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Human Factors Engineering, Workplace Safety, and Productivity Improvement in Industrial Environments

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ABSTRACT:

Human factors engineering (HFE) is an important area of the cross between ergonomics, cognitive psychology, systems design, and industrial safety science and has a significant impact on the safety of the workplace and the productivity of the operation in manufacturing environments. The objective of this study was to explore how the principles of HFE are applied, understood and experienced in the industry and to investigate the connection between ergonomic practices, quality of HM interaction, the safety culture in an organization and measurable productivity outcomes. The study adopted a qualitative research design, informed by an interpretivist paradigm, and involved a purposive sampling of 23 participants: Industrial workers, production supervisors, a safety manager and a HFE consultant from some manufacturing units of the four industries in the study – automotive, chemical, pharmaceutical, heavy engineering, and construction. A semi-structured, indepth interview was conducted supplemented with structured workplace observations and a systematic review of the organizational safety reports and policy documentation. These themes were identified through a thematic analysis of the resulting data, which produced four main themes: ergonomic environment quality, human-machine interaction dynamics, safety behaviour and culture, and productivity linkages. It was discovered that poor ergonomic design of the workstation geometry, repetitive motion hazards, noise exposure and lighting inadequacy, are the major sources of occupational injury risk and productivity losses in the observed industrial work areas. HFE integration scores were found to be significantly lower for organizations with a low score compared to those with a high score, with the latter scoring 17 percentage points higher in terms of Overall Equipment Effectiveness (OEE) and 72% lower in terms of lost-time injury rates. It is concluded that the integration of HFE is not just a compliance requirement, but a very important investment in productivity, and recommendations for industrial practitioners, safety practitioners and policy makers are provided to help put the concepts of HFE into practice and demonstrate how to achieve better operational levels.

Keywords: human factors engineering, workplace safety, ergonomics, productivity, industrial environments, human-machine interaction, safety culture, qualitative research, occupational health, manufacturing.

INTRODUCTION:

Human factors engineering and its impact on industrial outcomes has become one of the most significant areas of study in modern occupational science and industrial engineering. In a nutshell, human factors engineering (as defined by the International Ergonomics Association, 2020) is the science of understanding the interactions between the human and other components of a system, and the use of theory, principles, data and methods to optimize human well-being and system performance. In industrial production environments, where physical demands are high, machines are sophisticated, errors have serious repercussions, and production is subjected to a constant pressure, the quality of the integration of HFE has direct and measurable effects on the safety of workers and the productivity of the organization.

After decades of incremental progress in industrial safety regulation and technology, the burden of occupational injury and illness in industrial workplaces is still enormous. According to the International Labour Organization (ILO, 2023) the annual number of work-related deaths is estimated to be around 2.3 million worldwide, while 374 million non-fatal injuries and illnesses are recorded each year. Staggering proportions of these are in manufacturing and heavy industry, with a disproportionately high percentage of musculoskeletal disorders, repetitive strain injury and noise induced hearing loss (ILO, 2023). The economic costs of occupational injury (medical costs, loss of productivity, workers' compensation claims, regulatory fines, and reputational damage) have been estimated to amount to 4-6% of the global GDP each year, highlighting the business case for investing in comprehensive HFE, not just for humanitarian reasons (Takala et al., 2014).

The science of ergonomics and human factors has built a strong evidence base to establish the causal relationships between poor workstation design, excessive physical loading, inadequate human machine interface design, and acute injuries and chronic musculoskeletal conditions. The leading category of occupational disease in manufacturing workplaces worldwide is musculoskeletal disorders (MSDs), which include low back pain, neck and shoulder syndromes, carpal tunnel and other tendinopathies, and account for about a third of all occupational health conditions, and direct costs in the United States alone of more than $60 billion annually (National Safety Council, 2023). Epidemiological studies have been well documented to link the exposure of ergonomic risk factors and the incidence of MSD's, and multiple systematic reviews have established the effectiveness of ergonomic intervention programs in reducing MSD incidence and related productivity loss (Tompa et al., 2019).

In current industrial contexts, in which processes are becoming more and more automated, more and more digital, and incorporating Artificial Intelligence in the production system, the human-machine interaction dimension of HFE assumes particular salience. The nature of human work is shifting due to the evolution of manufacturing technology from physical execution to supervisory control, exception management and complex decision making in automated environments, which creates new cognitive ergonomic challenges in addition to the classic physical ergonomic challenges (Carayon et al., 2020). To meet safety and productivity goals, interfaces for control, alarm, supervision, and collaborative workspace design must consider human attentional capacity, situation awareness maintenance requirements, and human-automation team psychological dynamics of trust and reliance.

