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Title page

Title: Participatory ergonomics simulation of hospital work systems: The influence of simulation media on simulation outcome

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Participatory ergonomics simulation of hospital work systems: The influence of simulation media on simulation outcome

Abstract

Current application of work system simulation in participatory ergonomics (PE) design includes a variety of different simulation media. However, the actual influence of the media attributes on the simulation outcome has received less attention. This study investigates two simulation media: full-scale mock-ups and table-top models. The aim is to compare, how the media attributes of *fidelity* and *affordance* influence the ergonomics identification and evaluation in PE design of hospital work systems. The results illustrate, how the full-scale mock-ups' high fidelity of room layout and affordance of tool operation supports ergonomics identification and evaluation related to the work system entities *space* and *technologies & tools*. The table-top models' high fidelity of function relations and affordance of a helicopter view supports ergonomics identification and evaluation related to the entity *organization*. Furthermore, the study addresses the form of the identified and evaluated conditions, being either identified challenges or tangible design criteria.

Keywords: Participatory Simulation, Hospital Work Systems, Participatory Ergonomics.

1. Introduction

A recognized problem in work system design is the occurrence of ergonomics problems after implementation of system changes, resulting in resource demanding and cost full readjustments to comply with the problems (Hendrick 2008). One way of preventing the ergonomics problems already during the design process is to include the future workers in participatory ergonomics (PE) (Wilson et al., 2005). PE has been defined as “the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals” (Wilson, 1995).

Participatory simulation is a PE method that involves the future workers in design of work systems. A work system can be defined as “...a system in which human participants and/or machines perform work using information, technology, and other resources to produce products and/or services for internal or external customers” (Alter, 2006). Simulation has been defined as ‘an imitation of the operation of a real-world process or system over time’ (Banks et al., 2010), and may have two purposes. The first being a method for identifying and evaluating the future work practices and ergonomics conditions (Daniellou, 2007; Daniellou et al., 2014; Nelson et al., 2013) and the second being a social process mediating mutual learning between workers and designers (Béguin, 2014). This study will concentrate on the first purpose.

A key component in participatory simulation is the simulation media (Daniellou, 2007), which represent the work system to be designed. Within the PE field, a variety of different simulation media are applied, all with the purpose of identifying or assessing ergonomics conditions and problems of the work system to be designed. Physical simulation media such as mock-ups and prototypes are applied for assessing work posture (Sundin et al., 2004), muscular discomfort (Paquet and Lin, 2003), physical layout and spatial conditions (Broberg et al., 2011; Steinfeld, 2004; Watkins et al., 2008). Computer based simulation media such as 3D computer animation and mixed reality have been applied for assessing muscular fatigue (Hallbeck et al., 2010; Perez et al., 2014), repetitive work and critical work sequences (Sundin and Medbo, 2003; Sundin et al., 2004).

The variation in ergonomics conditions indicates that different media support identification and assessment of different ergonomics conditions, which is a common reflection point in the literature (Hallbeck et al., 2010; Paquet and Lin, 2003; Steinfeld, 2004; Sundin and Medbo, 2003; Watkins et al., 2008). In addition, some studies indicate that the media have certain attributes, but these are not reflected upon in relation to the ergonomics conditions or problems actually possible to identify by applying the media. The media attributes indicated are the ability of the media to represent the reality (Hallbeck et al., 2010; Steinfeld, 2004; Watkins et al., 2008) and the possible actions the media support (Broberg et al., 2011; Steinfeld, 2004). Within the interaction design field, these attributes are recognized as *fidelity* (Hall, 2001; Lim et al., 2008) and *affordance* (Norman, 2002; Turner, 2005). Fidelity may be defined as “the level of detail or sophistication of what is manifested” (Lim et al., 2008). Affordance may be defined as “the perceived and actual properties of the thing... that determine just how the thing could possibly be used” (Norman, 2002). How these two media attributes influence the outcome of simulations, in the form of identified ergonomics conditions, has received little attention in the participatory simulation field.

The Danish healthcare sector is currently a relevant empirical setting for exploring the influence of the simulation media attributes. At the moment, the sector is in a comprehensive design process for new public hospitals, which includes an extensive application of participatory simulation, involving healthcare professionals in PE design. The design activities may be conceptualized as a matter of designing hospital

work systems. This study is based on two case studies of participatory simulation events, applying two different simulation media: full-scale mock-ups and table-top models. The aim is to compare, how the fidelity and affordance attributes of these two types of simulation media may influence the ability to identify and evaluate ergonomics conditions during PE design of hospital work systems.

Our basic assumption was that the two simulation media would have different capabilities in supporting *identification and evaluation of ergonomics conditions* because of difference in the attributes. By adapting the International Ergonomics Association's definition, *ergonomics conditions* are defined as: (1) conditions influencing the healthcare professionals' well-being in the future work system, e.g. work posture, psychosocial work load, indoor climate, safety and division of labor; and (2) conditions influencing the work system's overall performance, e.g. efficiency, consumption of resources, quality of system output and risk of errors. We refer to *identification* as the process of simulation participants being able to articulate or visually show possible ergonomics challenges of the future work system. We refer to *evaluation* as the process of participants being able to formulate tangible design criteria based on discussions of the identified ergonomics conditions.

