Does Ergonomics Improve Product Quality and Reduce Costs? A Review Article

Mohsen Zare,[1,2] Michel Croq,[3] Farhad Hossein-Arabi,[4] Rene Brunet,[1] and Yves Roquelaure[1]

1 Laboratory of Ergonomics and Epidemiology in Occupational Health (LEEST), LUNAM University, University of Angers, Angers, France
2 Department of Occupational Health, School of Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
3 Occupational Medicine, Safety and Health Department, SCANIA Production Angers SAS, Anger, France
4 Département de l'Ergonomie Groupe PSA Peugeot-Citroën, Paris, France

Abstract

Competition is an ongoing challenge confronting industrial corporations, particularly automobile manufacturing. Striving to improve product quality and productivity, automotive industries have used different quality management approaches, such as reduced variability, total quality management, and lean management, over recent years. Furthermore, incorporating proactive ergonomics such as physical and organizational ergonomics and psychosocial factors into the structure of a company is considered to be a support for productivity and quality. Several studies have shown the effects of ergonomics on better quality. Application of both quality management approaches and ergonomics in an integrated manner in the manufacturing production system is emphasized because they are similar concepts with the same objectives, that is, to improve efficiency. In this study, a comprehensive review was undertaken and 25 studies were reviewed in order to define how integration of an ergonomic approach in the manufacturing production system can reduce defects and improve quality in the production process. © 2015 Wiley Periodicals, Inc.

Keywords: Ergonomic approach; Product quality; Errors; Automotive industry

1. INTRODUCTION

Industrial companies and manufacturers have to be competitive as they face new challenges in the industrial world. Higher quality, lower waste, and efficiency are important factors to achieve success in the market (Falck & Rosenqvist, 2012; Törnström, Amprazis, Christmansson, & Eklund, 2008). Companies have always tried to attain greater efficiency and the least cost in their processes. Many disciplines were therefore introduced, such as Taylor's theory, total quality management (TQM), Six Sigma, the Toyota Production System, lean management, and kaizen (Liljedahl & Muftic, 2012). The main idea of these tools is to define a set of principles and mechanisms to generate systematic improvement in the process to achieve customer satisfaction and reduce waste (Törnström et al., 2008). However, most of the quality management approaches focus on methods and tools to gain advantages, while human aspects have been ignored or paid little attention to. Reports in the literature have stated that, without considering the ergonomic approach, quality management disciplines will not achieve their goals (Hines, Holweg, & Rich, 2004; Liljedahl & Muftic, 2012; Taleghani, 2010; Williams et al., 1992). Nevertheless,

Correspondence to: Mohsen Zare, LUNAM Université, Université d'Angers, Laboratoire d'ergonomie et d'épidémiologie en santé au travail (LEEST), Angers, France. Phone: +33787722141; e-mail: mohsen@zare.fr

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managers see ergonomics as a strictly health and safety tool that is useful for injury/illness prevention instead of recognizing its potential to improve productivity and quality and to reduce costs. This misconception in companies thus prevents ergonomics thinking within firms' production systems or quality management systems (Neumann & Dul, 2010). Although most manufacturers have recently established production system approaches as principal procedures for production, the role of ergonomics has been seen more as prevention of musculoskeletal disorders (MSDs) than as a tool for quality development.

According to the literatures, adverse ergonomic risk factors influence not only human well-being but also human performance, such as increasing rejection rates and decreasing product quality (Govindaraju, Pennathur, & Mital, 2001; Kazmierczak, Neumann, & Winkel, 2007). The costs of errors and failures were estimated about 10–40% of a company's income (Falck & Rosenqvist, 2012). Several studies suggest that errors, rejection rates, and reworking would decrease significantly with the integration of ergonomics in the production system (da Silva, Pruffer, & Amaral, 2012). The new strategy of the SCANIA group for the year 2020 is to produce 120,000 trucks, 15,000 buses, and 20,000 engines with the same staff. They believe that it would be possible to reach this goal if they could achieve zero failures. A study in this group showed that ergonomics and the work environment could help to prevent the frequent occurrence of production failures (poor quality; Liljedahl & Muftic, 2012). The Volkswagen group confirmed the need for ergonomics in the production system to prevent health hazards, to optimize production time, and to improve product quality (Toledo, 2012). Dul and Neumann (2009) showed a link between business factors and ergonomic design of the workplace, and Neumann, Ekman, and Winkel (2009) emphasized the integration of ergonomics in the production system. Battini, Faccio, Persona, and Sgarbossa (2011) developed a new 14-step integrated methodological model to achieve productivity and quality performance in an assembly system in which different tools, such as assembly time measurement, ergonomic evaluation, and ergonomic improvements, were integrated. This framework was tested in two case studies and showed improvement in line flow and in flexibility (Battini et al., 2011).

Integration of ergonomics in firms' strategies or production systems of manufacturing has thus emerged. Companies should be convinced that incorporation of an ergonomic approach in a firm's production system would be profitable in the short and long term, as its effects may vary, from human aspects, including reduction of discomfort, pain, and fatigue, to system aspects, such as speed of performance, decreased rejection rates, and good quality of service (Genaidy, Salem, Karwowski, Paez, & Tuncel, 2007). The main purpose of this article is to document empirical evidence that supports the proposition that incorporating an ergonomic approach in a firm's production system should be considered a key business objective because the benefits of ergonomics would have not only effects on health and injury prevention but also on product and process quality by reducing errors and the costs of poor product quality.

2. CONCEPTUAL FRAMEWORK FOR EFFECTS OF ERGONOMICS ON COST

The conceptual framework is shown in Figure 1. This framework illustrates the consequences of a poor ergonomic approach in a production system. Work characteristics, including physical ergonomic, organizational ergonomic, cognitive, and psychosocial factors, are defined as the ergonomic approach, and these independent characteristics influence human well-being and production levels. Finally, business and marketing would be affected in terms of brand image reduction, problems with recruitment of new employees, and price. In this study, we reviewed the effects of each dimension of the ergonomic approach on quality of products. A poor ergonomic approach influences production level, particularly quality loss, which would increase errors, scrap, and reworking. The potential quality gains of the appropriate ergonomic approach were more than US$900,000 per year in a car assembly plant (Falck, Örtengren, & Hogberg, 2010). In this review, we did not study the impact of the ergonomic approach on productivity and human well-being. However, as shown in Figure 1, there are strong interactions between these concepts.