The third key aspect of how HFE affects industrial outcomes is safety culture, defined as the values, beliefs, norms, and behavioral patterns that a group or organization holds about safety priority and risk management. Organizations that are actively and robustly managed to have strong safety cultures have significantly lower incident rates, higher near-miss reporting behaviour, and better compliance profile than organizations with compliance-oriented or reactive safety cultures (Reason, 2016). There is a two-way relationship between the quality of the safety culture and the depth of HFE practice: organisations which invest in applying work design to improve their safety culture reap benefits from the signal effect of the visible and tangible commitment to worker well-being as part of the work design, and strong safety cultures help to create the conditions for continued implementation of HFE practice.

This study was inspired by three related observations about the state of the practice and research of HFE in the context of industrial manufacturing. One, the literature on ergonomics and occupational health is vast but qualitative studies of the lived experiences and contextual understandings of industrial practitioners of HFE are relatively small and sparse, especially across the wide range of contexts in the industrial manufacturing sector. Second, in both research and practice, the productivity aspect of HFE is often seen as less important than safety, although there is strong evidence that safety and productivity are not competing but complementary goals in well-designed work systems. Third, new demands for HFE exist due to the transition challenges brought by the growing industrial automation and digital manufacturing technologies, which current practice frameworks are not able to meet completely.

This study aims to develop an in-depth, practitioner-informed perspective on the implementation of the principles of HFE in the realities of the industrial workplace, their influence on safety and productivity outcomes, and the institutional, organizational and individual factors that support or hinder the effective implementation of HFE.This study aims to capture the principles of HFE in practice within the industrial workplace, how their application impacts upon safety and productivity outcomes, and the institutional, organizational and individual factors that facilitate or hinder the effective application of principles of HFE. The results have immediate relevance for industrial safety experts, HR practitioners, manufacturers' engineers, organizational decision makers and policy makers involved in the development and control of occupational health and safety systems.

The article will be structured as follows. In Section 2, the relevant research in the main thematic areas of the research is reviewed. The methodological approach is presented in Section 3. The empirical analysis findings are presented in Section 4 by means of thematic findings. In Section 5, critical discussion takes place. The article ends in policy recommendations and directions for future research.

In the modern industrial world, with increasing global competition, rapid technological development and changing regulations for worker safety, the opportunities and challenges associated with effective integration of the HFE discipline are more complex and more important than ever before. The findings of this study will therefore have application beyond academic learning to the practical issues confronting industrial organisations looking to achieve greater safety and productivity performance in an increasingly challenging operating context.

LITERATURE REVIEW:

The Theoretical Knowledge and Practical Applications of Human Factors Engineering

The human factors engineering theoretical foundations are rich in interdisciplinary background, ranging from experimental psychology to industrial engineering, cognitive science, systems theory, and occupational health science. The formal beginnings of human factors as a separate discipline are attributed to the study of human factors in equipment accidents and failure during World War II by military psychologists and engineers (Wilson, 2014). The transfer of the principles of these insights to industrial and civilian applications after the war began the conceptual paradigm which still guides contemporary HFE practice: that human systems will perform and be safe if designed for the whole spectrum of human capabilities and limitations rather than requiring human adaptation to poorly designed systems.

Carayon et al. (2020) gives an excellent overview of the theory of HFE and its current application fields, including digital technologies, military use, transportation, and healthcare, along with an industrial application. Their SEIPS (Systems Engineering Initiative for Patient Safety) model was developed in a healthcare environment, but they have applied their model to manufacturing, and stress that the components of work systems (tools and technology, tasks, environment, organization, and person) are related to safety and quality outcomes and these relationships are bidirectional. This systems perspective is especially useful in industrial HFE because it avoids simplistic interpretations of why things went wrong for the individual worker and signals to the analyst to focus on the design features of the larger sociotechnical system in which human performance takes place.

The economic literature which reports on investment returns from HFE interventions offers strong quantitative context to consider the productivity aspects of an ergonomic/human factors intervention. Tompa et al. (2019) systematically reviewed economic evaluations of ergonomic interventions in the workplace and reported median ROI ratios of 2.4:1, with the higher ratios more focussed on high exposure manufacturing work activities that had a history of measurable injury costs. The results contradict the long-standing manager's notion that spending on HFE is a compliance expense, and instead tell a different story: HFE is a strategic investment that is an effective way to increase productivity financially.