In the following, we first define the key work system concept, followed by the methodological approach, including the introduction of the two cases. We present the results from the analysis in the form of the identified and evaluated ergonomics conditions of the two cases and the influence of fidelity and affordance. In the discussion, the results of each case are compared and related to existing studies on full-scale mock-ups and table-top based models. We end with concluding remarks, including implications for practitioners.

2 The work system concept

In order to analyze the participatory simulation phenomenon, we introduce the work system concept. A work system have been defined as consisting of different interconnected entities (Alter, 2006; Carayon, 2009; Horgen et al., 1999; Kleiner, 2006). We operate with six entities: *work practice*, *participants*, *information*, *tools & technologies*, *space* and *organization*. The *work practice* is the work activities within the work system (Alter, 2006). The *participants* are the people who perform the work (Alter, 2006) and have psychosocial, cognitive and physical characteristics (Carayon, 2009). The *information* is explicit and tacit knowledge, which is exchanged as participants perform their work (Alter, 2006). The *technologies & tools* are the tools that helps participants work efficiently (Alter, 2006; Carayon, 2009). The *space* is the physical environment and workspace design (Carayon, 2009; Horgen et al., 1999). The *organization* is the organizational design, the organization of work, coordination of work (Kleiner, 2006), work scheduling and culture (Carayon, 2009). The six entities of the work system concept are applied as an analytical frame to help identify, to what extent the entities are addressed in the two simulation cases.

3 Methodology

The Danish healthcare sector is designing and building new public hospitals, with the purpose of increasing the quality and efficiency of the healthcare service. The design process includes redesign of the current hospital work systems. To facilitate user participation in the work systems design, the Danish Regional Councils have established innovation centers spread around the country. A significant part of the centers' activities are based on participatory simulation, involving healthcare professionals from the existing hospitals. We had the opportunity to study participatory simulation in two innovation centers, each related to a hospital design project. The first center applied full-scale mock-ups as simulation media, and the second center applied table-top models as simulation media. We considered the simulation activities of the centers as naturally occurring data, described as "real interactions happening naturally out in the world" (Potter,

2004), contrasting controlled laboratory experiments. These naturally occurring simulation activities provided a unique opportunity for studying, how the fidelity and affordance of these two types of simulation media may influence the ability to identify and evaluate ergonomics conditions. We approached the simulation activities of the two hospital design projects as two case studies, each constituting of four simulation events viewed as nested units of analysis (Thomas, 2011). The simulation activities in both cases had the purpose of providing input to the engineers and architects, who designed the new hospital buildings during complex design processes. However, in this study we focus exclusively on the actual ergonomics outcomes of the simulations. The two cases are described in the following sections 3.1 and 3.2.

3.1 Full-scale mock-ups

The innovation center of the first case study was part of the building process of a new hospital, which replaced two current hospitals. The center was located in a hall at the construction site, containing mock-ups facilities. The facilities were managed by two center employees: one with a clinical background and one with an occupational health and safety background. The purpose of the center was to test standard room proposals for the somatic hospital and thereby contribute to the architectural design process.

The four simulation events, constituting the case as presented in Table 1, were based on blueprints of room proposals provided by the consulting architects. The room proposals were key rooms in the sense that the rooms would be extensively repeated throughout the hospital. The proposals were transformed into full-scale mock-ups based on movable chipboard walls, big foam bricks and standard hospital interior, see Figure 1. The mock-ups were constructed by the two center employees prior to the simulation events.

(Insert Table 1)

Table 1: Key characteristics of the four simulation events of the first case study. (Two column table)

(Insert Figure 1)

Figure 1: Full-scale mock-ups applied in the first case. (One column figure)

The participants of the four simulation events were healthcare professionals with various professions; project employees from the project owner organization; engineers and architects from the consulting companies; and the two center employees. The center employees selected the participating healthcare professionals on the criteria of having work experience in the room to be tested.

Each of the four simulation events constituted of two parts. The first part was an introduction meeting, where the center employees introduced the simulation participants to the architect's room proposal. The introduction led to discussions of possible challenges of the room, e.g. problems about work postures or work practices. Using the identified challenges as a starting point, the participants developed scenarios based on possible future work practices, e.g. handling of a wheelchair in an examination room. The second part comprised the simulation in which the healthcare professionals initiated work processes in the mock-ups. The simulation was facilitated by the center employees in an open manner, in the sense that the direction of the simulation was highly influenced by the participants continually developing the simulation scenarios further. The continual scenario development resulted in a mixture of; experimental simulation, where the participants enacted scenarios in the mock-ups, e.g. pushed a bed around the cornered corridor; and narrative simulation, where the participants discussed scenarios while standing in the mock-ups, e.g. how coordinating technology could support the work of the nurses.

3.2 Table-top models

The simulation events of the second case study were a part of a healthcare innovation project managed by the regional innovation center. The project aimed at contributing to the designing of a new outpatient department building for an existing hospital. Furthermore, the project was a research project for testing simulation methods in healthcare innovation. The vision for the project was to involve healthcare professionals from the existing outpatient department, consultants from industry, simulation consultants from the Danish Institute of Medical Simulation and researchers.

The four simulation events of the case are presented in Table 2. The simulation media were in table-top size, consisting of an A0-poster, where LEGO figures and cardboard boxes were arranged, see Figure 2. The LEGO figures depicted patients and healthcare professionals. The cardboard boxes illustrated rooms, and the configuration of the boxes illustrated conceptual building layouts. With a foundation of comprehensive research in the work practices of the current outpatient department, the layout proposals were developed by the participating healthcare professionals before each simulation event.