3. MATERIALS AND METHODS

This article represents a literature review of the empirical evidence that emanated from the relationship between ergonomics in the workplace and its effects on product quality and rejection rates. According to the guiding principles of the Cochrane Collaboration System (Higgins, Green, & Cochrane Collaboration,

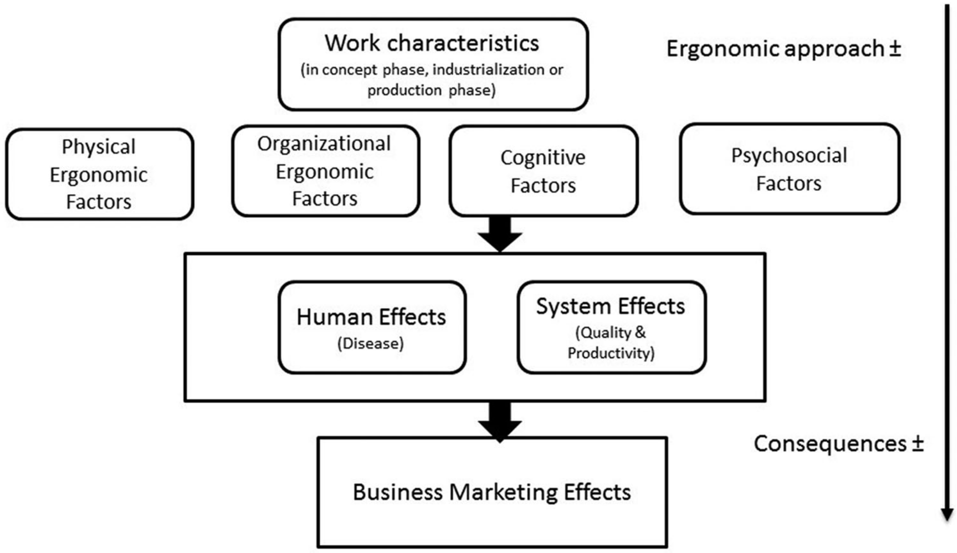

Figure 1 Conceptual framework illustrates the consequences of poor ergonomic approach

2008), the methodological steps of this literature review were the criteria for considering peer-reviewed articles for inclusion, search methods for identification of peer reviews, selection of peer reviews, appraisal of peer reviews included in the study, and data synthesis. The academic databases, which were searched from 1980 to March 2014, were Google Scholar, EMBASE, Web of Knowledge, Science Directs, Wiley-Blackwell, the Cochran Library, and Springer. In addition, some peer-reviewed journals, such as *Ergonomics* in Taylor & Francis, *Work: A Journal of Prevention, Assessment & Rehabilitation*, *Applied Ergonomics*, and *Human Factors and Ergonomics in Manufacturing & Service Industries* were specifically searched. We used different search strategies and words for each database to obtain the best results and to avoid missing literature. First, to formulate the search strategy, the important concepts within the question were identified. Then, the search terms to describe those concepts were specified, and the synonyms of those terms were considered. Finally, our search strategy was prepared. Our queries consisted of a set of phrases that were combined using different Boolean operators, such as "AND," "OR," parenthesis, and wildcards (stemming). As far as possible, we tried to use the phrases that were combinations of words that were found in the exact order in the search documents. In our queries, two or three concepts that included six or seven words were applied. We classified all key words in four categories as ergonomics and occupational health, quality and system effects, manufacturing and company system, and cost-benefits. The first set of phrases related to ergonomics included 20 terms, for example, Occupational Ergonomics, Human Factors, Human Factor Engineering, Ergonomics Solution, Ergonomics Integrat(ion, ed, ing), Work(s, ing, place) Condition, Workstation Design(ing), Participat(ory, ing, ion) Ergonomics, Occupational Health & Ergonomics. The second category of key words were 25 expressions, for example, Qualit(y, ies), Process Quality, Service(s, ing) Quality, Improv(ed, ing) Quality, Poor Quality, Continu(e, ing) Improv(ement, ing), Production Waste, Rejection Rate, Reduced Scrap, Human Error. The third category included Assembl(y, ing) Plant, Assembl(y, ing) System, Production System, Firm Strateg(y, ies), Manual Assembly, Automotive Manufactur(ing, er, e), Automotive Industry, Production Process. The final category of phrases included key words related to Cost-Savings, Cost Benefits, and Cost Effectiveness. These terms were combined several times and in different ways with the Boolean operators. Furthermore, to ensure that all peer-reviewed articles were reviewed in this area, we checked the reference lists of the relevant articles. Combining the results of all databases and journals searched provided more than 260 results for inclusion in the review. We reviewed the titles and abstracts of the articles identified. Some articles were excluded following scanning of the abstracts and some after reading the full text. The articles included in our review finally consisted of peer-reviewed studies undertaken in industrial workplaces, particularly the automotive industry throughout the world. Studies in health-care facilities and service sectors, such as medical centers and hospitals, were excluded. Occupational health and safety interventions were excluded unless they had clear ergonomics involvement. Research dealing with the effects of ergonomic interventions on only human effects or productivity was excluded. The articles included were appraised and the information on the aims of the research, interventions, study design, populations, factory and workplaces, confounding factors, outcomes, results, and conclusion were gathered.

4. RESULTS

The comprehensive search in the above databases yielded several articles that had investigated the effects of the ergonomics approach on humans and systems. Following a review of the articles found and primary screening of full articles, 29 studies were finally selected for inclusion in our review. Assessment of methodological quality was then undertaken for the 29 eligible studies, from which four were then excluded (da Silva et al., 2012; Drury, 2003; Inman, Blumenfeld, Huang, & Li, 2003; Silva et al., 2012), because of incompatibility with this review. Table 1 shows the characteristics of the 25 articles finally included with key findings and summaries of the investigations conducted. These studies include the effects of organizational and physical ergonomic factors as well as cognitive and psychosocial factors on quality of products. The articles reviewed mainly demonstrated system and human effects of the ergonomic approach elements.