There are two areas of ergonomic application: physical and cognitive ergonomics, as is the case in industrial settings. Physical ergonomics concerns the design of workstations, tools, equipment and work processes with regard to anthropometric, biomechanical and physiological characteristics of humans. Cognitive ergonomics relates to the design of information displays, decision support systems, human/machine interfaces and organizational procedures with respect to human perceptual, attentional, memory and decision making capacities. The physical-cognitive HFE approaches are more likely to be needed in contemporary industrial environments, where the distinction between manual and knowledge-intensive work activities is becoming more and more ambiguous due to the increased use of digital manufacturing technologies (Stanton et al., 2017).

Ergonomic Practices and Musculoskeletal Health in Manufacturing

Work related musculoskeletal disorders prevention by ergonomic intervention is the most well studied application of industrial HFE. Epidemiological studies have clearly shown that there are links between specific physical workload exposures (exertions, repetitive movements, awkward postures, whole body vibration and contact stress) and incidence of MSD in almost every context within the manufacturing sector (Buckle & Devereux, 2002). The hierarchical control framework is the structure for ergonomic risk management programs in well-governed industrial environments, in which the most effective way to eliminate ergonomic hazards is to redesign work processes, rather than use personal protective equipment or administrative controls.

In recent years, scholarship has focused increasingly on a number of organizational and management issues that influence the likelihood of implementing workplace changes based upon an ergonomic assessment. While the technical quality of the intervention design was not the strongest predictor of the effectiveness of ergonomic interventions, the organizational commitment to ergonomic improvement—such as through senior management support, allocation of resources, and development of ergonomic competency—was identified as the single most influential predictor of intervention effectiveness, aside from the technical quality of the intervention design itself by Driessen et al. (2018). This is an important finding because it highlights that HFE should be viewed as an organizational change management problem, rather than a purely technical engineering challenge, and thus how to implement the design and communicate an ergonomic improvement program to organizational decision makers.

The link between ergonomic practice quality and productivity from the work force has been explored using various methodological strategies. The productivity gains from HFE programs focused on work place ergonomics estimated to be 10-25% productivity improvement, due to decreased error rates, decreased product defect incidence, improved operator task performance and decreased absenteeism due to MSD related illness, (Andrews and Hendrick 2003). In more recent analyses, these estimates were expanded to include indirect productivity impacts arising from better worker health and wellbeing, such as greater worker engagement, less presenteeism (attending work while ill), and better quality of worker information processing, especially in knowledge-intensive manufacturing contexts where the quality of information processing has a direct impact on product quality outcomes.

Participatory Ergonomics has become a methodology paradigm that has greatly contributed to the practice of industrial ergonomics by integrating the knowledge of the workers in the identification of hazards and design of interventions (Hignett et al., 2015). Participatory approaches involve workers' active involvement in the process of finding ways to improve the ergonomy of their work site, as opposed to simply relying on the expertise of health and safety professionals who are external to the workplace setting. In summary, a great deal of evidence from participatory ergonomic interventions (PI) in manufacturing organizations consistently indicates good implementation compliance and long-term effectiveness compared to implementations driven by specialists at the top.

Human-Machine Interaction and Interface Design

The field of human-machine interfaces (HMIs) is one of the areas in HFE where the uses of scientific principles in industry are growing more and more. While these are still fundamental design principles of classical HMIs, they must be adapted and extended to deal with the new challenges of supervisory control in highly automated industrial systems (Wickens et al., 2021).

Endsley (1995) stated that the most important cognitive factor for safe and effective human supervision of complex industrial systems is situation awareness, which is described as the ability to perceive elements of the environment, understand their meaning, and anticipate what will happen in the future. HMI designs that help maintain situation awareness include formats that match operator mental models, provide the right level of automation transparency, and have alarm management systems that shift operator focus to the truly safety relevant system state and reduce the need for the operator to focus on nuisance alarms. The costly issues associated with HMI design in today's factory settings are all too obvious in alarm flooding, where an industrial process control operator is presented with a hundred or more alarms all at once in an abnormal scenario.

Combining collaborative robots (cobots) in manufacturing environments creates a new class of human-robot interaction challenge, which has been receiving more and more research attention. Matheson et al. (2019) outline the ergonomic, cognitive and safety concerns about cobbots used in manufacturing environments including the design and placement of shared workspace boundaries, the predictability of the robot's motion, task allocation and communication interface quality. In their analysis, they show that poorly designed systems involving human-cobot interaction can actually raise the physical risk of injury (due to unexpected robot motion) and the cognitive stress of working with unpredictable automated partners (due to the need to monitor them) at the same time, thus compromising the safety and productivity goals that are driving the adoption of cobots.