(Insert Table 2)

Table 2: Key characteristics of the four simulation events of the second case study. (Two column table)

(Insert Figure 2)

Figure 2: Table-top models applied in the second case. (One column figure)

The participants of the four simulation events were healthcare professionals from the existing outpatient department, simulation consultants, consultants from industry and researchers. However, the healthcare professionals had the most active simulation role, whereas the researchers and consultants from industry observed and occasionally participated, when multiple patient treatments were simulated. Furthermore, one of the simulation consultants acted as the main game-master. The participating healthcare professionals were selected by management of the outpatient department based on the criteria including representatives from the three main employee groups: physicians, nurses and secretaries.

Each of the four simulation events constituted of two parts. The first part was the actual simulation event based on simulation scenarios, previous developed by the simulation consultants and department management. The scenarios were based on comprehensive research of the work practices at the department and illustrated patient trajectories from the existing outpatient department. The scenarios included a list of tasks with assigned simulation time as a third of real time. In combination with the predefined scenarios, each simulation event was aiming at investigating a simulation question, e.g. “what if we introduced two physicians per three examination rooms?”

For the simulation, each of the participants was assigned a scenario role reflecting their professional background, a LEGO figure and a colored marker pen. The participants, who were assigned the role as patients, were supplied with an egg-timer for managing the simulation time of the scenarios. The participants moved the LEGO figures around the table-top model according to the scenario while simultaneously drawing the movements on the A0 poster. During the simulation, the game-master introduced predefined disturbances, e.g. the need for experienced physicians supervising less experienced physicians. The disturbances challenged the participants to develop creative solutions within the frame of the scenarios. The second part of the simulation event was an extensive debriefing managed by the game-master and the

researchers. In the debriefing, the participants were able to discuss the insights obtained from the previous simulations.

3.3 Case selection

Our initial assumption for this study was that different simulation media have different capabilities in supporting identification and evaluation of ergonomics conditions due to variation in media attributes. The two cases provided a unique opportunity for studying this assumption, which until now has received minimal attention in the human factors and ergonomics field. Furthermore, the two cases complied with the case selection criterion on maximum variation (Flyvbjerg, 2006) by applying two ‘opposite’ simulation media in terms of fidelity and affordance. The variation in fidelity and affordance is elaborated in Table 3. The purpose was to search for both differences and commonalities. Differences in relation to our assumption of different capabilities of the media. Commonalities in relation to a common pattern in how media attributes connect to these capabilities. Identification of commonalities is argued to be strengthened when the cases vary in maximum degree (Neergaard, 2010).

(Insert Table 3)

Table 3: The fidelity and affordance of the two simulation media. (Two column table)

3.4 Data collection and analysis

The data analysis was based on video-recordings of the simulation events. The video-recordings were executed with a fixed camera with the purpose of getting a wide view of the simulation activities, and thereby capture as much interaction and visual conduct of the participants as possible (Heath et al., 2010). The authors had different roles in relation to the data collection and analysis. The first author recorded and observed the simulation events of the first case. The second author recorded and participated as one of the researchers in the second case, applying an action research perspective. In both cases, the simulation events were not conducted with a research purpose of media attributes in mind, the overall purpose was to contribute to hospital work system design. Thereby, the comparative potential of the cases was recognized afterwards. Aiming at conducting a comparative analysis, the first author analyzed the video-recordings of both cases from the perspective of being an observer of the recorded events. During the analysis the second author acted as discussion partner.

The first author’s observations of the ‘live’ simulations of the first case and the second author’s participation in the simulations of the second case provided insights into the activities taking place before and after recording periods. These insights were important for understanding reasons behind discussions and actions of the simulation participants as captured in the recordings. Furthermore, the observations of the first case gave the opportunity for viewing actions, which were not explicit to the camera because e.g. people occasionally stood behind walls in the full-scale mock-ups. In these cases, the observations were necessary to fill in these particular sequences in the video-recording.

The video-recordings of each case were analyzed in two phases. The first phase investigated the types of ergonomics conditions identified in both cases from a quantitative perspective. The second phase investigated the evaluation possibility of the identified conditions and the relation to the media attributes from a qualitative perspective. The two phases of analysis were intended to supplement each other by providing both a quantitative and qualitative view on the two case studies as a triangulation strategy (Silverman, 1993). The two phases are illustrated in Figure 3 and elaborated in the following paragraphs.

(Insert Figure 3)

Figure 3: The first and second step of analysis. (Two column figure)

The first phase of analysis was a content analysis (Berg, 2001) of the video-recordings. The analysis was based on coding for identifying video-sequences where simulation participants *identified ergonomics conditions*, and ordering these according to the *six work system entities*, step 1 and 2 in Figure 3. The first author coded the videos for sequences where participants identified ergonomics conditions. By *identify*, we mean simulation participants articulated or visually showed ergonomics conditions, e.g. by discussing or acting out possible future ergonomics challenges. By *ergonomics conditions*, we mean conditions that influence the well-being of the future healthcare professionals or the performance of the future work system. The identified sequences were transcribed as a combination of voice and visual conduct (Heath et al., 2010). We ordered the sequences according to which of the six work system entities the identified conditions related to. Some sequences were related to several entities and were thereby represented more than once, whereas other sequences only related to one entity. The total number of transcribed sequences, including duplicates, was 259 of the first case and 323 of the second case. The number of sequences per work system entity was normalized according to the total number of sequences per case.

