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Ergonomics as Integrating Constituent in Occupational Safety and Health—Past, Present, and Future

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Ergonomics as a discipline was in the past, is in the present, and will be in the future, an integrating constituent in occupational safety and health (OSH). This statement is based on the self-conception of ergonomics and the level concept of human work. It is further supported by the results of about 120 interviews with German experts involved in research projects of the last 2 decades and the results of a quantitative analysis of international literature. The most important themes of past research are compiled and a prognosis of research themes of the future is given. The future role of ergonomics is exemplified by its contributions to the further development of OSH management systems.

ergonomic research level concept of ergonomics
occupational safety and health management systems prognosis

1. THE SELF-CONCEPTION OF ERGONOMICS

"Ergonomics is the systematic analysis, systematic order, and systematic design of technical, organizational, and social conditions of work processes,

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aiming at offering humans working in productive and efficient work processes

- harmless, manageable and undisturbed working conditions,
- the fulfillment of social standards regarding content of work, task, working environment, remuneration, and co-operation,
- the expansion of their scope of activity, the acquisition of competence and the preservation and development of their personality in co-operation with others'' [our translation].

This is how ergonomics was defined by Luczak, Volpert, Raeithel, and Schwier (1987, p. 59) in a research project funded, among others, by the German Ergonomics Society (Gesellschaft für Arbeitswissenschaft, GfA). Hence, the German Ergonomics Society holds itself responsible for the goals of individual safety and occupational health, the social appropriateness of work, and technical and economic rationality (GfA, n.d.). A 1995 survey among the members of the German Ergonomics Society showed the important role occupational safety and health (OSH) has for them. With almost 60%, it is the most often mentioned field of interest for the members of the German Ergonomics Society (Figure 1). So it is not surprising that Zülch (2000) designates ergonomics as the reference science for OSH.

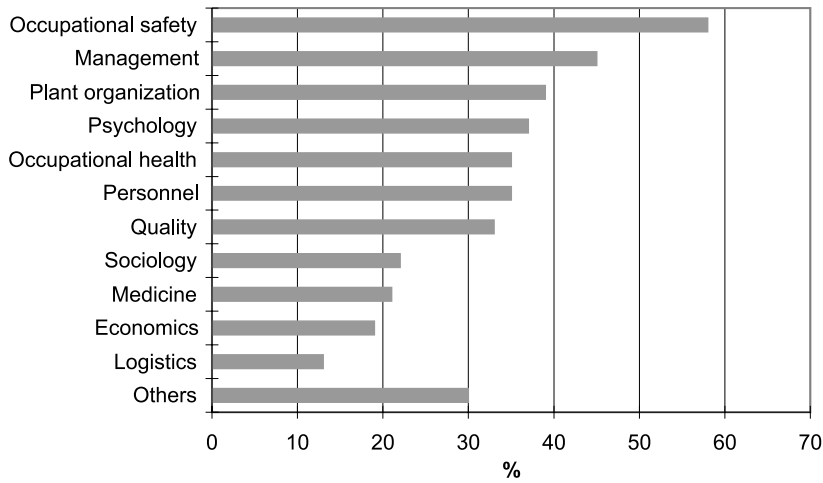

Figure 1. Focus of interest of the members of the German Ergonomics Society, according to a 1995 survey (multiple answers possible; redrawn after Gesellschaft für Arbeitswissenschaft, n.d.).

Based on this appreciation, ergonomics as a discipline should research the scientific basis of OSH, should disseminate this knowledge in vocational and further training, and, by doing so, it will further help to extend ergonomic knowledge in the applied field.

In addition, ergonomics as a discipline should systemize the different foci of human work. For this, the level concept of ergonomics, as devised by Luczak et al. (1987), is helpful. It distinguishes seven levels, starting at the level of the vegetative systems and environmental factors and ending at the level of the political and societal organization of work (see Figure 2). At the lower three levels a discrimination between (1) working subject and (2) work object and environment is made (cf. Figure 2).