The influence of organizational factors on the effectiveness of improvements in HMI design has been the topic of greater attention in the industrial HFE literature. Carayon et al. (2020) stress that the effect of safety and productivity resulting from design interventions to HMI must be part of a larger organizational change process involving proper operator training, reengineering of procedural documentation, changes to supervision structure and adjustments to the performance management system. The frequent finding that technically successful HMI redesigns are not successful in realizing their potential benefits because of sub-optimal organizational implementation processes is illustrative of the need to consider HMI improvement as a sociotechnical change project, not just an engineering project.

Safety Culture and Behavioral Safety in Industrial Environments

The organizational safety culture — the complex of shared values, attitudes, competencies, and behavior patterns that influence organizational commitment to and proficiencies in health and safety management — has received much attention as a factor that affects occupational safety outcomes in industrial settings. In the groundbreaking research on organizational accident causation, Reason (2016) identified latent conditions of organizations — such as culture, management practices, or systemic design features — as the underlying causes that are evident in incident investigation reports as human errors and technical failures. This paradigm shift brought a change in the focus of the safety management from the individual compliance to the behaviour conditions, which are the organizational and the system level.

One major difference between compliance-based and commitment-based safety cultures is that it is crucial to understanding the productivity linkages between safety culture quality. Zohar (2010) showed empirically that, when workers think that management is truly committed to safety, beyond its concern with production, they will be able to sustain superior safety outcomes by internalizing safe behaviour patterns; that is, by becoming more similar to their supervisors in the way they behave on the job. Most importantly, commitment-driven safety cultures are also associated with better productivity performance, because the conditions that foster the real commitment to safety also foster the organizational capabilities that underlie operational performance excellence — such as communication, participative decision-making and intrinsic worker motivation.

Behavioral safety programs have been widely used in manufacturing settings as tools to enhance safety culture quality and lower the rate of incidents, and are a systematic application of principles in behavior analysis to the observation, feedback, and reinforcement of safety-relevant worker behaviors. The general evidence base for the effectiveness of behavioral safety programs is positive, with Cooper (2009) reporting average incident reductions in published behavioral safety intervention studies in industry of 20-30%. There are however some critical voices in the literature of safety culture that warn against simplistic solutions to the problem that rely on workers' attitudes and behaviors without consideration of the organizational and system factors that create the pressure for workers to make unsafe decisions.

METHODOLOGY:

Research Design and Paradigm

The study was designed qualitatively to be based on an epistemological paradigm of interpretivism. Interpretivist epistemology, as described by Denzin and Lincoln (2018), is based on the belief that social phenomena such as the workplace safety practices, ergonomic experiences, organizational behaviors, and many other phenomena investigated by social scientists cannot be fully understood in terms of measurement and quantification alone, and must be studied based on interpretive investigation of how people perceive, act upon, and respond to the phenomena being studied in the context of their meanings, understandings, and contextual dynamics. Industrial safety and human factors practices are inherently social and organizational phenomena with manifestations in real world contexts that take on the form of local cultures, leadership practices, resource limitations, and historical accident experiences which do not lend themselves to easy and quantitative characterization. A methodologically sound approach to the production of this understanding grounded in the practice of the practitioners that this study aims to produce is therefore the qualitative inquiry.

The qualitative design was supplemented by an observational aspect that allowed the research team to support the interviewee-based insights with their own observations of work conditions, working practices and human-machine interaction dynamics in the workplace. The use of interview and observational data collection methods increases the validity of the findings as it allows for a cross validation between what the participants are saying and what they are doing in their practice, which may highlight differences between the espoused safety practices and enacted practices, especially relevant to understanding the organizational reality of HFE implementation.

Sampling and Participants

Participants were selected through a purposive sampling technique for having first-hand knowledge of the practices related to HFE, occupational safety management, or industrial production processes. The last sample consisted of 44 respondents in four professional groups: industrial workers (n = 8), production supervisors (n = 7), safety managers (n = 5), and HFE consultants (n = 3). Three manufacturing areas were selected for the recruitment of participants and the process of recruitment was done through contacts of the professionals, industry association and institutional gatekeepers. Data was collected continuously with periodic monitoring of saturation; thematic saturation was reached during the 20th interview, and validated with two additional confirmatory interviews.

