cycle, repeated operations (Mathiassen 2006). This might cause absenteeism but moreover presenteeism (i.e. productivity loss due to employees actually showing up for work while having disorders or experience discomfort). One aspect of flexibility concerns the growing level of customization and a shorter product lifecycle resulting in smaller batch sizes and more variety in products. In order to produce small batch sizes of varying products, production systems must be both flexible and efficient. There is no machine as flexible as a human being, which is the reason that manual handling will continue to exist (Rosecrance, et al., 2005).
Another aspect of flexibility deals with fluctuations in volume demand throughout the year. Many companies are exposed to relatively short periods of times (about one or two months), where the volume demands are significantly higher compared to the rest of the year. In some companies these periods are predictable, in other these are not. Companies have the impression that these fluctuations become more and more unpredictable. To improve flexibility there is –again- an increasing awareness of the role of the human workers. The adaptability of human workers makes them the most flexible part of the production system (Paquet and Lin, 2003).
In all these manufacturing companies it is the question how to immediately increase the output volume if the demand increases without compromising efficiency, quality, costs and workload on employees.
With regard to the workers, musculoskeletal disorders (MSD) are a major issue in terms of the economic and health burdens. In the EU, MSDs are the biggest cause of absence from work in practically all member states. In some, 40% of the costs of workers' compensation are caused by work related MSDs and up to 3% of the gross domestic product of the country itself; reducing the productivity and adding to the social costs of government (EU OSHA, 2007). Work-Related Upper Extremity Disorders (WRUED) are one of the most serious work-related health complaints in Europe (Eurostat 2010). One fifth of the work-related health problems were associated with upper extremity problems. A review of the literature by Buckle and Devereux (2002) showed 12-month prevalence among various EU countries ranging from 15 to 40%. In the Netherlands the costs of WRUED were estimated 2.1 billion Euros per year (Blatter et al. 2006). In Europe, almost two-third of the people with WRUED experienced some or considerable limitations in

normal daily activities either at work or outside of work (Eurostat 2010). These limitations are an important concern not just for worker but also for employers. Presenteeism might have catastrophic effects on a company's performance and complementary to absenteeism lead to substantial costs. Although studies focusing on presenteeism and musculoskeletal problems are sparse, productivity losses as a consequence of working with WRUED were considered as a main cost driver and estimated to be 808 million Euros per year in the Netherlands (Blatter et al. 2006).
One of the primary goals in participatory ergonomic processes involves the reduction of musculoskeletal disorders by eliminating the physical and psychosocial risk factors that are associated with the disorders (e.g. Kilbom 1994; Bernard 1997; Bongers et al. 2006). Many of the physical risk factors associated with MSD are often the result of inefficient and poorly designed work practices. Other risk factors that needs attention have to do with the temporal pattern of the load during the day. Aspects of this time pattern or 'rhythm', like work rest schedules, task variation, cycle time, and work pace may clearly affect the worker, both mentally and physically (e.g. Bosch et al 2007). These risk factors can be evaluated and rated in occupational settings with a variety of risk assessment methods as described in a recent systematical review (Takala et al. 2010). These risk assessment methods usually combine awkward postures with external loads, frequency of movement and duration of the task (e.g. CEN, 2002; ISO, 2005; De Kraker et al. 2008).
When a participatory ergonomics and a lean manufacturing process are integrated, it may be possible to improve productivity and prevent injuries and illnesses to a greater extent possible than if either one is performed in isolation (Rosecrance, et al., 2005, Vink et al., 2008).
In this paper two examples of integrated production improvements are described. One example concerns the change from a batch production to a mixed flow assembly system including ergonomically designed work stations. The second example focus on alternatives in work rest schemes to increase productivity and flexibility and to reduce fatigue. In both cases the effects in terms of both productivity, flexibility, and physical and mental loads on the workers were studied.