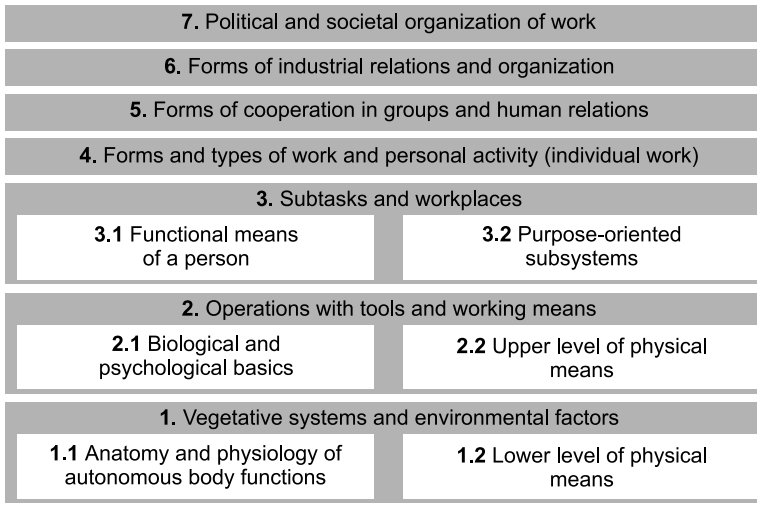

Figure 2. Level concept of ergonomics (Luczak, Volpert, Raeithel, & Schwier, 1987).

For the design of work places and tasks these three levels have a great importance. On the part of the working subject, the fundamentals of human physiological (e.g., coordination of movement, body forces) and psychological (human memory, human information processing) functions are focused upon. On the part of the working object, the focus is on the interaction of human and equipment.

The central, fourth level focuses on the working individual and his or her qualifications, motivation, aptitude, and so forth. The fifth level describes the cooperation between several individuals and working groups, whereas

the sixth level describes industrial relations. And finally the seventh level specifies the broader societal implications of work (e.g., laws regarding work, the labor market, concepts of vocational education). Levels four to seven can be subsumed as macroergonomics.

As part of a recent balance of OSH research within the last two decades in Germany (e.g., Luczak & Rötting, 2001; Luczak, Rötting, & Brueggmann, 2000; Scheuch, Haufe, & Weihrauch, 2000), about 120 experts involved in such research projects—either as administrator, researcher, or company representative—were interviewed. The interviews covered, among other areas, the experts' perceptions of past OSH research and their suggestions for future research themes. The following sections will present some of the results regarding the past and future contribution of ergonomics to the field of OSH.

To facilitate the presentation, the themes mentioned by the experts are discussed following the level concept of ergonomics (Luczak et al., 1987).

2. PAST FOCUS OF ERGONOMIC RESEARCH

2.1. Research Focus at Level One: Vegetative Systems and Environmental Factors

Figure 3 gives an overview of the research themes of the last 20 years that were mentioned in the interviews and can be associated with the first level, the vegetative systems and the environmental factors. According to the experts, researchers from ergonomics focused on environmental factors, whereas research of anatomy and physiology of the autonomous body functions was mainly carried out by researchers from occupational medicine.

The opinion of the experts is seconded by a quantitative analysis of the scholarly literature (see Brueggmann, Roetting, & Luczak in this volume for a description of the databasis and the general procedure) for the same time period (Figure 4). For this particular analysis, only such items were selected that could be identified as having originated in ergonomics. In the 1980s, the majority of papers dealt with environmental factors, but the number of papers declined in the early 1990s. This corresponds with the German research funding in the field of OSH, especially in the research programs "Humanization of Working Life" and later "Work and Technology," both funded by the Federal Ministry of Research and Technology, and the research funded by the Federal Institute of Occupational Safety and Health (cf.

Luczak, Brueggmann, Rösler, & Rötting, 2000). An opposite development can be seen for papers about the vegetative systems. The experts stated in the interviews that a change occurred in how accidents and occupational illnesses were perceived. The focus was broadened from purely looking for causal relationships to the impact of the whole work system on the employees. This implies the recognition of psychological factors as well as an increased use of physiological parameters for stress and strain analysis.

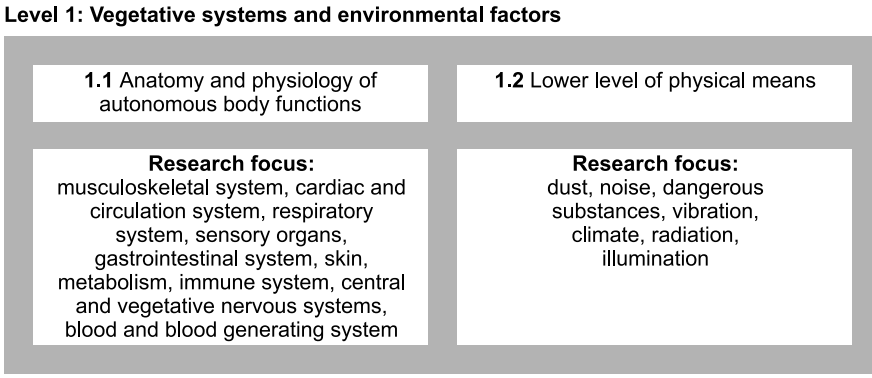

Figure 3. Research themes of the past at the level of the vegetative systems and environmental factors (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