Table 1. Participant Profile Summary

Participant Category	**n**	**Industry Sector**	**Experience (Years)**
Industrial Workers	8	Automotive / Metal Fabrication	5–22
Production Supervisors	7	Chemical & Pharmaceutical	8–28
Safety Managers	5	Heavy Engineering / Construction	10–30
HFE Consultants	3	Cross-sector (Multiple units)	12–25
Total	23	Mixed Industrial Manufacturing	Avg. 15.6

Note. Participant numbers by category reflect final sample composition after saturation assessment. Experience ranges represent self-reported tenure in current industry sector. All participants are anonymized using coded identifiers throughout the analysis.

Data Collection

Three complementary methods were used to gather primary data. The main data source was semi-structured, in-depth interviews, which ranged in duration from 50 to 85 minutes, and were conducted according to a thematic interview protocol with the following topics: (1) daily ergonomic challenges and HFE practice experiences; (2) human-machine interaction quality and interface usability; (3) safety behavior norms and culture perceptions; and (4) observations of the connection between safety practices and production performance; and (5) recommendations for enhancing the integration of HFE. Two participants were used to pilot the interview guides and they were adjusted accordingly before engaging in the main data collection. Each interview was audio recorded and professionally transcribed with the consent of the interviewees.

Interviews were conducted in eight of the manufacturing units involved, with structured observations of workstations and human-machine interfaces, worker motion patterns and compliance with safety procedures. Observation sessions varied in duration from 2 to 4 hours for each of the units and were captured in the form of standardised field notes and observation checklists derived from existing ergonomic audit documents. To contextualize interview and observational data, a documentary analysis of organizational safety reports, incident investigation reports, ergonomic assessment records, and safety training reports were performed in all participating organizations.

Thematic Analysis

Braun and Clarke's (2006) six-phase thematic analysis approach was used for data analysis. After repeated readings of the transcriptions and review of field notes, initial open coding was performed on all the transcripts using NVivo software for qualitative analysis. Iterative theme development and review processes then were used to group codes into thematic clusters. The analysis revealed four main themes: ergonomic environment quality, human-machine interaction dynamics, safety behavior and culture, and productivity linkages. The 15 out of 23 participants were asked for member checking of theme definitions and supporting evidence and two independent academic colleagues, each in his own field of expertise, underwent peer de-briefing.

Trustworthiness and Ethics

Ethical approval was secured before the start of data collection. All subjects gave informed consent with a clear opportunity to withdraw without prejudice at any time. Participant anonymity was assured by the use of codes and the participating organisations were described only by sector and size classifications. Interviews were recorded and transcribed, with recordings and transcripts stored on access-controlled servers, which are secured with encryption. Methodological triangulation was used to confirm trustworthiness by using both interview, observational and documentary data sources; member checking of thematic summaries; audit trail of all analytical decisions; and reflexive journaling of researcher positionality during the inquiry process.

ANALYSIS AND FINDINGS:

The Ergonomic Environment Quality and Physical Risk Factors:

The theme that was most dominant and consistent throughout participant responses was ergonomic environment quality, suggesting overall consensus concerning the importance of physical workstation design, postural demands, and manual handling demands as factors impacting workers' health and performance. This was especially evident in the responses of worker and supervisor participants regarding their specific ergonomic shortcomings in the manufacturing environment and their consequences, as experienced during the daily realities of physical wellbeing and quality of task performance.

Of the manufacturing units that participated in the study, the most common ergonomic risk factor reported as a concern was repetitive motion strain (17 of 23). The cumulative physical impacts of high frequency repetitive assembly, sorting and inspection tasks were described by worker participants in ways that were very clear and clearly represented the progressive musculoskeletal deterioration characteristic of work related upper limb disorders, including chronic, ongoing discomfort in the wrist, forearm, shoulder and neck that workers generally attributed to job demands, not to individual pathology. Some participants commented that the culture of the workplace was such that it was accepted to have a high level of chronic discomfort, and that there was both a social norm against complaining and a lack of confidence by some participants that management were going to believe their discomfort.

A secondary ergonomic concern reported was work position height and geometry mismatches with reported discomfort by a number of worker and supervisor participants of sustained trunk flexion or shoulder elevation or neck extension that were not only uncomfortable at the moment but also a risk of developing MSD in the longer term. The HFE consultant participants agreed that the anthropometric range of the workforce (such as stature, functional reach, limb length etc.) was a challenge in fixed height workstations and non-adjustable tooling in industry. The organizations with the height-adjustable workstations in their ergonomic improvement programs noted that there was a substantial decrease in worker-reported discomfort and a significant increase in the accuracy of task throughput.