The second phase of analysis was an inductive approached searching for patterns (Thomas, 2006) within the transcribed sequences of each work system entity, step 3 in Figure 3. This resulted in identification of several subgroups of identified conditions within each work system entity. We assessed these subgroups on two levels: the *evaluation possibility* and the *influence of media attributes*, step 4 and 5 in Figure 3. The *evaluation possibility* was assessed to find out whether the subgroups were purely identified ergonomics conditions or actually possible to evaluate. The following question guided the assessment: what is the possibility for the simulation participants to formulate a tangible design criterion from discussions of the identified ergonomics conditions? A tangible design criterion is a statement that a work system designer can directly apply, e.g. “this wall must be moved one meter as minimum, in order to have a proper work posture.” A less tangible design criterion is a statement of a challenge to take into consideration during work system designing, e.g. “there must be sufficient natural light inflow for the work taking place.” The *influence of media attributes* was assessed from the guiding question: how are the media attributes of fidelity and affordance influencing by either supporting or opposing the evaluation process?

4. Results

In this section, we present the results of the analysis: the ergonomic conditions identified and the evaluation possibility of the subgroups of identified conditions. The quantification of identified ergonomics conditions is presented in Figure 4. The figure shows the distribution of video-sequences, where the participants identified conditions related to one or more of the six work system entities. The first case study of the full-scale mock-ups had a high percentage of identified ergonomics conditions related to *space* and *technologies & tools*. The second case study of the table-top models had a high percentage of identified ergonomics conditions related to *organization*. The exact distribution percentages of identified ergonomics conditions are presented in Appendix 1.

(Insert Figure 4)

Figure 4: The distribution per case study of the amount of video-sequences where the simulation participants identified ergonomics conditions in relation to the entities of the six work system entities. (Two column figure)

During the second step of analysis we realized that the simulation participants were not able to evaluate all the subgroups of identified conditions. This difference in evaluation possibility was especially interesting for the identified conditions related to *space* and *technologies & tools* in the first case, and *organization* in the second case. We expected that the media's high capabilities in supporting identification of conditions related to these work system entities would additionally lead to high evaluation possibilities of these conditions. However, assessment of the subgroups revealed that not all identified conditions were able to be evaluated by the simulation participants. The fidelity level and affordance showed influence on the evaluation possibility.

In the situations where the participants were able to evaluate conditions, the fidelity relating to that condition showed to be high. Furthermore, affordance of actions relating to the condition under evaluation also showed to support the evaluation possibility. In the situations where the participants had difficulties in evaluating a condition, the media attributes showed not to influence the discussion. These discussions were triggered by the simulation media, but became detached from the media along the way, in the sense that the participants could not actively apply the media in their argumentation. Thereby, the participants did not reach a common agreement. The evaluation possibility and the influence of media attributes are presented in Table 4. For an overview of the evaluation possibility for subgroups of all six work system entities see Appendix 1.

(Insert Table 4)

Table 4: The evaluation possibility of the subgroups of the three dominating work system entities, and the influence of the media attributes. (Two column table)

5. Discussion

The results of the first step of analysis showed differences between the full-scale mock-ups and the table-top models in relation to the number of identified ergonomics conditions related to the six work system entities. The differences indicate that the two types of simulation media and their attributes support different ergonomics identification of the future hospital work systems. Furthermore, the media attributes additionally showed an influence on the evaluation possibility of the identified conditions, leading to the discovery that not all the subgroups of the work system entities could be evaluated. Considerations on the influence of media attributes are discussed in the following sections together with considerations on influencing contextual factors.

5.1. Influence of media attributes on identification

The two simulation cases represented 'opposite' media in terms of media attributes. The full-scale mock-ups had a high fidelity level in regards to room dimensions, room layout, tool positions and tool dimensions. Furthermore, the full-scale mock-ups afforded configuration of the movable walls and operation of tools. These attributes connected to the high amount of identified ergonomics conditions related to the entities *technologies & tools* and *space*. In contrast, the table-top models showed low fidelity of the room dimensions and room layout, because the rooms were 'black-boxed' into cardboard boxes. However, the table-top models had a high fidelity of the overall organization and building layout of the future work system. Furthermore, the table-top models afforded room configurations and a helicopter view. These attributes connected to the high amount of identified ergonomics conditions related to the work system entity *organization*.

In existing studies applying full-scale mock-ups in PE activities and hospital design, the ergonomics conditions identified are also related to the entities *technologies & tools* and *space*. Existing studies applying table-top based simulation in production and building planning also identify conditions related to *organization*. The identified conditions are presented in Table 5. The purpose of Table 5 is not to identify all published studies of full-scale mock-ups and table-top based models, but to identify studies representing the application variety of these simulation media in participatory design activities.

In some of the existing studies, the authors reflect upon the simulation media fidelity in the form of detail level (Watkins et al., 2008) or the situation being ‘too finished’ (Bligård et al., 2014). Some studies actually refer to the concept of fidelity as influencing discussions among participants (Persson et al., 2014), being important in different design phases (Watkins et al., 2008) and being ‘good enough’ (Hallbeck et al., 2010). However, the connection between the fidelity and the actual identified ergonomics conditions has not been analyzed or defined.