4.1. Effects of Physical Ergonomics on Quality

Twelve studies showed the relationship between physical ergonomic risks and product quality. In general, all the studies included showed a strong relationship between quality errors and high ergonomic workload. Falck et al., 2010 conducted a series of case studies in the Volvo manufacturing industry (including car engineering processes, car assembly plant, and quality tracking of completed cars in the market). A considerable relationship was found between poor physical ergonomics and quality errors in all three phases. Of the 352 quality problems logged in the manufacturing engineering phase for three new car models, 23.5% were related to ergonomic problems. In the assembly plant, 55 assembly tasks were analyzed for 24443 cars. The quality errors related to high physical ergonomic workload assembly tasks (red tasks) were 39%, and for medium physical ergonomic workload assembly tasks (yellow tasks) 48%, while there were 13% for low physical ergonomic (green tasks) workload tasks. Following 216 completed cars over 8 weeks after sales in the market indicated that 70% of the errors were related to red tasks, 27% were related to yellow tasks, and just one error was related to green tasks (Falck et al., 2010). In contrast to the market, yellow tasks caused more in plant-quality errors than red tasks. The possible reasons are the effect of other ergonomic factors (organizational/cognitive/psychosocial) and misclassifications of tasks as red or yellow (observer effects). The authors realized that high-risk tasks, such as working underneath/hidden/at distance, awkward postures, and forceful operations, created more errors. However, material handling, static tasks, and sharp edges showed zero errors. In another similar study by Flack et al. (2010), just one single task, evaluated as yellow, caused 92% of errors identified in the market. The errors identified for red tasks and green tasks were 7.4% and 0.65%, respectively. Analyzing 47 assembly tasks for 47,061 cars in plant showed that the failure rate was 55.1% for red tasks, 37.8% for yellow tasks, and 7.1% for green tasks (Falck, Örtengren, & Rosenqvist, 2014; Falck & Rosenqvist, 2014). In agreement with their hypothesis, the numbers of errors for green tasks were significantly less than for yellow and red tasks in both studies. However, inconsistency was observed between the error rates for yellow and red tasks in both studies of Falck and Rosenqvist (2014) and Falck et al. (2010). Falck et al. (2010) disregarded common physical ergonomic risks that created quality errors in their second study. The results showed that the type of physical ergonomic risks and other dimensions of the ergonomic approach probably changed the rate of failures/errors for high workload tasks. The similar case study by Almgren and Schaurig (2012) in Volvo truck manufacturing showed that red assembly tasks caused 12.68 errors/min on average, while green tasks created 4.79 errors/min. In this study, the authors classified tasks into two categories, and yellow tasks were ignored or distributed between green or red tasks. Furthermore, green tasks were identified in a different way compared to red tasks. Therefore, some tasks might have been classified wrongly (Almgren & Schaurig, 2012). In contrast to the studies by Falck et al. (2010, 2014), in the study by Almgren and

TABLE 1. Summary of Research Focus on Link between Ergonomics and Quality Errors

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
Hamrol et al. (2011)	Car wire harness assembly	Workplace risk factors, such as work monotony, noise level, and quality	Psychosocial and organizational factors and environmental ergonomics	Interviews with 100 assembly workers about the main reasons for failures and analysis of the relationships of work monotony, noise level, and their interactions with quality assembly process	Work monotony increased the risk of quality failures and interaction of work monotony threefold and noise level increased the risk of quality failures 10-fold while noise level alone did not have impact on quality
Almgren & Schaurig (2012)	6 sections of assembly line at Volvo truck manufacturing	Ergonomic workload and product quality	Physical ergonomic factors	Red and green tasks were selected, and technical information about them was gathered; quality defects of these tasks in Quils system were collected, and the results were compared	Errors for red were 165% of those for green tasks. The difference between correction times was 186%. Costs for red assembly tasks were more than US$50,000 in a year.
Axelsson (2000)	Assembly plant	Work postures and quality	Physical ergonomic factors	40 tasks were evaluated by RULA and 17 high-risk tasks were assessed as causing 80% of quality problems. 15 tasks were improved ergonomically; then RULA and quality assessment were performed after intervention	Ergonomic improvements reduced quality defects from 8.9% to 5.0%
Das et al. (2007)	Simulated drill press operations	Ergonomic, work design and modifications, task performance (quantity and quality of products), and worker satisfaction	Physical ergonomic factors	In an intervention study, ergonomic evaluation was undertaken in terms of production tasks, equipment, existing workstations. Workstation redesign and operator training were then performed. The variables were compared in two situations	Increase in output quality was 49.57%, and productivity was 22%. Operator satisfaction scores also increased after intervention

(*Continued*)

TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
De Looze et al. (2010)	Emergency light company	Participatory ergonomic approach	Participatory ergonomics (organizational and physical factors)	A 7-step participatory ergonomic approach was undertaken	25% reduction in reworking related to failure (quality). Benefit from increase in quality was €27250 per year
Eklund (1995)	Swedish car manufacture assembly	Ergonomic conditions and quality outcomes	Organizational, physical, and psychosocial factors	6 phases of study were performed in 8 departments. 58 tasks were categorized as physical demands, psychological demands, and design that made assembly difficult. Quality statistics were gathered and inspectors were interviewed	Relative risk of quality problems for high-risk tasks in final adjustment department was 2.95 ($P < .05$), and in the random disassembly inspection department the relative risk was 1.94
Erdinc & Vayvay (2008)	Machine sewing tasks	Ergonomic risk factors and quality	Physical ergonomic factors	A 3-phase intervention study, including planning, assessment, and implementation, was performed. Ergonomics training and workstation adjustment were undertaken after ergonomic assessment	Defects in products due to operators' errors were reduced from 7% to 3.4%. Ergonomic risk factor and awkward postures significantly reduced
Falck et al. (2014)	Car manufacture assembly	Ergonomics, quality errors, costs	Physical ergonomic factors	47 assembly tasks were categorized as high (16), moderate (18), and low ergonomic workloads. Then 47,061 cars were analyzed regarding error rates related to manual assembly	The percentage of quality errors for high, moderate, and low manual assembly were 55.1%, 37.8%, and 7.1%, respectively
Falck et al. (2014)	Car manufacture assembly	Ergonomics, assembly complexity, quality errors	Cognitive and physical ergonomic factors	Experimental study to analyze cognitive and physical ergonomics relating to errors	Cognitive ergonomics significantly increase quality errors