Table 2. Ergonomic Risk Factors Before and After HFE Intervention

Ergonomic Risk Factor	**Pre-Intervention Status**	**Post-Intervention Status**	**Productivity Change**
Repetitive Motion Strain	High – 68% workers affected	Low – 21% workers affected	+18% task throughput
Workstation Height Mismatch	Present in 74% of stations	Eliminated in 91% of stations	+14% error reduction
Excessive Manual Lifting	Avg. 28 lifts/hr per worker	Avg. 9 lifts/hr per worker	+22% fatigue reduction

Noise Exposure (>85 dB)	Reported by 61% of workers	Reported by 19% of workers	+11% concentration gain
Inadequate Lighting	Noted in 55% of work areas	Noted in 8% of work areas	+16% quality output

Note. Pre- and post-intervention data are drawn from organizational safety reports and ergonomic audit documentation provided by participating organizations. Productivity change estimates are based on supervisor and manager reports corroborated with available organizational performance records.

Evidence of explicit connections between ERF reduction and measurable results in productivity improvement outcomes was observed, reinforcing the research thesis that safety and productivity are complementary, not competing, goals of well-designed work systems. Several safety manager participants reported organizational performance data of dramatic decreases in the rates of defects, rework, and product quality rejections after specific ergonomic interventions, which they believed to be the result of a combination of reducing worker fatigue, increasing task concentration, and improved fine motor handling in lower-strain working conditions. These accounts show consistency with the theoretical predictions of the ergonomics productivity literature and rich confirmation of the causal mechanisms with which ergonomic improvement leads to manufacturing performance gains by the practitioners.

Participants from the HFE consultants brought practical information on the organizational and managerial setting to the understanding of the magnitude of the difference in the quality of ergonomic practice among the participating manufacturing units. Strong levels of management commitment to ergonomic improvement, as evidenced by having explicit ergonomic performance measures within the operational management framework, ergonomic competency roles and ergonomic budgets, were consistently linked to the best ergonomic practice profiles, with organizations that practice this approach showing superior profiles to those that view ergonomic improvement as a periodic compliance exercise. This was the most powerful organizational commitment measure found in the sample observed, thus it confirms the results of Driessen et al. (2018) on the importance of organizational factors in the effectiveness of ergonomic interventions.

Human-Machine Interaction Dynamics

The second overarching thematic area was related to human-machine interaction quality, where participants from all professional groups agreed that: user interfaces and human-automation interactions are important factors that affect safety risk and productivity in manufacturing processes. The theme reflects the fact that industrial work in these days is rapidly changing due to ever increasing automation and digital process control and has created new classes of human factors challenge in addition to traditional physical ergonomic challenges addressed in Theme 1.

The quality of interface design emerged as one of the main points of concern for HMI, as the workers and supervisors shared their experiences with process control displays, machine control panels, and production monitoring systems, which were in multiple examples confusing, lacked adequate information organization, provided poorly designed controls, and lacked state feedback and nuisance alarm rates. There were some parallels drawn between organizations that have a good design of their HMIs, where the operator could easily keep track of what is happening, and make the right decisions in their work, and those that don't, where the operator's cognitive burden was high, error rates were raised, and response times to abnormal conditions were significantly longer.

Table 3. Human-Machine Interaction Themes and Key Participant Insights

Theme	Sub-Themes	Key Participant Insights
Interface Design	Display clarity; control layout; feedback mechanisms	Workers reported 34% fewer operational errors when machine displays were redesigned to reduce cognitive load and improve visual hierarchy.
Automation & Worker Role	Skill displacement; supervisory demands; trust in automation	Supervisors noted that partial automation increased worker vigilance demands without adequately redesigning roles, generating safety risks.
Training & Competency	Simulation-based training; refresher cycles; competency gaps	Safety managers emphasized that HFE-aligned training programs reduced incident rates by an estimated 27% across observed manufacturing units.
Safety Culture	Organizational commitment; reporting norms; leadership behavior	Workers in high-safety-culture environments demonstrated significantly greater near-miss reporting behavior, enabling proactive hazard mitigation.

Note. Themes and sub-themes derived from thematic analysis of interview transcripts (n = 23) and observational field notes. Participant insights represent synthesized cross-participant perspectives rather than verbatim quotations.

Partial automation and collaborative robotics are a growing part of manufacturing processes, which created complex and conflicting participant accounts about the implications for safety and productivity issues. Many supervisor and safety manager participants voiced concerns regarding the supervisory difficulty of operating automated systems that involve operating a machine without direct contact with the activity, but instead require a high level of vigilance for extended periods of time — the so called vigilance decrement problem, which has been well documented. Indeed, several near-miss incidents were reported which were blamed by the safety managers for lapses in attention during these low engagement supervisory moments, thus revealing the paradoxical safety risk that can be found in the deployment of automation that is inappropriate.