Case 1 Changing from batch to flow assembly in the production of emergency lighting devices

An (ergonomic) process innovation project was performed at a company that produces emergency lights. This company experienced a steep increase in the market demand. Due to lack of space, plans were already made for a new production facility, but the management decided to have the production systems first critically analyzed. Therefore we applied a participatory and integrative approach. Crucial elements in this are the involvement of company representatives and the integration of the disciplines of ergonomics and assembly engineering. The approach includes seven steps.
The first step is the initialization of a multidisciplinary working group consisting of a mixture of internal professionals (operators, middle management, process engineers, planners, line and company management) and external specialists: one assembly engineer and one ergonomist. The second and third steps involve the analysis of the assembly process and the analysis of issues (bottlenecks) with regard to the material flow and ergonomics. To give input to the working group sessions, direct observations and interviews took place addressing items like factory layout, delivery of components, availability of tools and equipment, time required to walk and search for tools and components, and physical and mental loads in assembly or transport. In the fourth step, potential alternative production systems including transportation systems are identified and subsequently evaluated in the working group on criteria like: the flow of materials, the logistics, the balancing of activities, the work content per individual, the time to learn (for new employees), the flexibility to cope with volume and product variances, and the required space and the investments. Finally, one production system is selected. In the fifth step, the selected system is designed in detail. This includes the definition of tasks, and ergonomical work station and

equipment design. In the sixth step, mock-ups of workstations are built and tested. On the basis of the test results the assembly line and workstations are actually built and the new process is implemented. The final step concerns the evaluation of the new situation. The detailed results of each step were described by Van Rhijn et al. (Van Rhijn 2005). In this paper, we summarize the main system changes. In final assembly, we changed the production system from a batch-wise type of production into one-piece flow production. We integrated ergonomics in the workstation design during the process engineering design. We replaced the large tables by two parallel workstations, where the large part of the required assembly steps are performed by two operators, and a third station in series, where the products are finished and packed by one operator. Inclined roller conveyors make the products glide from the first two workstations to the final one. All three work stations were ergonomically well-designed.

Measurements case 1

In the effect evaluation six workers, who were familiarized with the traditional and the new concept (for a period of six months at least) participated. Their general experience in assembly work ranged from 1.5 to 12.5 years. The average age of this subject group was 30.7 years (range 21 to 41 years). As both assembly concepts, the traditional and the new one, were simultaneously operative, we were able to test the subjects in both conditions and thus, to apply a within-subject design wherein the work condition (traditional vs. new) was the independent variable and the various production and human factors variables were the dependent ones.

In both conditions we measured the productivity in terms of the number of products per person per day. Furthermore, we calculated the order lead-time, i.e. the duration of stay of product in the line. The required floor surface was measured including the workbench, the walking space at the work place and the material storage space at the work place. From video recordings in both conditions, we divided the activities into added value (assembling, mounting) and non-added value (walking, sorting, searching) activities and we calculated the time of added value activities as a percentage of the total working time.

With respect to the physical load on the workers, we determined the time of occurrence of awkward body postures (CEN 2002, ISO 2005), the occurrence of high risk lifting situations (Waters et al., 1993) and the perceived physical load and fatigue. To measure the locally perceived discomfort (LPD) in the various body regions we used the validated LPD-method (van der Grinten 1991), where levels of discomfort are rated on a BorgCR-10 scale, ranging from 0 to 10, where 0 = no discomfort and 10 = extreme discomfort (almost maximum) and the other numbers points are also verbally anchored. In addition, we used a standardized questionnaire to evaluate the old and new situation. This questionnaire addresses the following items: physical load, the mental load, the worker's satisfaction, the health risks and the experienced fatigue.

Results case 1

An increase of 44% in productivity and a reduction of the order lead-time of 46% was obtained. The time that workers spent to added value activities significantly increased from 74% to 92%, without any increase in postural and experienced loads. The NIOSH equations for lifting boxes in the old and new situation showed an improved and safe way of lifting in the new situation. In the traditional situation the lifting situation was unacceptable due to the low placement (the vertical factor) of the pallets on the floor (30 cm) and the reaching (horizontal factor) before placing. In the new situation the boxes were placed on a pallet at adjustable height (70-80 cm) on a lifting table and reaching was less far. The workers experienced significantly less overall fatigue at the end of the day in the new situation.