The existing studies acknowledge in some ways that simulation media have different affordances. The full-scale mock-ups are referred to as giving a bodily experience (Bligård et al., 2014; Persson et al., 2014) and being flexible to use (Paquet and Lin, 2003; Peavey et al., 2012; Villeneuve et al., 2007). The table-top based models are discussed as providing an overview (Bligård et al., 2014; Ruohomäki, 2003; Savolainen, 1997). However, these properties are not defined as affordance, nor are they analyzed in relation to the conditions actually identified. Our study contributes to the existing studies by actually analyzing the connection between the identified ergonomics conditions and the media fidelity and affordance. We argue for the importance of considering this connection, when planning participatory simulation with the purpose of contributing to work system design by identifying ergonomics conditions.

(Insert Table 5)

Table 5: Identified ergonomics conditions of existing studies of full-scale mock-ups and table-top based simulation. (Two column table)

5.2 Influence of media attributes on evaluation

In this study, we distinguish between identification and evaluation of ergonomics conditions. We define conditions with high evaluation possibility as fostering development of tangible design criteria, ready to be applied by work system designers. Whereas conditions with low possibility for evaluation have the characteristics of being less tangible and having the form of challenges to take into consideration during design. Existing studies on full-scale mock-ups and table-top based models show little consideration in regards to the form of the simulation outcomes, whether being directly applicable in design or challenges to take into account. Few studies define tangible design criteria (Hignett et al., 2010; Villeneuve et al., 2007; Watkins et al., 2008) and assess conditions (Daniellou et al., 2014; Hallbeck et al., 2010; Paquet and Lin, 2003; Ruohomäki, 2003). However, the development of these design criteria and assessment of the conditions are not analyzed in relation to the media fidelity and affordance.

During our analysis, we identified the fidelity of the full-scale mock-ups and table-top models as influencing the conditions possible to be identified. For example in the mock-ups, the ergonomics conditions, relating to the high fidelity areas of room dimensions and room layout, illustrated evaluation possibility. In contrast, the ergonomics conditions, relating to areas of the work system that the mock-ups manifested with a lower level of fidelity, were harder to evaluate. The mock-ups manifested e.g. the light and noise conditions of the hospital work systems to a low fidelity, because the mock-ups were situated in a hall, not reflecting the

natural light and noise level. Thereby, the fidelity level manifested certain parts of the work system to a higher degree, seeming to support the evaluation of conditions related to these work system parts.

Furthermore, we identified the affordance of the full-scale mock-ups and table-top models as influencing the evaluation possibility. As an example, the table-top models' affordance of room configurations supported evaluation possibility of ergonomics conditions related to work organization and coordination between rooms and healthcare staff. However, ergonomics conditions related to e.g. external functions outside the simulated hospital department were harder to evaluate. This was possibly because the table-top models afforded configuration of rooms and functions defined to be situated within a specific department. In this way, the affordance related to certain parts of the work system demonstrated to support evaluation of these parts.

To increase the integration of the simulation outcome in the work system design, we argue for the importance of considering the form of the simulation outcome. In this manner, not simply aim at identifying ergonomics conditions, but actually evaluate these. The ergonomics conditions of interest may vary according to the stage of the work system design process. The fidelity level should be high in relation to the elements that are of evaluation interest, and the affordance should support overview or configuration of these elements.

5.3 Influence of three contextual factors

This study argues that simulation media attributes influence the capability of supporting identification and evaluation of ergonomics conditions. Nevertheless, three contextual factors might also influence the identification and evaluation. The first contextual factor was the *scenarios*. The scenarios in the two cases were narratives of possible future work challenges and questions related to the work system represented by the simulation media. However, the two cases introduced the scenarios in different ways. In the first case, scenarios were continually developed during the simulation events by the healthcare professionals. In the second case, scenarios included a time factor and were defined beforehand by the simulation consultant and department managers. Existing studies show that scenarios stimulate the ideation in design (Carroll, 2000; Suri and Marsh, 2000). Thereby, the difference in the introduction of scenarios in the two cases of this study might have resulted in different stimulation of ideation, influencing the ergonomics identification and evaluation.

The second contextual factor was the *facilitation*. Both the cases had facilitators directing the progress of the simulation events. However, the facilitation style was different in each case. The facilitation in the first case was 'open' in the sense that the participants led the simulation event in an exploratory manner. In the facilitation in the second case was regulated by the progress of the predefined scenarios and disturbances. Existing studies on facilitation in simulation as an education method show a high importance of the facilitation style in relation to the participants' educational profit (Clapper, 2014). Drawing on this research, the facilitation style may well be important for the profit of simulation as participatory ergonomics design method. Thereby, the difference in facilitation style of the two cases might have influenced the potential for ergonomics identification and evaluation.

The third contextual factor was the *participants*. The two cases included different participants in the sense of having different personal skills, backgrounds and experiences. Some of the participants were the future work system users, where other participants were designers of the future work system. Existing studies show the difficulty in choosing the 'best' participants in participatory processes (Reuzeau, 2001), indicating that

different participants bring different perspectives to the process. In this way, the different participants of the simulation events might have brought different perspective on the ergonomics identification and evaluation.