Training and competency development for HMI operation was one of the major sub-themes and it was found that the lack of training was a key determinant between the quality of the HMI design and actual operation by the participants who were safety manager/supervisors. Workers operating complex process control or cobot collaboration systems were often under-trained by the manufacturer to meet the cognitive demands of the job, or unprepared through depth of training to meet the changing needs through a formal system of refresher training. It was noted that complexity of the system and lack of training provision was a systemic organizational issue that has a direct impact on production efficiency and safety incident rates.

Safety Behavior and Organizational Culture

The third key thematic area of analysis was safety behavior patterns and organizational cultural contexts which influence them. Participant accounts indicated that there were large differences in the norms for safety behaviour, near-miss reporting and safety leadership between the different manufacturing organisations involved, differences that were clearly related to the different incident profiles and the productivity performance of the organisations.

Almost incident reporting culture became a very sensitive measure of the quality of organisational safety culture. Workers in organisations with high safety cultures, who had clearly defined commitment to safety from their leaders, non-punitive reporting processes and full transparency in communication of hazards reported that they felt safety incidents were being reported and that they were frequent and regular, and that such reports would result in real action being taken to correct the hazard. In those organisations with less positive safety cultures, reporting near misses was described as being rare and sporadic, largely as a result of having a statutory reporting requirement rather than an internalised commitment to proactively manage hazards. The safety manager participants in high reporting organizations consistently reported that they believed near miss information was giving them the intelligence necessary to help them prevent incidents from turning into injuries or diseases by taking action before they happened.

This link was found to be a consistent theme in the participant accounts of the supervisors and workers, between safety leadership behavior and safety climate quality. Leadership behaviors identified that positively influence the progress towards a positive safety culture included: demonstrating personal leadership adherence to safety standards; prioritizing safety in production planning and decision-making regarding resources; openly discussing with workers concerns that are related to safety without dismissing them in terms of interfering with production; and providing timely and meaningful feedback on safety improvement measures. Consistently practiced at organizational (senior management) and immediate supervisor levels, these behaviors contributed to organizational conditions that fostered worker safety motivation, as opposed to compliance pressure — a difference that has important implications for the sustainability and depth of safety behavior change.

Productivity Linkages and Performance Outcomes

The fourth thematic domain specifically examines how the quality of integration of the HFE relates to operational productivity outcomes – based on quantitative organizational performance data received from the participating organizations in conjunction with qualitative participant reports of how safety and ergonomic practices relate to manufacturing productivity. Linking these data sources offers a very detailed portrait of the productivity argument for investment in HFE that supplements and helps to frame the empirical performance data.

Table 4. Safety Behavior Outcomes and Productivity Correlates Across HFE Integration Levels

Safety Behavior Indicator	**Low HFE Integration**	**High HFE Integration**	**Productivity Differential**
Lost-Time Injury Rate (per 100 workers)	7.4	2.1	−72% LTI reduction
Near-Miss Reporting Frequency	Low (avg. 2.1/month/unit)	High (avg. 14.6/month/unit)	Proactive hazard mitigation
Worker Absenteeism (Days/Year)	12.8	5.3	−59% absence reduction
Overall Equipment Effectiveness (OEE)	71%	88%	+17% OEE improvement
Defect / Rework Rate	9.2%	3.1%	−66% quality improvement

Note. Performance data derived from organizational safety reports, production records, and management documentation provided by participating organizations. High and Low HFE Integration classifications based on composite ergonomic audit scores, HMI quality assessments, and safety culture survey results.

The data on the organizational level summarized in Tab. 4 are strong quantitative evidence for the thesis that high quality HFE integration results in significant and measurable productivity benefits, in addition to the safety benefits. Organizations that were identified as having high quality HFE integration (combined score on the four subscale elements of the ergonomic practice quality, HMI design adequacy, strength of safety culture, and comprehensiveness of training programs) showed lost-time injury rates

72% lower than comparator organizations, 17 percentage-point higher scores in Overall Equipment Effectiveness, and 66% fewer defects. These performance differentials translate into significant competitive advantages, which, in turn, can be converted to numbers into the return-on-investment equation, which is very favourable to investing in HFE.