Case 2 Alternative pause schemes in shaver assembly

In this case the question was of how to temporarily (in times of peak demand) increase the output of a line in a shaver assembly plant at Philips, which is already optimized to attain the “normal” output rate. Instead of a costly reconfiguration of the line
creating extra workstations for more operators, we applied an approach of keeping the line intact, adding two extra operators, and applying a scheme wherein the operators took their breaks alternately while the line kept running. For two different alternating break schemes, we compared the productivity rates, the physical load on operators, and the operators’ experiences to those of the traditional situation. 14 operators at Philips DAP took part as a subject in the experiment. They worked in a line of twelve work stations. Their task, which was repetitive and monotonous, comprised of assembling activities and technical and visual control (cycle times 12-45s).
The operators were tested in three conditions. In the traditional condition (T), 12 operators were present: one for each work station. The pause scheme comprised a lunch break of 30 minutes and 4 short breaks over the day (figure 1). The operators took all breaks group-wise.

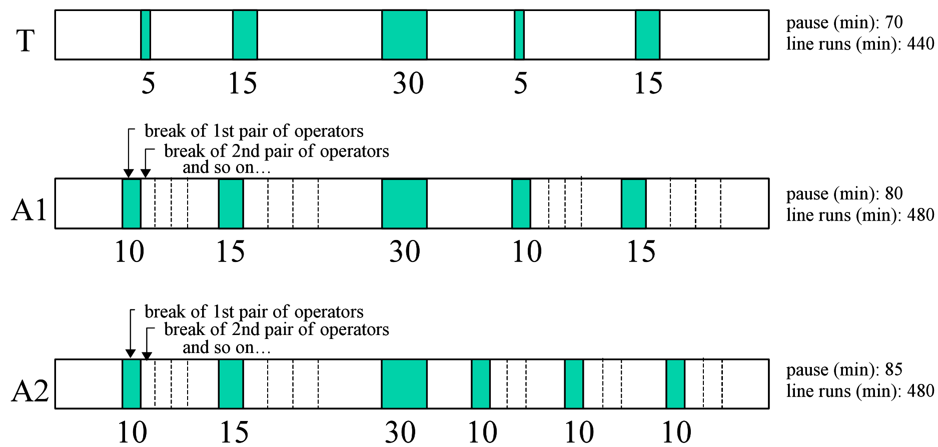

Figure 1. The work/rest schemes applied in the three conditions: traditional situation (T), the first alternative situation (A1), and the second alternative situation (A2). In A1 and A2, all breaks (except for the lunch break) were taken alternately in pairs of two operators. Also indicated are the total pause time and the total running time of the production line per shift.

In the first alternative condition (A1), 14 operators were present in the same line of 12 work stations. They took their lunch break all together, but the short breaks were taken alternately in couples of two. During the time periods that none of the fourteen workers had a break, the two extra operators did some cleaning, supplying or giving some help elsewhere. The second alternative (A2) was similar to the first, except for an extra (fifth) break in the second half of the shift.
The total pause time per day for each operator was 70, 80 and 85 minutes in T, A1 and A2, respectively. The total time that the line was not running was 70 minutes in T and only 30 minutes in A1 and A2 (Figure 1). All operators were exposed to each condition during two weeks. In the second week the measurements took place.

Measurements case 2
The productivity of the line was expressed as the number of products per day. In addition, the mean productivity of the operators in the first evaluation was determined by dividing the line output by the number of operators. In the second evaluation, the productivity was monitored for each individual worker.

The physical load on workers was expressed as the level of locally perceived discomfort (LPD) using a Borg CR-10 rating scale in the various body regions (e.g. hands, lower arms, upper arms, neck, the high, middle and low region of the back, the buttocks, upper legs, lower legs and feet) indicated on a body map (van der Grinten, 1991). Other individual experiences were addressed in a questionnaire at the end of the tests.

Results case 2

The detailed results were described by de Looze and co-authors (de Looze et al., 2010a). For the alternating pause schemes the line productivity was significantly higher as compared to the traditional pause scheme: A1 and A2 resulted in a 12 and 16% higher output, respectively. There were no significant differences in line output between A1 and A2. The productivity per operator per shift was not significantly different across conditions, despite the longer total pause times in A1 and A2.

The local levels of discomfort were found to increase significantly during the day only in the neck and shoulder region. This increase, which was most pronounced in condition T and A1, is shown in Figure 2. The discomfort level at the end of the shift in scheme A2 was significantly lower compared to A1, whereas the time integral of discomfort over the shift in scheme A2 was significantly lower compared to the traditional condition T.