5.4 Methodological limitations of the study

The study is based on two cases of naturally occurring (Potter, 2004) simulation events. This gave in-depth understanding into the influence of simulation media on ergonomics identification and evaluation of these eight events. This in-depth understanding is obtained within the boundaries of the two case studies, which in some degree limits the generalizability (Thomas, 2011). However, findings of common patterns between cases are argued to be strengthened when the cases vary in maximum degree (Flyvbjerg, 2006; Neergaard, 2010). Despite of the high variation between the type of conditions identified and evaluated, the comparative analysis actually showed a common pattern in how the fidelity and affordance influenced the identification and evaluation of ergonomics conditions. As verification, we have in addition compared the results of the two case studies with results of existing studies of full-scale mock-ups and table-top based models. The identified and evaluated conditions in the existing studies show to be consistent with our results. However, the connection between the media attributes and the conditions is not analyzed in the existing studies, as we aim for in this study. For further validation of this connection, we suggest research of other media such as virtual reality or small-scale mock-ups.

6. Concluding remarks

The aim of this study was to compare how the fidelity and affordance attributes of full-scale mock-ups and table-top models might influence the ability to identify and evaluate ergonomics conditions of future hospital work systems. This aim addressed the under-researched topic of the connection between simulation media attributes and the simulation outcome. Naturally occurring (Potter, 2004) simulation events in two Danish hospital building projects provided a unique opportunity for studying this connection from a case study perspective. The first case was based on full-scale mock-ups and the second case was based on table-top models.

Investigation of the two cases showed a difference between the identified and evaluated ergonomics conditions related to the future hospital work systems. The two types of media had a high level of fidelity in relation to different entities of the future work systems. Furthermore, the two media afforded actions in relation to different work system entities. In both cases, high fidelity and affordance of actions, relating to certain work system entities, appeared to support identification and evaluation of ergonomics conditions especially in relation to these entities. Existing studies of full-scale mock-ups and table-top based models showed identification of the same types of conditions. However, they did not analyze how media attributes influenced the identification. Neither did they address the importance of the form of the simulation outcome, in the sense of being identified challenges to taking into account when designing or being tangible design criteria developed from ergonomics evaluation. This study emphasized the importance of considering the form of the outcome, and how the media attributes influence the possibility of reaching that outcome.

6.1 Implications for practitioners

We suggest the following implications for practitioners:

- When choosing simulation media in the planning of participatory simulation activities, practitioners should consider the relation between the intended simulation outcome and the attributes of fidelity and affordance.

- One media cannot support identification and evaluation of all types of ergonomics conditions. Thereby, the media attributes should target the areas of the work system, which are intended to be evaluated.
- The choice of simulation media should correspond with the present phase of the design process, where different phases require different ergonomics contribution. E.g. the concept design phase of buildings might require input about organization of functions, whereas the project phase might require input about detailed room layout.

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Appendix A

(Insert Table A.1)

Table A.1: Results from the analysis of the two multiple case studies. (Two column table)

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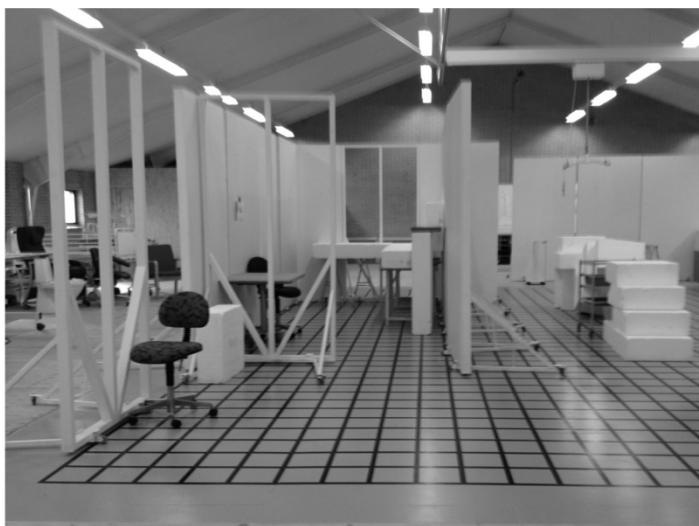