(*Continued*)

TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
Falck et al. (2012)	Survey in 5 Swedish companies	Proactive ergonomics, quality and assembly errors, assembly complexity, geometry	Cognitive ergonomic factors	Interviews were conducted with 64 engineers about their opinions, experience, and knowledge of ergonomics. The questions involved assembly ergonomics, product geometry, assembly complexity, and product quality.	78% of respondents believed that poor assembly ergonomics caused quality losses. 89% thought that there are relationships between assembly complexity and assembly errors and scrap
Falck et al. (2010)	Automobile company in Sweden	Quality defects, ergonomics, and costs in 3 processes, including manufacturing engineering, assembly process, and factory complete cars	Physical ergonomic factors	The study started in manufacturing engineering, and 3 new car projects were chosen. Ergonomic workload and quality for assembly items were compared. Then 55 assembly items of 24,443 cars during 8 weeks were analyzed in assembly production. Finally, quality problems for 55 selected assembly items for completed cars were collected over 16 weeks in the after-sale market	In manufacturing engineering, 80% of the tasks with high and medium ergonomic workloads had quality defects. In production assembly, assembly items with high and medium workload had 3 and 3.7 higher quality risks compared to lower physical workload assembly items. In after-sale market, 61% of errors were related to high-risk tasks, 37% to medium-, and 0.01% to low-risk tasks
Fritzsche et al. (2014)	Large automotive industry in Germany	Ergonomics, team diversity, absenteeism, and quality performances	Physical ergonomic factors	In a cross-sectional study over 1 year, 56 automotive assembly teams (*n* = 623) were	High workload tasks increased errors by 80%. Age diversity was not related to

(*Continued*)

TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
				studied regarding the effects of ergonomics, age, and gender on absenteeism and quality performance	error rates while gender diversity has positive effects on errors
Guimarães et al. (2012)	Brazilian shoe industry	Macro-ergonomic intervention to improve both human well-being and system performance	Participatory ergonomics (organizational and physical factors)	An intervention, including noise reduction, substitution of solvents, changing layout of production area and working hours, and implementation of socio-technical model, was undertaken in a pilot line for 2 years. Human and system benefits were then compared before and after intervention	Reworking and spoilage (quality) decreased to less than 1%, productivity increased by 3%. The savings after intervention were US$433,347
González et al. (2003)	Metal factory	Ergonomics, production quality	Physical ergonomic factors	Folding sector was selected, then direct observation to identify quality records, and RULA method was applied to identify ergonomic risks. Interventions were performed and new process was defined according to RULA score.	After ergonomic intervention reprocessed parts reduced by 22% and rejected parts reduced by 45%
Il ardi (2012)	Manual deboning process in salmon fish industry in Chile	Quality, productivity, and ergonomics	Physical ergonomic factors	OCRA method and Nordic Questionnaire were used to determine ergonomically high-risk tasks. The information regarding quality of deboned meat was collected	No significant correlation was found between quality and ergonomic high-risk tasks
Larson et al. (2012)	500 companies of US 3M	30 years integration of ergonomics in	Integrating ergonomics in the production	Ergonomic program integrated in 3 phases, including	Reduction in the MSDs and increase in quality and productivity

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TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
		US 3M manufacturing	system (organizational and physical factors)	micro-ergonomic strategy, participatory ergonomics, and macro-ergonomics	
Lin et al. (2001)	Assembly of disposable cameras	Ergonomic workload (time pressure and awkward postures), quality performance	Organizational and physical ergonomic factors	2 lines (an older nonautomated and a newer semiautomated line) followed for 6 and 3 weeks, respectively. The regression model for the number of defective cameras (quality index) and ergonomic variables were calculated	The error per week for Line B showed 52.3% variance from Line A
Motamedzadeh et al. (2003)	2 hospital and medical equipment manufacturers	5-stage participatory ergonomics, working conditions, productivity, and quality	Participatory ergonomics (organizational and physical factors)	A 5-stage participatory ergonomic intervention was performed in Factory A (case) while Factory B (control) had an ergonomist consultant who proposed some changes and modification in the processes. To assess the effectiveness of the model, the determined indexes was compared before and after intervention in Factory A and with the results of Factory B	After performing the participatory program in Factory A, quality index showed improvement about 10%. In addition, productivity and working conditions index significantly increased
Neubert et al. (2012)	Volkswagen automotive industry	Model describing positive impact of the ergonomics on reducing losses	Physical ergonomics	Ergonomic workplace design impact on various indicators of production level, workforce level, and business level of the organization to generate efficiency	Reducing reworking, scrap and time, decrease in health risks and finally increase in quality and productivity. 20%

(*Continued*)

TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
					return for ergonomics investment
Neumann (2004), Neumann et al. (2009), Neumann & Village (2012)	Electronic and automotive industries	Focus on stakeholders to integrate ergonomics	Integrating ergonomics in the production system (organizational and physical factors)	In the new production system, human factors were integrated in various stakeholder groups. Feedback about productivity, quality and health defined	The aim of this model was to achieve 20% improvement in both health and system effects (quality & productivity)
Thun et al. (2012)	German automotive industry	Ergonomic risk factors, worker impact, ergonomic modification, workplace impact, ergonomic modification, and economic and social improvement	Organizational and physical ergonomic factors	Questionnaire containing ergonomic issues such as harmful tasks and conditions, potential ergonomic modifications, and economic and social indicators was filled out by manufacturing managers. The companies were divided into high implementation of ergonomic practice and low implementation of ergonomic practice to assess impact of ergonomics on economic and social factory	Automotive manufacturing managers believed that companies with high implementation of ergonomic practice could achieve better productivity and human effects but not quality improvements
Sen & Yeow (2003)	Electronic motherboard section in a computer manufacturing factory	Cost-effectiveness of ergonomic redesign	Organizational and physical ergonomic factors	First, site walk-through and interview with engineers and managers and operators undertaken to identify ergonomic risks, followed by direct observation and ergonomic redesign	After ergonomic redesign, motherboard defects reduced about 67% and the factory saved US$469,715
Vieira et al. (2012)	Automotive factory in Brazil	ergonomics and kaizen	Integrating ergonomics in the production	Integrating of ergonomics and kaizen concepts in a	30% increase in vehicle production