A majority of the operators entitled this alternating break scheme as 'pleasant' (90%), but wanted the scheme to be applied only during the periods of peak demand because of social aspects (80%).

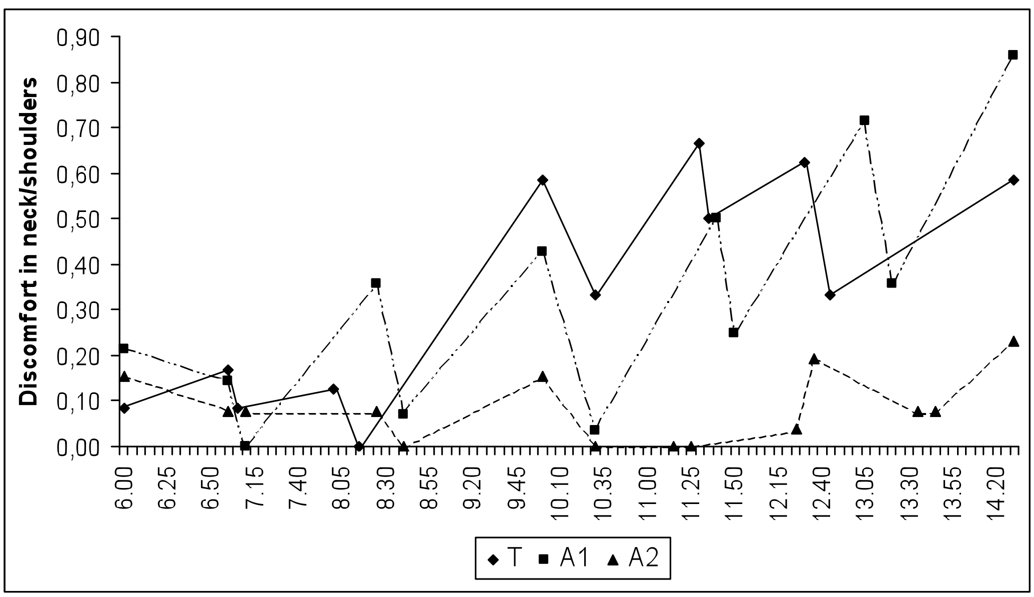

Figure 2 The average level (across participants) of discomfort in the neck and shoulder region during the day in the various conditions. Each point in the graph reflects a measuring point; all these measuring points took place just before or directly after each break.

Conclusions and discussion

In case 1 the change of the production concept in combination with some ergonomic work place modifications resulted in some clear effects. There appeared to be no need for the company to invest in factory expansion. On the same factory area, it appeared to be possible to produce about twice as much when applying the new assembly concept. In addition, we observed a significant reduction in order lead time (46%) and a significant gain with respect to productivity (44%). The detailed costs and benefits of these interventions are described in de Looze et al. (2010b). This gain in productivity is partly based on an increase in the percentage of time that is spent on added-value activities.

This shift towards more added value assembly work did not lead to a clear increase in the physical or mental loads on the workers. Instead, we observed a decrease in the occurrence of stressful lifting activities and a decreased overall fatigue at the end of the day.

One remaining point to discuss concerns the increased time percentage of direct work. Some argue that such development (also addressed as work intensification) may well increase the risk for musculoskeletal injury (Winkel et al. 2002). Also, monotonous work in the production industry has been associated with more health problems in the upper extremities and elevated sick leave rates (Johansson et al 1994, Olafsdottir et al. 1998, Parenmark et al. 1993). The theory behind this is that the long periods of time of monotonous assembling activities without interruption of other kinds of (indirect) activity, give body structures not enough opportunities to recover during the day (Winkel et al. 2002). At higher percentages of direct work, the need for some kind of variation interrupting the assembly work so now and then, thus increases.

This variation and interruption was studied in case 2, the alternative pause schemes.