Figure 1

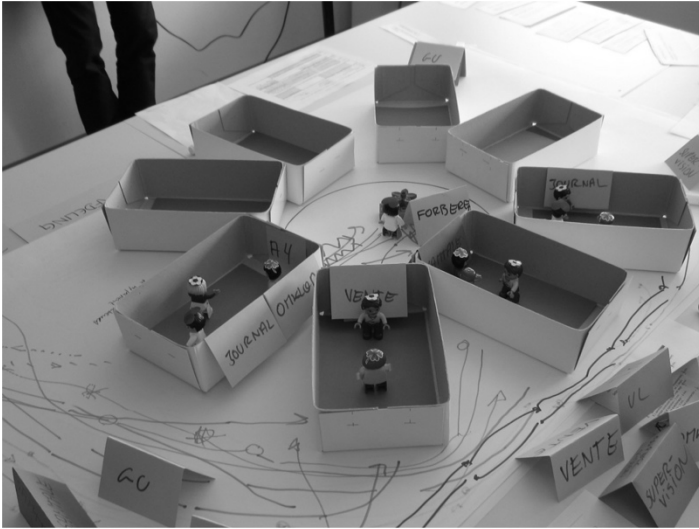


Figure 2

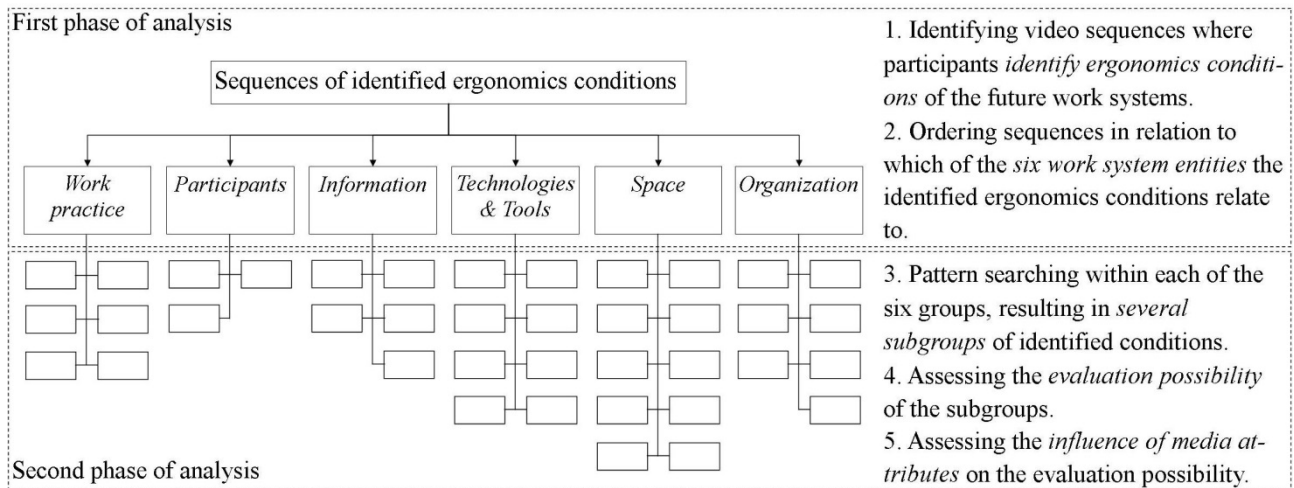


Figure 3

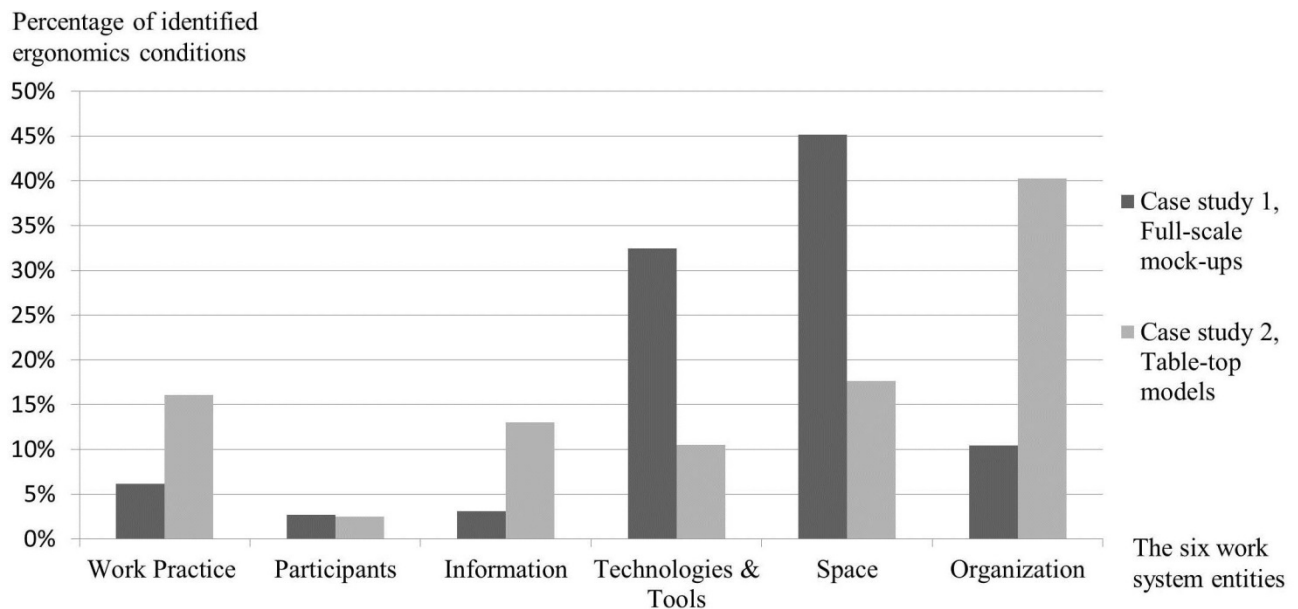


Figure 4

	Sim event 1	Sim event 2	Sim event 3	Sim event 4
Duration	1 hour	1 hour	1,5 hour	2 hours
Simulation medium	Full-scale mock-up of standard reception in bed ward.	Full-scale mock-up of standard examination room in outpatient department.	Full-scale mock-up of depot in standard bed ward.	Full-scale mock-up of standard bed paternoster lift and hallway.
Participants	<ul style="list-style-type: none"> - Three medical secretaries. - One executive medical secretary. - Three executive nurses from three areas of specialization. - One staff member from hospital management group. - One staff member from project division focusing on space documentation. - Two IT consultants. - Two center facilitators. 	<ul style="list-style-type: none"> - Three medical secretaries. - One executive medical secretary. - Three executive nurses from three areas of specialization. - One staff member from hospital management group. - One staff member from project division focusing on space documentation. - Two IT consultants. - Two center facilitators. 	<ul style="list-style-type: none"> - Three executive nurses from three areas of specialization. - One staff member from project division focusing on logistics. - One staff member from project division focusing on space documentation. - Two center facilitators. 	<ul style="list-style-type: none"> - One hospital orderly. - One employee from the hospital technical department. - Two staff members from project division focusing on logistics. - One consulting architect. - One project engineer. - Two technical consultants. - Two center facilitators.
Purpose	Exploring work tasks of logistical coordination within the layout of the reception and back-office area.	Exploring work tasks of patient examination within the layout of the examination room.	Exploring work tasks of aids handling and storage within the layout of the depot.	Exploring work tasks of bed handling within the layout of the bed paternoster and hallways.

Table 1: Key characteristics of the four simulation events of the first case study. (Two column table)

	Sim event 1	Sim event 2	Sim event 3	Sim event 4
Duration	1,5 hour	1,5 hour	2 hours	1,5 hour
Simulation medium	Table-top model of separate examination and conversation rooms.	Table-top model of one examination room per two conversation rooms.	Table-top model of multifunctional examination rooms and staff area.	Table-top model of multifunctional examination rooms and staff area.
Participants	<ul style="list-style-type: none"> - One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics. 	<ul style="list-style-type: none"> - One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics. 	<ul style="list-style-type: none"> - One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics. 	<ul style="list-style-type: none"> - One chief surgeon related to the outpatient department. - Three outpatient department nurses. - Two outpatient department physicians. - One OHS consultant from industry. - One construction consultant from industry. - One simulation consultants. - Three researchers in performance and ergonomics.
Purpose	Exploring work tasks of patient examination within the classic layout of the outpatient department.	Exploring work tasks of patient examination within layout based on a shared examination room per two conversation rooms.	Exploring work tasks of patient examination within layout based on multifunctional examination rooms.	Exploring work tasks of patient examination within layout based on multifunctional examination rooms.

Table 2: Key characteristics of the four simulation events of the second case study. (Two column table)

Media	Fidelity		Affordance	
	High	Low	High	Low