(*Continued*)

TABLE 1. Continued

First Authors	Workplace	Variables	Ergonomic Approach Studied	Study Description	Quality Outcomes
			system (organizational and physical factors)	lean production system	without reworking (quality), increase in productivity, decrease in absenteeism and accident index
Yeow & Sen (2006)	Manual component insertion line printed circuit assembly factory	Ergonomic intervention, quality, productivity, and costs	Physical ergonomic factors	Questionnaire filled out to identify ergonomic risks and causes of poor productivity and quality. Then direct observation undertaken for each higher-rated cause. Finally intervention performed for root causes of errors	Intervention decreased quality defects in factory by 29.6% and at customer sites by 11.4%. Productivity increased by 50.1% and revenue raised by 59.8%. Saving was US$943,296 per year
Yeow & Sen (2003)	Electrical test workstation in printed circuit assembly factory	Ergonomic workstation design, productivity, quality, cost, and occupational safety and health of workers	Physical ergonomic factors	Interviews and subjective assessment performed to identify the ergonomic risks and workstation design requirements. Direct observation was then undertaken and intervention planned for major problems in workplace	Quality defects of customers' site and factory site reduced by 3% and 2.2%, respectively. 6.1% reduction in the cycle time and 6.5% increase in productivity were achieved. Total cost saving was US$717,600

Schaurig (2012) assembly operators (instead of ergonomists) identified ergonomic high-risk tasks. The validity of the ergonomic evaluation might therefore have been uncertain. This is probably the reason that red tasks in this study influenced quality errors (2.65 times more than green tasks) less than in Falck's study (2014; 7.8 times more than green tasks). Almgren and Schaurig (2012) illustrated common quality errors made with high-risk tasks. However, common physical ergonomic risk factors that had created more failures were overlooked. The most common quality errors made with high-risk tasks in the study of Falck et al. (2010) in a car assembly were fairly consistent with Almgren and Schaurig's study (2012) in truck assembly. Falck et al. (2010, 2014) and Almgren and Schaurig (2012) gathered information on quality errors in the assembly plant retrospectively as analysis of errors was performed after they took place. With regard to rapid change in manufacturing plant due to customer and production requirements over time, retrospective studies provide confounding factors as ergonomic risks were not similar according to the time-quality errors that occurred. Moreover, interactions between different elements of the ergonomic approach and their impact on quality were disregarded in these studies.

Eklund (1995) showed that relative risk of quality errors for high workload tasks in a car assembly plant was almost three times higher than for other tasks. High-risk physical ergonomic workload tasks resulted in 79 errors per task, and 58% of tasks with high physical ergonomic demands resulted in quality errors. Quality errors increased further along the assembly line as quality errors for ergonomically high-risk tasks were higher in the final adjustment department (RR = 2.95) than the random disassembly inspection department (RR = 1.94; Eklund, 1995). The question regarding where quality errors occurred most frequently in the assembly line and the possibility of quality errors accumulating throughout the process was mostly overlooked in previous studies. In the study by Eklund (1995), various people in each department analyzed the ergonomic workload, which might have increased observer bias in assessing the task workloads. Furthermore, the severity of workloads for each task was not evaluated. Moreover, the types of ergonomic problems that created more quality errors were not revealed. However, Eklund (1995) estimated that 40% of quality errors were more related to fitting deficiencies than material handling tasks.

Fritzsche, Wegge, Schmauder, Kliegel, and Schmidt (2014) conducted a study among 623 assemblers in a German automotive industry. Ergonomic workload was assessed by an in-house version of the Automotive Assembly Worksheet method. A total of 22821 errors were selected and classified according to the Reason method (Reason, 1990) as 53% slips (task execution), 36% lapses (memory failures), and 11% mistakes (work planning). The results showed that in general the errors increased by 80% for the highest physical workloads. Physical workloads increased the risk of slips by 3.66 and lapses by 2.44, although there was no relationship with mistakes. In this study, the confounding factors of age and diversity were considered and common errors were classified (Fritzsche et al., 2014). The type of errors that occurred was consistent with the findings of Falck et al. (2010) and Almgren and Schaurig (2012), as task execution failures were the most frequently identified errors. However, Fritzsche et al. (2014) did not study the impact of different physical workloads, psychosocial factors, and organizational factors.

Axelsson (2000) showed that 17 tasks with high ergonomic risks caused 80% of operators' errors. Intervention was undertaken for 15 tasks out of 17, and the rejection and failure rates reduced by 3.9% (Axelsson, 2000). González et al. (2003) showed that, after physical ergonomic intervention, the quality of products increased by 2%, and reprocessing of parts significantly reduced. Although loss of materials decreased to less than 45%, the number of rejected parts was not statistically different after intervention. The possible reason is that physical ergonomic risk factors were solved by providing facilities (lifting tools) and instructions (for taking good postures) although task workloads remained high in nature. Production changes, design, and other dimensions of the ergonomic approach were not investigated in this intervention study. Amounts of scrap after intervention still remained high, which indicated that intervention had little effect on crucial cases of quality errors. Furthermore, lack of a control group made it difficult to conclude on the effectiveness of intervention on quality (González et al., 2003).

Yeow and Sen (2006) demonstrated in an electronic company that low-cost physical ergonomic interventions can yield 30% error reduction (quality) in plant and 11% at customer sites. Productivity raised by 50% and the factory increased profit by US$950,000 per year (Yeow & Sen, 2006). The strength of this study was that the authors explained clearly the types of error and the interventions in addition to costs and benefits for each separately. Task execution failures (slips) were the most common errors, and interventions included extra facilities (such as using weighing scales, conveyors, and tools), good illumination, and training. However, assessment of the ergonomic problems was ambiguous, and the effects of its severity on quality were not reported. Furthermore, ergonomic interventions showed a much greater influence on quality and costs than in other similar studies. In another similar study conducted by Yeow and Sen (2003) in an electrical test workstation in the same factory, quality errors decreased by 3% in plant and 2.2% in the market. Productivity also increased by 6% (Sen & Yeow, 2003; Yeow & Sen, 2003). Reductions in quality errors were significantly different in these two similar studies. These positive results might reflect the impact of other elements, not only ergonomic interventions but also factors such as the Hawthorne effect as the operators produced their best performance because of monitoring. Considering a control group might prove the effectiveness of interventions.