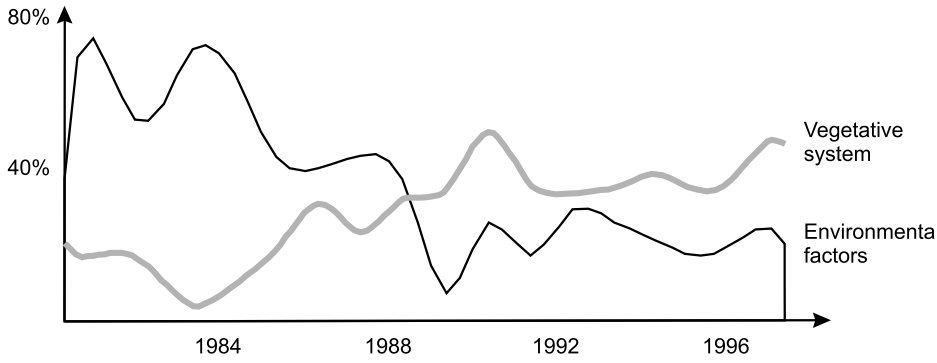

Figure 4. Relative proportion of published articles mentioning the vegetative systems and environmental factors of all published articles with relation to ergonomics (cf. Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

2.2. Research Focus at Level Two: Operations With Tools and Working Means

The focus of the research at the level of operations with tools and working means as perceived by the experts is listed in Figure 5. Very often safety of equipment was mentioned as the most important result of past research efforts. A number of research projects focused on basics for technical and technological work design. Themes were the constructive, ergonomic, and informational design of working equipment. Especially noteworthy are the projects dealing with the design of visual display units (VDUs) and work with them. The participation of ergonomists gained results that found their way into standards and national and international regulations.

With a focus on the subject, the biological and physiological basics of human-machine interaction were mentioned. Although the basics for a tabulation of human anthropometry originates well before the scope of the current balance, anthropometry was a continuous theme. Similarly, the stress and strain concept was guiding the design of ergonomic research.

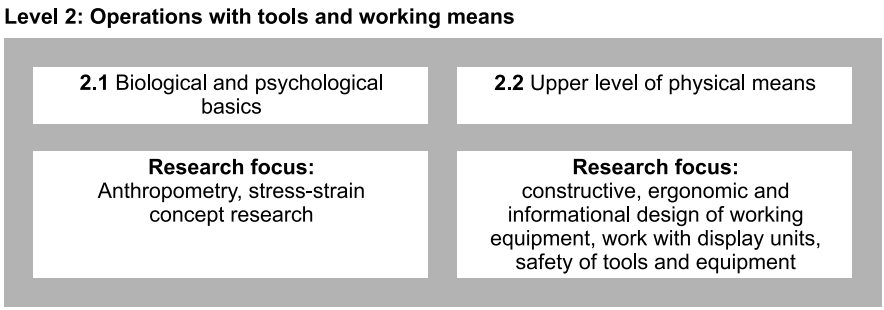

Figure 5. Research themes of the past at the level of operations with tools and working means (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

Again, the qualitative view from the expert interviews can be supplemented with quantitative data from the literature analysis. A continuously decreasing trend for the relative number of publications regarding the biological and physiological basics can be found. The field of ergonomics seems to have put greater emphasis on research about technical work design. But again an overall decreasing trend can be ascertained, with an exception in the early 1990s, when the federal research program "Work and Technology" followed up the program "Humanization of Working Life."

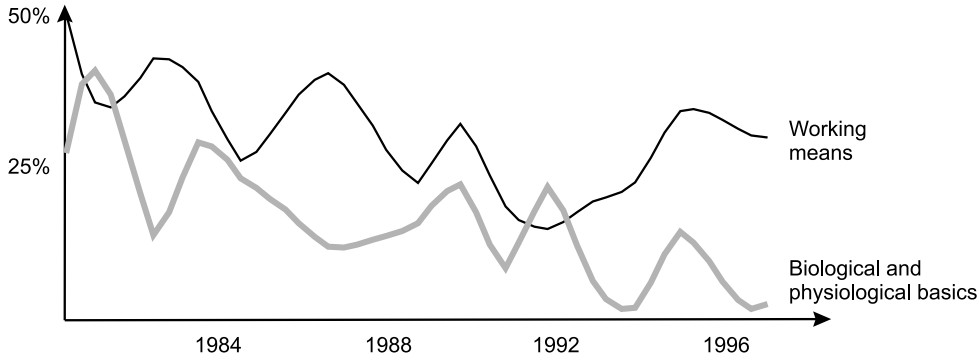

Figure 6. Relative proportion of published articles mentioning biological and physiological basics and working means of all published articles with relation to ergonomics (cf. Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

2.3. Research Focus at Level Three: Subtasks and Workplaces

On the level of subtasks and workplaces (Figure 7), according to the interviewed experts, the focus of ergonomic research in the field of OSH was on the purpose-oriented subsystems. Most often mentioned were projects about work design, disturbance analysis, and protection at the workplace.