Through participant accounts, a variety of specific productivity mechanism pathways were identified that relate to the quality of the HFE and manufacturing performance. First, fatigue - caused by ergonomically optimized workstations - will directly lead to an increase in the quality of cognitive performance in the second half of the shift, before fatigue has a negative impact on performance quality, resulting in higher error rates. For the multiple supervisor participants, the goal of improving the ergonomics of the workstation was paralleled by measurable gains in quality measures of production in the late shift following workstation ergonomic interventions, consistent with empirical and theoretical literature on fatigue and performance degradation in manufacturing settings. Second, with lower rates of absenteeism due to MSD, workforce availability and scheduling flexibility are enhanced, which lessens the impact on production when workers must be absent unexpectedly and limits the risk of poor quality work and product due to unfamiliar employees filling in for a worker who has not fully learned how to execute the task.

The motivational element of productivity gains through the embedding of HFE was expressed particularly clearly by the HFE consultant participants, who highlighted how a sense of commitment to the quality of the workplace from the organisations themselves is a strong indicator of actual respect for their employees, which motivates employees to give back in their work. This motivational linkage is one way in which the complementarity between safety and productivity plays out in the workplace: When organizations invest in workers' health, workers feel the organization is investing in them, which in turn leads to greater productivity engagement and quality commitment. A few of the consultant participants described this as the 'safety dividend' of genuine HFE integration – a performance gain which goes beyond ergonomic or HMI improvements to include the wider spectrum of the worker's discretionary contribution to their organization's performance.

DISCUSSION:

The results of this study offer ample empirical evidence of human factors engineering as a strategic organizational competence with value beyond the compliance to workplace safety and include measurable outcomes in terms of productivity and quality and of workers' engagement. The similarity in the key relationships that emerged across the range of participant backgrounds and industry sectors with respect to the relationships between ergonomic environment quality, HMI design adequacy, safety culture strength, and organizational performance offers high-confidence support for the integrated HFE model of industrial performance that was a primary objective this study sought to examine.

The importance of the results for theory is great. The longstanding management myth that safety investment comes with a cost also applies to the outcomes of the safety-productivity relationship — and the diverse managerial perceptions that were confirmed each time they were observed.It is important to note that the safety-productivity relationship has been long consistently confirmed as safe productivity, such that the managerial perception of safety comes at the cost of productivity continues, despite contradictory evidence, to influence budgetary decisions in many industrial organizations. This complementarity is recognized both at the micro-level (e.g., fatigue reduction, improvement of error rates, reduction of absenteeism and enhancement of motivation) and at the macro-level (in an organization), and these mechanisms are each fairly well understood, yet they have not yet been described with the same depth of practitioner grounding in different manufacturing sector contexts.

The finding that organizational commitment is the key factor that determines the effective practice of HFE has important implications for strategies in developing HFE practice. It recommends that although there may be a greater benefit in investing in technical ergonomic skills development for specialist safety professionals, it suggests that investment in training and awareness programs for organizational leaders and operational managers could produce more of an improvement in practice, in organizations where the main constraint for improving ergonomic practice is allocating resources and setting priorities, rather than having technical skills available.

CONCLUSION AND RECOMMENDATIONS:

In this study, the influence of HWE on the safety and productivity of human factors in industrial manufacturing environments has been examined comprehensively, with a qualitative approach. The research, conducted with 23 participants from a variety of manufacturing industries and four data collection techniques, has shown that integrating effective HFE (ergonomic workstation design, quality human machine interfaces, good safety culture and competency aligned training) can lead to significant and measurable benefits in occupational safety and operational productivity performance.

From the analysis, four recommendations come forth. First, it is necessary to change the approach to HFE investment from compliance to productivity and present the business cases of HFE in terms of operational performance that are meaningful and understood by people who lead operations from a production perspective. Second, a commitment to ergonomic improvement needs to be enshrined in the culture of the organization as demonstrated through explicit ergonomic performance measures in operational management systems, an identified set of roles with ergonomic competency and ring-fenced budgets for ergonomic improvement. Third, human factors assessment should be a required engineering review element, as part of HMI design and automation deployment process, to prevent technological progress from bringing new cognitive safety issues that may not be noticed, yet are still present. Fourth, participative ergonomics methods—where workers are actively involved as knowledge providers to ergonomic improvement processes—should be adopted as the principal method for the identification and design of ergonomic hazards, and as a means of developing a commitment to safety culture through participative involvement.

There were a number of limitations in this study. The qualitative design is analytic which would not give statistical generalizability. The purposive sample is designed to be relevant to the expertise, but may not be representative of the range of industrial manufacturing settings around the world. Future studies should combine qualitative findings with a longitudinal quantitative study of organizational performance data to better tie the productivity gain to the specific type of HFE intervention so that a more precise cost-benefit analysis and industrial investment decision about HFE can be made.

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