Erdinc and Vayvay (2008) undertook low-cost physical ergonomic interventions and ergonomics training in two machine sewing lines. The interventions resulted in 5% reduction in quality defects for Line 1 and 3%

reduction for Line 2 (Erdinc & Vayvay, 2008). The majority of interventions in this study consisted of training and work instructions, which raised the possibility of the Hawthorne effect. The participants might have improved their performance not only for ergonomic interventions but also in response to their awareness of being observed. The effects of other dimensions of an ergonomic approach were not investigated.

Neubert, Bruder, and Toledo (2012) showed that awkward postures led to many quality defects, such as leakages, loose clips, neglected screws, and crooked placements. A model, including production level (cycle time, reworking and scrap), business level (quality and productivity), and operators' level (health and performance), was therefore proposed that was influenced by physical ergonomics. Although the authors did not examine their model experimentally, they estimated that, depending on the industry, ergonomics in such a model could save 20%. Evidence related to the effects of awkward postures on quality errors and reducing costs was not reported in Neubert's study (Neubert et al., 2012).

In an experimental study, Das, Shikdar, and Winters (2007) proposed ergonomic interventions such as suitable chairs and tables, changes in design and layout, and comprehensive training methods (using Methods-Time Measurement (MTM) analysis) in a drill press operation. An experimental investigation that included two groups was then designed to test productivity (number of holes created), quality (number of good holes), and operator satisfaction. There was a significant improvement in quality (50%), and productivity increased by 22% (Das et al., 2007). However, this study was performed in a laboratory in an academic setting in which the participants were not professional operators, and there are many confounding factors, such as workplace conditions, and cognitive and psychosocial factors in the real work environments that affect results.

4.2. Organizational Ergonomics: Integration of Ergonomics in Production Systems

Three studies reported integrating ergonomics in entire manufacturing production systems and its multiple outcomes such as quality, productivity, and human well-being (Larson, Oshiro, & Camargo, 2012; Larson & Wick, 2012; Neumann et al., 2009; Neumann & Village, 2012; Vieira, Balbinotti, Varasquin, & Gontijo, 2012). In a series of studies, Neumann et al. (2004) proposed a new organizational ergonomic approach for integration of ergonomics in production systems. This approach required the involvement of a wide range of stakeholders, including manufacturing strategies, selection of new services and products, product design, system and organization design, and implementation in the workplace. Indeed, human factors and ergonomics should be integrated at each stage, and the advantages of ergonomics should encourage the stakeholders to support this approach. Proactive ergonomics and risk tracing would thus be adopted in a regular manner throughout the organization instead of late consideration of ergonomics in the final stages of an existing system. Feedback relating to disorders, quality defects, and productivity would be received by stakeholders at each level to help them find solutions and continuous improvement. This approach aims to reach 20% improvement at three levels in the company (human well-being, business and marketing, and production; Dul & Neumann, 2009; Neumann et al., 2009; Neumann & Village, 2012). Neumann et al. (2004) tested this approach in case studies within the automotive and electronic industries. Although in both studies productivity and ergonomic performance increased significantly, no evidence was shown regarding quality improvements because there was a lack of comparative quality data for the old and new design systems (Neumann, 2004; Neumann, Kihlberg, Medbo, Mathiassen, & Winkel, 2002; Neumann, Winkel, Medbo, Magneberg, & Mathiassen, 2006).

Vieira et al. (2012) integrated ergonomics into a lean production system in an automobile factory in Brazil. This system initially included 5'S, dexterity, standardization, kaizen, time measure, quality control, performance management of resources, just in time, and guidelines for management. The researchers then added ergonomics to this system. They found that the percentage of vehicles without reworking increased from 48% to 78% after integration of ergonomics. There was also a decrease in absenteeism and accidents and an increase in productivity. The main gap in this study was that the authors did not explain clearly the phases in which ergonomics were integrated in the production system (design/development, engineering process, or assembly). Furthermore, lack of information about the nature of the ergonomic interventions (physical, cognitive, or psychosocial) make it difficult to conclude on the effectiveness of the program on quality.

In two linked studies by Larson and Wick (2012), the integration of ergonomics was monitored over 30 years at 3M Company throughout the world. The company ergonomics program was divided into three stages. The first included micro-ergonomics, the second participatory ergonomics, and the third transition from a U.S. technical program focused on engineering changes to a global program using participatory ergonomics in the framework of macro-ergonomics. The results of this change in the company production system were increase in quality, productivity, and efficiency as well as a 75% decrease in the risk of exposure to MSDs. Moreover, case studies at 3M factories in Brazil and Poland showed significant increases in product quality and quality of life of the workers. However, the evidence of quality improvement was not investigated, and Larson and Wick (2012) just received feedback regarding quality improvements.

Three intervention studies included in the review introduced comprehensive macro-ergonomics and a participatory model and showed cost-benefits. Motamedzade, Shahnavaz, Kazemnejad, Azar, and Karimi (2003) designed a participatory ergonomics model in a medical equipment manufacturing company in Iran. Scraps, reworking, and rejection reduced by 5%, 8%, and 10% after intervention, respectively. Although the researchers demonstrated positive trends in quality and productivity indicators following ergonomics interventions, durable process changes were not observed because there was no commitment by top management. This is the only intervention study reviewed that included a control group in their study design (Motamedzade et al., 2003). Guimarães, Ribeiro, and Renner (2012) investigated the impact of a macro-ergonomic intervention in a large footwear factory. Organizational intervention, such as teamwork and increasing workers' skills, reduced reworking and spoilage by 0.8% and 0.9% in the new pilot line. Furthermore, the cost saving just on quality issues was US$173400. Guimarães et al. (2012) also reported reduction of accidents, absenteeism, and risk of MSDs. Moreover, the cost-benefit ratio of ergonomic interventions was more than 7 (Guimarães, Ribeiro, & Renner, 2012). Nevertheless, the Hawthorne effect might have positively influenced results. Quality, productivity, and human effect indicators were collected 2 years after launching the intervention (instead of periodically during the study). It is possible that system and human improvements were not merely related to ergonomics interventions and that other aspects of production yielded these findings. Furthermore, they performed a range of ergonomic interventions (organizational and environmental), but the interactions between these dimensions were not reported. De Looze, Vink, Koningsveld, Kuijt-Evers, and Van Rhijn (2010) applied a participative and integrative ergonomic approach in a print assembly company and in final assembly of emergency lighting. It was estimated that reworking and failures reduced by 25% due to the ergonomic intervention. However, the company changed the quality policy, and significantly less reworking in the new situation was also related to the new company policy. The total investment of €141,210 over 5 years provided €215,789 benefits per year in terms of productivity, quality, and health. The benefit related to quality was €27,250 per year (de Looze et al., 2010).