Projects focusing on the human were, in the majority, done by occupational psychologists (cf. Sonntag, in this volume) rather than by ergonomists. The major themes were theory of action regulation, methods of workplace analysis, stress at the workplace, and cognitive demands.

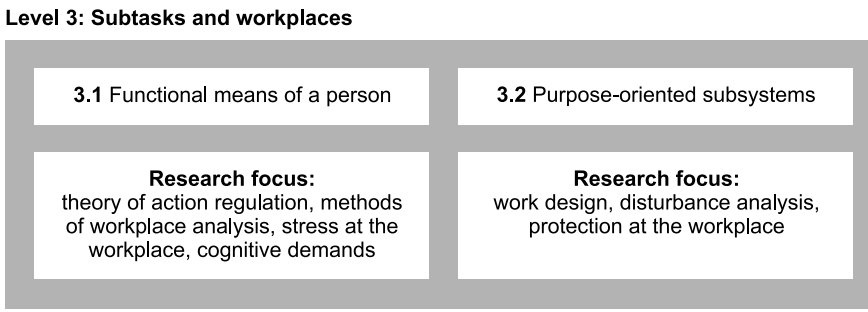

Figure 7. Research themes of the past at the level of subtasks and workplaces (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

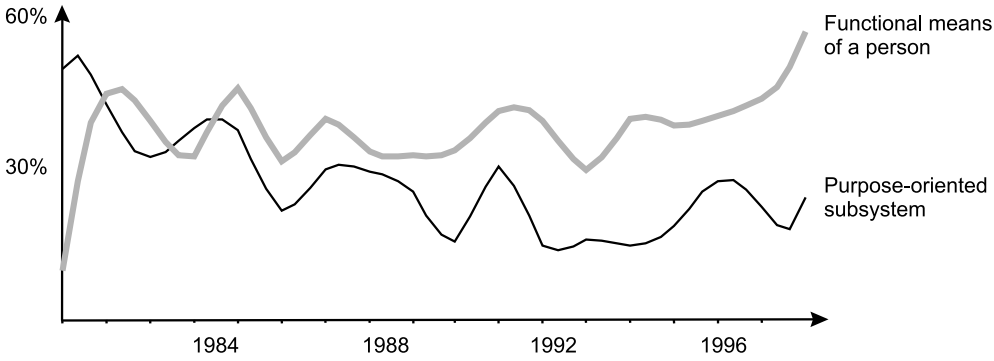

Figure 8. Relative proportion of published articles mentioning the functional means of a person and purpose-oriented subsystems of all published articles with relation to ergonomics (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

2.4. Research Focus at Level Four to Six: Macroergonomics

The statements of the experts regarding levels four to six will be discussed in context, as the levels highly interact with each other. According to the experts, ergonomic research dealt with the following themes: OSH as a task for management and leadership, OSH management systems, OSH and

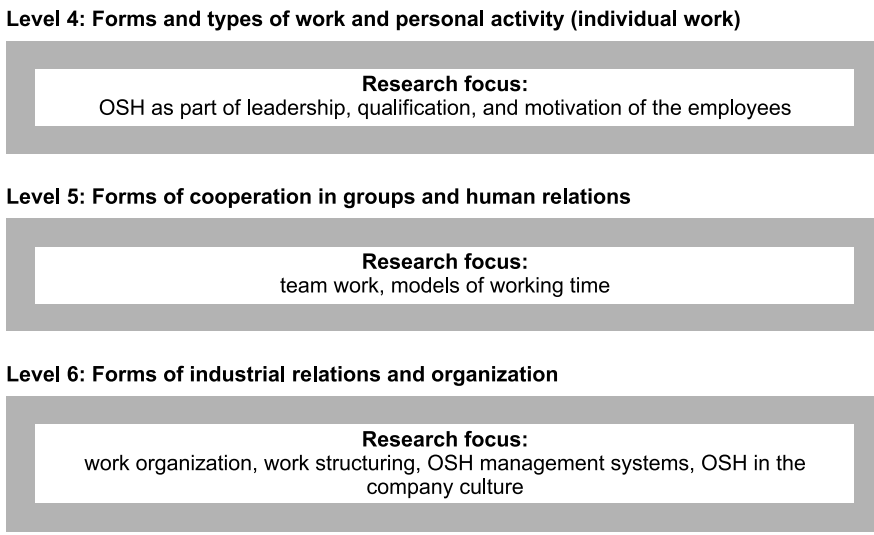

Figure 9. Research themes of the past at the level of macroergonomics (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001). *Notes.* OSH—occupational safety and health.