It appeared that an increase in volume flexibility can be achieved by adding two extra workers and applying an alternating work rest scheme, and thus, without a costly reconfiguration of the line. Two extra workers and the implementation of an alternating work/rest scheme resulted in a 12–16% higher line output. Simultaneously, the operators experienced less physical load on their neck and shoulders, particularly in the alternating scheme with the highest number of breaks and highest total break time;

This alternating work/rest scheme is recommended only during time periods of peak demand (up to 2 months) because of social aspects. In this alternating work rest scheme the workers have a break in couples while in the traditional rest schemes they have a break together with the whole team. The Hawthorne effect, a form of reactivity whereby participants improve an aspect of their behaviour being experimentally measured simply in response to the fact that they are being studied (Landsberger, 1958), might have influenced the results in the current study. However, productivity results were collected over a two week period without being known by the operators. Other measures were compared in a within subject design at the end of each condition so if any effect existed it might be small and probably occurred in all conditions.

Finally we would like to discuss two issues with regard to these two cases.

Firstly these two cases are examples of improvements of both productivity and working conditions by innovations in production systems, workstation and organisation. Traditionally, most companies focus either on technological innovations or on the organizational structures or on enhancing human resources. The best performance however, will be realized when all three factors are involved. Corporate success can be enhanced by balancing technological, organizational and human factors in the production process (Vink et al, 1996). Recent paper by Dul and Neumann (2009) confirmed the importance of health and performance measurements. Manager usually associate ergonmics with occupational health and not with business performance. The focus of human factors should be linked to business strategies and the management world.

Secondly these two cases are examples of experimental studies in which effects were determined in short periods of time and with small sample sizes. We acknowledge that the described Hawthorne could occur. From these studies focus on risk factors of MSD. However no direct link to MSD could be determined

With regard to the musculoskeletal disorders (MSD) a recent overview of longitudinal studies by Bongers and colleagues (Bongers et al 2006) indicated that perceived stress and high demands in combination with low control at work are often related to neck and upper limb symptoms. Furthermore, several factors like individual characteristics (age, gender etc.), motivation, work experience and skills might affect the relationships between exposure, responses and disorders. To reduce the risk of MSD requires an integrated approach consisting of a combination of interventions on organisational, workstation and individual level. Further research is needed to assess the effects of these interventions on both productivity and MSD reduction.

References

Beer, de J. and van Wissen, L., 1999. Europe: One Continent, Different Worlds. Population Scenarios for the 21st Century. Kluwer Academic Publishers (Dordrecht 1999).

Bernard, P. (1997). Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity and Low Back (Cincinnati, Ohio: NIOSH).

Blatter B, Houtman I, Van den Bossche S, Kraan K and Van den Heuvel S.; Gezondheidsschade en kosten ten gevolge van RSI en psychosociale arbeidsbelasting in Nederland, The Hague, 2006

Bongers PM, IJmker S, van den Heuvel S and Blatter BM (2006). Epidemiology of work related neck and upper limb problems: Psychosocial and personal risk factors (Part I) and effective interventions from a bio behavioural perspective (Part II). Journal of Occupational Rehabilitation, 16 (3), 272-295

Bosch T, Looze MP de, Dieën JH van. Development of fatigue and discomfort in the upper trapezius muscle during light manual work. Ergonomics 2007;50(2):161-177.

CEN (2002). CEN, EN 1005-3. Safety of Machinery—Human Physical Performance—Part 3: Recommended Force Limits for Machinery Operation (2002).

Das, B. (1999). Development of a comprehensive industrial work design model. Human Factors and Ergonomics in Manufacturing, 9(4), 393– 411.

Dul J and Neumann PW. Ergonomics contributions to company strategies. Applied Ergonomics, 40 (4), 745-752

Eurostat (2010). Health and safety at work in Europe (1999-2007): A statistical portret. Luxembourg: Publications Office of the European Union

ISO (2005). ISO, ISO/DIS 11228-3. Safety of Machinery—Human Physical Performance—Part 5: Risk Assessment for Repetitive Handling at High Frequency (2005).

Johansson JÅ and Nonås K, 1994, Psychosocial and physical working conditions ans associated musculoskeletal symptoms among operators in five plants using arc welding in robot stations. International Journal of Human Factors in Manufactoring, 4(2) 191-204.

Kilbom, Å ., (1994). Repetitive work of the upper extremity Part II: the scientific basis (knowledge base) for the guide. International Journal of Industrial Ergonomics, 14, 59–86.