Lin, Drury, and Kim (2001) reported the increase of quality errors per week due to poor physical and organizational ergonomic factors in two lines of camera assembly. The more time pressure and the poorer the work postures the more quality errors produced per week (Lin et al., 2001). However, a small number of workstations and tasks were evaluated. Furthermore, awkward postures and time pressure were the single type of physical and organizational ergonomic factors that were investigated. In a survey among 100 car wire harness assembly operators, Hamrol, Kowalik, and Kujawińsk (2011) cited time pressure as the main reason for operators' failures. Though, the authors did not report evidence about relationships between time pressure and risk of errors (Hamrol et al., 2011). Eklund (1995) demonstrated that long assembly time related to the design involved difficult-to-assemble and high workload tasks. However, Falck et al. (2014) reported a nonsignificant relationship between ergonomic level and assembly time. There was a gap in the literature on the relationship between operation times and ergonomics and quality errors.

The literature showed that design of products could significantly influence time operation, ergonomic workloads, and quality. Eklund (1995) reported that design involving difficult assembly led to the largest number of quality errors (130 errors/tasks). Falck et al. (2010) reported that design engineers overlooked the consequences of poor product design on the difficulty of assembly, ergonomic workloads, and quality. Baraldi and Paulo (2011) compared two automotive assembly lines, the first of which was new, with high ergonomic investment in design and organization, and the second was traditional with low consideration of ergonomics. The new assembly line had 30% fewer quality errors compared to the traditional assembly line. Assembly time and absenteeism on the new ergonomic assembly line were also lower (Baraldi & Paulo, 2011). The interactions between various ergonomic interventions and also their exclusive impact on quality were not investigated in this study. Confounding factors, such as operators' skills and product complexity for each line, were not reported.

Thun, Lehr, and Bierwirth (2011) undertook a questionnaire survey in 55 automotive industries in Germany where the respondents were manufacturing managers. They believed that organizational ergonomics are more harmful than physical ergonomics (task-related risk factors and environmental ergonomic risks). An ergonomic approach (both organizational and physical) could significantly influence systems and human well-being such as increase in productivity, flexibility, safety, work comfort, motivation, and satisfaction. In terms of quality effects, manufacturing managers responded that a high-quality ergonomic situation could not significantly reduce errors in comparison to a poor ergonomic situation. The manufacturers believed that work-focused ergonomics interventions can decrease the risk of mistakes and defects much more than worker-focused intervention. This survey showed that implementation of an ergonomic approach in manufacturing industries requires development of managers' perceptions regarding the impact of ergonomics on poor production quality (Thun et al., 2011).

4.3. Impact of Cognitive Ergonomics and Psychosocial Factors on Quality

We found two studies in the literature that investigated the interactions between assembly complexity, physical ergonomics, and quality (Falck et al., 2014; Falck & Rosenqvist, 2012). In this review, we considered assembly complexity as cognitive workload. Falck and Rosenqvist (2012) interviewed 64 engineers in five Swedish companies: 90% of respondents thought poor physical ergonomics led to quality defects, 73% of the engineers perceived that poor ergonomics were related to assembly complexity, and 85% stated that assembly complexity was the cause of errors and scrap. This survey showed the positive opinions of engineers regarding interactions between different ergonomic approaches. In another experimental study, Falck et al. (2014) showed that both physical and cognitive ergonomics (complexity) significantly increased errors in assembly plants. The authors also reported a relationship between physical and cognitive ergonomics. However, it was unclear which dimension had more effect on quality errors. Action costs for high cognitive workload tasks were 22 times more than low cognitive workload tasks. The authors considered only one aspect of cognitive ergonomics (complexity) while cognitive workloads have various elements (e.g., memory, perception). Furthermore, complexity of assembly is such a complicated concept that its measurement is a matter of debate in the literature.

Very few researchers have investigated the impact of psychosocial factors on quality. In a survey study, Hamrol et al. (2011) reported employee fatigue, work monotony, noise, and manual work as main reasons for operators' failures. The relationship between work monotony, noise level, and the assembly process quality was then investigated. Work monotony increased the risk of failure threefold, whereas noise level did not influence the quality. The interaction of work monotony and noise level increased the risk of failure 10-fold. Eklund (1995) showed that 70% of tasks with quality errors were tasks with high psychological demands. González et al. (2002) reported on the impact of psychosocial factors on quality errors without providing evidence. Revealing a relationship between psychological factors and risk of errors, particularly interactions with other ergonomic approaches, is still a matter of debate because of the subjective nature of psychosocial factors.