company culture, work organization and work design, OSH and group work, qualification, motivation, and models of working time. Figure 9 shows the relation of these themes to levels four to six.

Figure 10. Relative proportion of published articles mentioning remuneration, working time, work form, and management and leadership of all published articles with relation to ergonomics (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

Figure 10 gives an overview of themes from these levels in the published literature. Shown is the relative proportion of published articles with relation to ergonomics mentioning remuneration, working time, work form, or management and leadership. As can be seen, working time is the most prevalent theme, due to the research activities related to shift work in the early 1980s and the recent discussion of flexible working time. Only of minuscule importance were the discussions of remuneration in the context of OSH, whereas an increased number of papers discuss management and leadership, paralleled by the discussion of OSH management systems at the beginning of the 1990s. An almost constant number of papers over the years discuss different work forms.

2.5. Research Focus at Level Seven: Political and Societal Organization of Work

ontrary to the previous six levels, on this level work is discussed in a societal context. No longer is an individual or an organizational unit in the focus, but rather work in a global context. Themes therefore are questions of standards and guidelines, societal implications of occupational diseases and accidents, possibilities of prevention, salutogenesis, the system of accident insurance, and technology assessment.

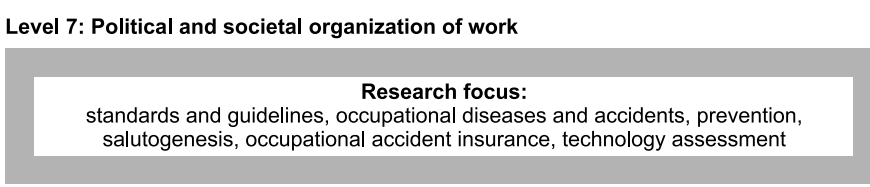

Figure 11. Research themes of the past at the level of the political and societal organization of work (Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

There were very few projects looking into this issue without relating it to more practical problems. Rather, results from projects focusing on the lower levels touched this level as well. According to the interviewed experts, ergonomists therefore played an important role as advisors in various boards, educating the public, and sensitizing it to ergonomic problems.

2.6. Emphasis at the Different Levels

After the focus of past ergonomic research in the field of OSH has been analyzed at the different levels of the work process, Figure 12 gives an image of the relative importance of the different levels. About 50% of all papers with relation to ergonomics focus on levels one (26% of the articles) and two (23% of the articles). Another 19% of the articles deal with problems that are positioned at level three, so that a little over two thirds of all articles are in the domain of what can be called microergonomics. With a focus on OSH it can be stated that the weight of ergonomic research in Germany in the last 20 years was on the individual working person and the work place.

The remaining third of the published articles with relation to ergonomics focus on the upper four levels of the work process: 15% of the articles can

be assigned to levels four and five and about an equal number to level six and a marginal 4% to level seven.

Over the years no dramatic changes in the distribution occurred. Levels one and two had an almost constant share of the papers. Papers regarding levels three to five show a decrease at the end of the 1980s and an increase in the second half of the 1990s. The number of papers allotted to level six continuously increases in the 1990s. It can be noted that the number of papers allotted to level seven was at the beginning about twice as high as at the end of the period under review.