Kraker de H and Douwes M. (2008). The development of a practical tool for risk assessment of manual work - the ‘HAT-tool’. In: Helgadóttir B, Ed. NES 2008 Abstracts: Ergonomics is a lifestyle. Reykjavik: Gutenberg, 190.

Landsberger HA. Hawthorne Revisited. Ithaca: Cornell University Press; 1958

Looze, M.P. de, Bosch,T., Rhijn, J.W. van. Increasing short-term output in assembly work. Human Factors and Ergonomics in Manufacturing & Service Industries 20 (5) 470–477

Looze, M.P. de,Vink, P., Koningsveld, E.A. P., Kuijt-Evers, L., & Van Rhijn, J. W. (2010). Cost-effectiveness of ergonomic interventions in production. Human Factors and Ergonomics in Manufacturing&Service Industries, 20(4), 316–323.

Mathiassen SE (2006). Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Applied Ergonomics, 37, 419–427

Ólafsdóttir H & Rafnsson V , 1998, Increase in musculoskeletal symptoms of upper limbs among women after introduction of the flow-line in fish-fillet plants. International Journal of Industrial Ergonomics , 21, 69-77.

Paquet, V and Lin, L. (2003). An Integrated Methodology for Manufacturing Systems Design Using Manual and Computer Simulation, Human Factors and Ergonomics in Manufacturing, 13(1), 19–40.

Parenmark G., Malmkvist A.K. & Örtengren R. ,1993, Ergonomic moves in an engineering industry: Effects on sick leave frequency, labor turnover and productivity. International Journal of Industrial Ergonomics , 11, 291-300.

Rosecrance, J., Douphrate, D. and Cross, S. (2005). Integration of Participatory Ergonomics and Lean Manufacturing: A Model and Case Study. Human Factors in Organizational Design and Management - VIII, Edited by P. Carayon, M. Robertson, B. Kleiner and P.L.T. Hoonakker. IEA Press, Santa Monica, California, USA, 437 - 442.

Stahre J., Vink P. (2006). The future of intelligent manufacturing systems and human factors. In: Pikaar RN, Koningsveld EAP, Settels PJM, Eds. Meeting Diversity in Ergonomics. Proceedings IEA2006 Congress. Oxford: Elsevier. CD-rom: art0526.

Takala EP, Pehkonen I, Forsman M, Hansson GA, Mathiassen SE, Neumann WP, Sjøgaard G, Veiersted KB, Westgaard RH, Winkel J., 2010. Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand J Work Environ Health. 36 (1), 3-24.

Van Der Grinten, M.P., 1991, Test-retest reliability of a practical method for measuring body part discomfort. In Designing for Everyone, volume 1, Y. Que´innec and F. Daniellou (Eds.), London: Taylor and Francis, 54–57.

Van Rhijn J.W., de Looze M.P., Tuinzaad G.H., Groenesteijn, L. , de Groot, M.S. and Vink, P. (2005). Changing from batch to flow assembly in the production of emergency lighting devices. International Journal for Production Research, 43, 3687-3701.

Vink, P. Rhijn, G. van, Dhondt, S. and J. Dul (1996): Ten times better: improving technological, organisational and human factors in companies. In O. Brown, H.W. Hendrick (Eds): Human Factors in Organisational Design and Management-V. Elsevier, A'dam.

Vink, P, van Rhijn, G. and Krassi, B. (2008) Collaborative design using mixed reality: suggestions from INTUITION partners In: Karwowski W, Salvendy G, Eds. Conference Proceedings, 2nd International Conference on Applied Human Factors and Ergonomics, AHFE 2008, 14-17 July 2008, Las Vegas, USA. Louisville: AHFE International, CD Rom.

Waters TR, Putz-Anderson V, Garg A, Fine LJ., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36 (7) 749-776.

Winkel, J., Forsman, M., Kazmierczak, K., Kjellberg, A., Mathiassen, S.E., Neumann, P.W., and Wells, R.P. , 2002, Ergonomic intervention for occuspational musculoskeletal health in manufacturing industry – trends, tools and processes. In:. Humans in a Complex Environment., Proc. 34th Congress of NES, pp 833-835, Linkopings University, Sweden.