5. DISCUSSION

The major hypothesis of this review was that a poor ergonomic approach is related to product quality in terms of errors and failures. The concept of the ergonomic impact on quality has been under investigation since the 1990s (Burri & Helander, 1991; Helander & Burri, 1995), but in this study, we included the most recent research. The focus of this review was mainly on studies involving automotive assembly because the link between work conditions and product quality is much stronger in the automotive industry. Of the 25 studies included, 13 studies had been conducted in automobile manufacture. Although there is strong evidence of the relationship between ergonomics and quality in the automotive industries, reviewing the ergonomics programs in many car manufacturing industries showed few links between ergonomics and quality policy. The Volvo Car Corporation (VCC) and Volkswagen are two examples of companies whose ergonomics programs are a part of their quality strategy (Hägg, 2003). The relationship between ergonomics and better quality is weaker in other industries such as the meat industry. Ilardi (2012) found no relationship between high-risk tasks and quality of deboning in the fish industry. Three studies by Falck et al. (Falck et al., 2014; Falck & Rosenqvist, 2014; Falck et al., 2010) in the VCC, which specifically focused on the quality errors related to physical and cognitive ergonomics provided strong evidence of the impact of ergonomics on quality in the automotive industries. The evidence was not the same in all of Falck's studies, and the risk of failures for high-risk ergonomic tasks varied from two to eight times. Eklund (1995) and Fritzsche et al. (2014) reported the risk of failures as three times and Almgren and Schaurig (2012) discovered more than twice as many errors for ergonomically poor tasks. The differences in ergonomic risk evaluation, work conditions, work methods,and standards might be the main reasons for these variations. Furthermore, the articles reviewed discussed the impact of ergonomically high-risk tasks on quality in general terms, and few articles reported most common ergonomic risk factors that had the most effect. Lifting heavy components does not have the same impact on quality as performing precise tasks. Eklund (1995) reported that 40% of quality errors were related to fitting defects. Falck et al. (2010) showed that obstructions, working underneath, and hidden assembly were main reasons for errors. In their survey among manufacturing managers, Thun et al. (2011) showed that repetition and manipulation are significant reasons for failure. The greatest gap is in empirical research investigating separately the effects of different physical ergonomic workloads on errors. Errors are not only due to the effects of physical ergonomic risk factors, whereas other job characteristics such as organizational, cognitive, and psycho-social factors have a major impact on product quality (Layer, Karwowski, & Furr, 2009). Lin et al. (2001), Thun et al. (2011) and Hamrol et al. (2011) showed that time pressure is an important factor in failures. In his survey among design and manufacturing engineers, Falck and Rosenqvist (2012) showed that cognitive demands (assembly complexity) are related to both failure rates and physical ergonomic workloads. Another empirical study showed a significant relationship between assembly complexity and both ergonomic workload and failure rates (Falck et al., 2014). More studies are required to make it possible to apply these results to other workplaces.

Ten studies involved intervention research, but none were performed in automotive industries. Electrical and computer assembly companies and shoe and metal industries have been the focus of most intervention studies. The results of quality improvement due to ergonomic intervention have varied considerably. Erdinc and Vayvay (2008) and Axelsson (2000) found a reduction in quality defects of about 4% after ergonomic intervention, while Yeow and Sen (2006) found about 30% reduction in errors in a manual component insertion line of printed circuit assembly. However, in another study by Yeow and Sen (2003) in an electrical test workstation, the reduction was about 3%. Laboratory studies (Das et al., 2007) showed a high percentage of quality improvements compared to empirical studies (Erdinc & Yeow, 2011). The Hawthorne effect might have occurred in several. Furthermore, the type of industry, type of ergonomic intervention (physical, organizational, or both), and the definition of quality indicators have a significant effect on these differences. The type of ergonomic intervention varied from solving single technical problems (physical approach) to integrating ergonomics in the company production system (organizational approach). In this review, three investigations proposed integrating ergonomic programs in the overall strategy of the production system. Although all of them mentioned the strong influence of integrating ergonomics in production systems on product quality, the quality and quantity of evidence were not sufficient. However, there was scientific evidence for such an influence on productivity, reduction in physical ergonomic workload, and human well-being (Ashraf Genaidy, Karwowski, & Christensen, 1999). Although some studies such as Hamrol et al. (2011) and Lin et al. (2001) showed that organizational factors had more impact on quality, most of the intervention studies reviewed contained technical and engineering changes through ergonomic modification of workstations and tools (physical ergonomic factors). Few intervention studies reported the effect of organizational factors' modification on quality failures reduction. As there is a lack of studies that prioritize the principal and common ergonomic risk factors that cause quality defects, a similar gap was found in the types of practical ergonomic interventions that could result in better quality or system effects. The range of interventions in the studies included was very wide, and studies focusing on valid ergonomic interventions leading to quality improvement are rare. However, Hendrick (2003), Erdinc and Vayvay (2008), and Yeow and Sen (2003, 2006) demonstrated that focusing on obvious physical ergonomic risks, which can often be solved by simple and inexpensive improvements, could have significant effects in terms of quality. Modifications such as providing suitable equipment (chairs, footrests, tables), proper layout and adjusting workstations, along with substitution of well-designed tools instead of poor tools sometimes have a highly significant cost-benefit payback (Hendrick, 2003). It is difficult to conclude that any quality improvement in intervention studies is actually related to changes in ergonomic approach because the quality policy and production system of the industries also changed. De Looze et al. (2010) estimated that just 25% of all total improvement in quality was related to ergonomic changes, as most improvements were because of quality policy changes.

Most intervention studies investigated the effects of ergonomics on both human and system outcomes, including quality and productivity. The impact on productivity has been a more frequent focus. In a review study that included 45 articles, Neumann and Dul (2010) showed that the main system effects of studies were productivity (89% of articles), while 31% reported quality effects of ergonomics.

Survey studies have shown the opinions of manufacturing managers, engineers, and workers. Thun et al. (2011) showed that automotive manufacturing managers thought that physical and organizational ergonomic intervention could reduce mistakes and would have cost-saving effects. However, the evidence for system effects was not strong, and the managers' opinions about ergonomics were more on its effectiveness in decreasing workloads and absenteeism, and increasing health, safety, satisfaction, and motivation. Neumann and Dul (2010) stated that managers recognize ergonomics as a health and safety tool. This misconception in companies affects the effectiveness of ergonomics and investment within industries. However, manufacturing engineers and quality inspectors in Sweden believed in the effectiveness of ergonomics for quality improvement (Eklund, 1995; Falck & Rosenqvist, 2012), and assemblers who were interviewed by Hamrol et al. (2011) had similar opinions. Therefore, changing the thinking of manufacturing managers and bringing it closer to the opinions of the engineers and assemblers should be considered.

6. CONCLUSION

The aim of this review was to investigate the impact of the ergonomic approach on product quality, particularly in automotive manufacturing. Twenty-five empirical studies were included. The studies reviewed provided evidence of the effects of the poor ergonomic approach on quality errors, mainly in the automotive industry. However, the interaction between different ergonomic dimensions (physical, organizational, cognitive, and psychosocial) and their effects on quality remain undemonstrated. Research on the effects of cognitive ergonomic and psychosocial factors on quality is still scant. Survey studies among manufacturing managers showed that they still see ergonomics as a health and disease prevention tool and not as a method for cost saving and waste reduction.

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