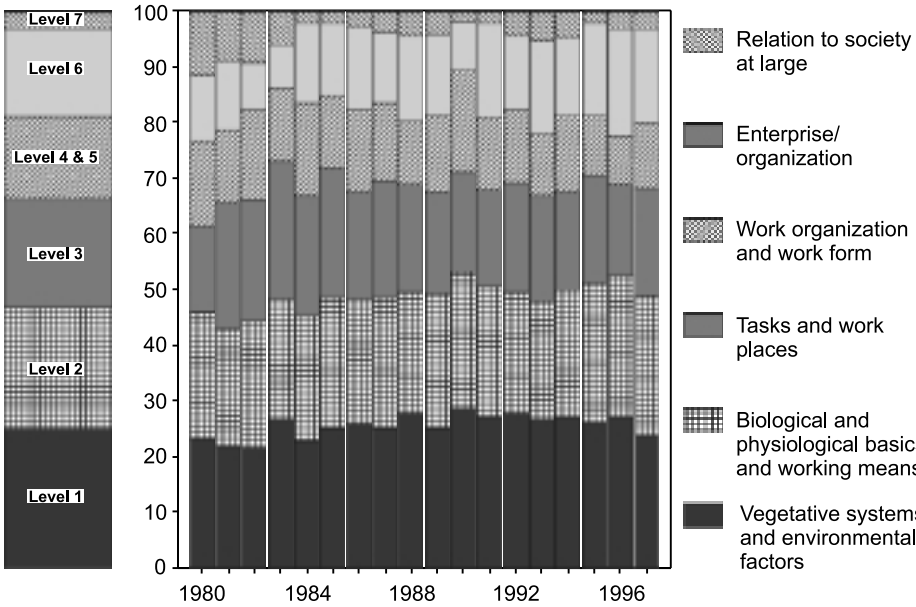

Figure 12. Overall distribution of published articles with relation to ergonomics allotted to the seven levels of the work process (left) and the relative proportion of published articles in relation to all published articles with relation to ergonomics over the years (cf. Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001).

3. RESEARCH THEMES OF THE FUTURE—A PROGNOSIS

In addition to the research themes of the past, the experts were asked for a prognosis of future themes of OSH research. Again, the themes with relation to ergonomics were extracted from the interviews and allotted to the seven levels of the work process (cf. Luczak, Brueggmann, Päßler, Rösler, & Rötting, 2001). Themes that could not be allotted to one of the seven levels will be discussed in an extra paragraph.

3.1. Level 1: Vegetative Systems and Environmental Factors

Based on the interviews with the experts, the long-term physiological effects of dangerous, especially carcinogenic and mutagenic substances will continue to be a major concern of OSH research. Of special interest will be the subjective effects of the combination of exposure to "classical" hazards (e.g., dangerous substances) and mental stressors. Additional research is expected for allergenic substances as well.

Looking at the working environment, the experts caution to put aside the classical strains. Manual materials handling will remain an important topic in OSH, owing to several factors: an increase in the care of sick and elderly at home, the greater mobility of the public and the related increase in dispatch and transport operations, and the reduction of personnel in transport operations. Similarly, noise will not cease to be of concern and questions of room acoustics will gain greater importance.

3.2. Level 2: Operations With Tools and Working Means

On the part of the subject, the experts named unspecific indisposition and illness as important themes. It is also necessary to enhance the concept of dose-effect relationship and to apply it to other areas.

The development of databases for exposure-stress relations are seen as an important task. In addition, the development of authoritative and practicable criteria and of methods for the evaluation of software are seen as important tasks. Similarly, designers need criteria for the evaluation of ergonomic quality, for example, in the form of checklists and methodologies. The quality and utility of standards needs to be scrutinized.

3.3. Level 3: Subtasks and Workplaces

In recent years, a trend from physical to psychological factors could be seen in OSH. This trend will continue, so the experts said in the interviews. Therefore, they expect an increased research demand in the measurement and evaluation of complex mental and emotional stressors at work. The increase in psychological and mental demands is due to an increased responsibility of a person for his or her own work, of an increasing significance of the human-machine interface, and an increase in load from multiple jobs or occupations (especially in the case of women).

Future research themes were therefore identified as the impact of stress on health and psychosomatic disorders. OSH research should look into the mental disablement caused by new technologies and changed social conditions and settings. Psychosocial consequences of new structures of work (e.g., working at home, phases of unemployment) should also be emphasized. In addition, new instruments and methods to match workplace demands and capabilities of the person need to be developed.

With a focus on the workplace, the experts recommended a holistic approach to job design and compensatory tasks for seated activities and office work.

3.4. Level 4: Forms and Types of Work and Personal Activity

For future research at level four, the following themes were identified:

- making employees more sensitive to OSH;
- studies about communication and the use of information;
- studies about mental strain;
- studies about employee behavior in an ever more complex working world and for the prevention of erroneous actions;
- OSH in the care giving professions (issues of working time, manual materials handling).

OSH research has to provide the practitioners in the companies with comprehensive instructions on how to deal with harassment, flexible working hours, shift work, and group work. The qualification of the OSH personnel at the companies must be further improved and be oriented towards future demands.

In general, OSH research must deal with methods of behavior modification and with OSH knowledge that can guide action. New methods and instruments must be developed for the service professions (e.g., teaching, catering professions, or public safety).

3.5. Level 5: Forms of Cooperation in Groups and Human Relations

In addition to questions of social support in groups of employees, OSH research must deal with issues of participation and the right to a say in OSH

issues. New ways of involving employees in questions of OSH must be developed.

3.6. Level 6: Forms of Industrial Relations and Organization

Regarding forms of industrial relations and organization, the majority of the experts expect a shift of OSH research towards questions of work organization and industrial organization. This assumption is based on the diminishing number of traditional work places. Questions of the organization of OSH in new forms of work must be addressed and organizational models that were developed for large enterprises must be adapted to the demands of small and medium enterprises (SME). Some of the experts pointed out that it is necessary to strengthen research and support for SME and nonprofit organizations. Regardless of the size of an enterprise, OSH must be integrated into all parts of a business and its efficient operation (e.g., by optimizing current approaches to OSH management systems). Other future research topics named were transcultural management, the optimization of work and rest schedules for mental work, and the design of phases of load and relief (e.g., working time and recreational time, short- and long-term leaves and vacations).

3.7. Level 7: Political and Societal Organization of Work

At the level of the societal context of work, the experts suggest that the future development of the German OSH system takes the European context into account, for example, the harmonization within the European Union Member States of how accident rates are calculated. In the light of the globalization of the economy, OSH regulations and performance figures of OSH should be harmonized worldwide and a respective information and documentation system be developed.

Developments at the level of society that, in the opinion of the interviewed experts, relate to OSH and open opportunities for future research are:

- the aging of society,
- changes in working time,
- the increase of work with display units and telecommuting,
- the development of new information and communication technologies.

OSH research has to develop new approaches for flexible working time and forms of job design that account for an aging work force. This should be accompanied by the development of a concept to research variations in work load over a person's life in the face of a greater flexibility of work biographies. The conditions and the acceptance of changes in the course of a person's life should be researched together with the consequences of the loss of classical career paths. Another focus is seen in the conception of new methods to evaluate domestic work and work outside of business organizations or unsalaried work. In addition, the OSH system, within as well as without company structures, should be evaluated using methods from social sciences.

3.8. Additional Research Themes of the Future

Some of the suggestions for future research themes could not be related to the levels of the work process and are therefore discussed in this section of the paper.

Regarding research methodology, the experts request more longitudinal studies to investigate complex causal relations and a broader support for field and evaluation studies. But the funding agencies should not lose sight of basic research.

Other themes related to instruments and methods for future research are:

- controlling integrated OSH and health promotion;
- defining effect and success criteria for quality assurance in OSH;
- moving away from numbers of employees' sicknesses and occupational diseases to other more appropriate measures;
- developing criteria that are based on performance and no longer on working time;
- improving the database for OSH;
- introducing a "health pass" for employees, where the specific working conditions of the person are recorded;
- developing instruments for an integrated interdisciplinary approach to OSH;
- developing guidance for action and persuasion within companies.

According to the interviewed, it is necessary to systemize research findings, especially in the field of the development of methods, and to transfer niche knowledge into other fields. The knowledge of the different

disciplines active in the field of OSH needs to be further interlocked and interdisciplinary endeavors need to be strongly supported.

As contents of a comprehensive OSH research plan, the following were specified:

- OSH in the information society and in the service sector, without neglecting the "traditional" production sector;
- preventive accident research and salutogenesis;
- studies regarding standards, conditions of transfer, application of technology, and problems of cost benefit analysis;
- research regarding handicapped persons and special groups, for example, young workers and apprentices.

The attractiveness of the current OSH must be enhanced and new ways should be tried out to activate and motivate OSH. Especially when addressing younger employees, the "grandfather mentality" ("be careful all the time and you will live a long life") must be overcome. It is necessary to identify the structures that support and impede the implementation of OSH in organizations. The possibility of extending OSH to family-like structures must be shown. Employers must be elucidated about the economic value of OSH measures. And, last but not least, OSH must be integrated into the curricula of students and apprentices.

In general, the results of OSH research must be better integrated into everyday practice. As was stated in one interview: "Why isn't anybody doing it? Because nobody knows!"

4. CONTRIBUTION OF ERGONOMICS TO THE DEVELOPMENT OF OSH MANAGEMENT SYSTEMS

In accordance with the importance the members of the German Ergonomics Society assigned to OSH, the society's 1999 conference focused on OSH management systems (Gesellschaft für Arbeitswissenschaft, 1999). In close relation to this conference, Zülch (Zülch, 2000; Zülch, Keller, & Rinn, 1998) stated the following research needs in the field of ergonomics regarding OSH management systems:

- Knowledge provision
  - A responsibilities information system
  - Ergonomic knowledge regarding the responsibilities
  - Updating knowledge

  - Linking of, for example, centrally maintained data with local management systems
- Evaluation of work
  - Threshold values (not only for hazards but also for disagreeableness and comfort)
  - Overall evaluation (superposition of different strains)
  - Assigning priorities for the execution of OSH measures
- Coordination with other management systems
  - Environmental management, quality management
  - Integrated management systems
  - Holistic management system with goal establishing, planning, control, and maintenance management
- Data keeping and data visualization
  - Minimize maintenance requirements, for example, by applying object-oriented database systems
  - ''State-of-the-art'' visualization
- Qualification
  - Training requirements at different levels

TABLE 1. Levels of the Work Process (Luczak, Volpert, Raeithel, & Schwier, 1987) and System Elements of an Occupational Safety and Health (OSH) Management System (cf. Bavarian Ministry of State for Labour and Social Affairs, Family, Women and Health, 1998): Deduction of Fields of Ergonomic Activities (cf. text for further explanation)

	Level						
System Elements of an OSH Management System	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Tasks and responsibility of top management of organization					X	X	(X)
Management system					X	X	
Requirements						X	X
Prevention	(X)	X	X	X	X		
Review, surveillance, and corrective actions		(X)	X	X	X		
Arrangements for breakdown and emergencies				(X)	(X)	X	
Purchasing	X	X	X	X	X	X	
Control of records					X	X	
Personnel		(X)	(X)	X	X	X	
Audits of occupational health and risk management system (documentation)						X	X

Notes. 1—Level 1: Vegetative systems and environmental factors, 2—Level 2: Operations with tools and working means, 3—Level 3: Subtasks and workplaces, 4—Level 4: Forms and types of work and personal activity (individual work), 5—Level 5: Forms of cooperation in groups and human relations, 6—Level 6: Forms of industrial relations and organization, 7—Level 7: Political and societal organization of work.

TABLE 2. Examples for Ergonomic Activities

Level 7: Political and societal organization of work	• Insurance systems (realized by private enterprises) • Deregulation and privately contracted legal relations • Motivating versus obligating character of instructions and recommendations • Personal responsibility versus having others be responsible for you • Change of work relations and occupational safety and health (OSH)
Level 6: Forms of industrial relations and organization	• Development and testing of integrated management systems • Responsibility of the employer • Incident and accident management • Outsourcing of dangerous tasks • Development of ''seals of quality'' for working conditions • Coupling of different risk management systems within a company • Establishment of OSH in virtual enterprises • Methods for assessing dependability (human and technology) • Methods of personnel selection • New media in OSH • Consideration of stress from multiple jobs and leisure time
Level 5: Forms of cooperation in groups and human relations	• OSH relevant aspects of information management • OSH and organizational learning • Heavily structured elements of OSH management systems versus autonomy of the employees • Questions of responsibilities of team members (legal, economic, social, etc.) • Team performance between under and over demanding • Allocation of contributions to prevention in team bonuses
Level 4: Forms and types of work and personal activity (individual work)	• Self-control and self-responsibility for prevention • Individual development of OSH competence
Level 3: Subtasks and workplaces	• Object-oriented OSH • Task specific clustering of prevention strategies
Level 2: Operations with tools and working means	• Intervention and prevention at repetitive strain injuries • Sensibility of special groups
Level 1: Vegetative systems and environmental factors	• Changing from stress to annoyance as assessment criteria • Effects of impulse noise • Protective equipment for ''new technologies''

The task of the further development of OSH management systems is well suited to exemplify the future role of ergonomics, as well in pointing out research needs as in describing fields of activity.

The Bavarian Ministry of State for Labour and Social Affairs, Family, Women and Health (1998) presented the system elements for an Occupational Health and Risk Management System (OHRIS). This system can be taken as a prototypical system. Table 1 compares the OHRIS system elements with the seven levels of the work process to deduce fields of ergonomic activity. In the table those areas, where an emphasis of ergonomic activity in the development of OSH management systems is seen, are marked with an X. Areas that to some extent require an ergonomic activity are marked with (X). All levels marked with either an X or an (X) and all hierarchically lower levels are shaded in gray to show the repercussions of ergonomic activities.

Examples for the kinds of activities on the different levels are given in Table 2.

It is not surprising that the focus of today's and future ergonomic research activities is on levels six (Forms of industrial relations and organization) and five (Forms of cooperation in groups and human relations). The lower levels have been well researched in the last decades with a wealth of consolidated findings. So these levels will successively become of lesser importance, although the settings on the higher levels still influence them.

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