Full-scale mock-ups	Room layout and specific dimensions of rooms. Positions and dimensions of technologies and interior.	Sole manifestation of single rooms excluding representation of external functions and coordination.	Easy configuration of the movable walls by the participants. Thereby, supporting redesign of the room dimension and shape in full-scale.	No configuration of more than a few rooms, resulting in low possibility for testing collaboration and coordination between several rooms.
Table-top models	Detailed manifestation of the overall building layout, internal relations and coordination.	Black-boxing each of the rooms of the future work system into shoeboxes, not manifesting layout and the technologies within.	Easy room configuration, giving a helicopter view of the overall building layout. Thereby, providing overview of collaboration and communication between different professions.	No changing of room dimensions and shape, the shoeboxes had only one geometry, representing the future rooms.

Table 3: The fidelity and affordance of the two simulation media. (Two column table)

	Subgroups with high possibility for evaluation	Media attributes related to high evaluation possibility	Subgroups with low possibility for evaluation	Media attributes related to low evaluation possibility
Full-scale mock-ups				
<i>Technologies & tools</i>	<ul style="list-style-type: none"> -Execution of work is influenced by placement of technology within the room. -Execution of work is influenced by the dimensions of the tools and technologies. -Work posture is influenced by the tools and technologies. 	High fidelity of dimensions of technologies and tools. Affording bodily operation of technologies and tools.	<ul style="list-style-type: none"> -Efficiency of work is influenced by the number of tools per room. -Efficiency of work is influenced by the types of tools within the room. -Efficiency of work is influenced by supporting tools for logistics and distribution of labor. 	Low fidelity of technical systems and specific specialized instruments. Do not afford exploration of relations between several rooms.
<i>Space</i>	<ul style="list-style-type: none"> -Work practice is influenced by room shape. -Work practice is influenced by dimensions of interior. -Work posture and practice is influenced by room layout. -Area utilization is influenced by arrangement of interior. 	High fidelity of room dimensions and layout. Affording bodily exploration and configuration of interior and room shape.	<ul style="list-style-type: none"> -Quality of work is influenced by noise level. -Psychosocial conditions are influenced by the room layout. -Physical conditions are influenced by light inflow. -Room layout and functions are influenced by external rooms' shapes and functions. 	Low fidelity of material properties and light inflow. Do not afford exploration of a several rooms e.g. in a department.
<i>Organization</i>	-	-	<ul style="list-style-type: none"> -Division of labor influences the rooms' layout. -Organization of work tasks for obtaining efficiency. 	Low fidelity of the overall department layout. Do not afford exploration of relations between several rooms.
Table-top models				
<i>Technologies & tools</i>	<ul style="list-style-type: none"> -Technologies for managing the overall patient flow. -Existing system problems are decreasing the efficiency. 	High fidelity of the flows of patients and staff. Affording test and overview of several patient trajectories at the same time.	<ul style="list-style-type: none"> -The sufficient types of tools within the rooms influence the efficiency. -Technology functions supporting key work. -Team formation supporting tools for effective collaboration. 	Low fidelity of the content of specific rooms. Do not afford test of the specific tools within the rooms.
<i>Space</i>	<ul style="list-style-type: none"> -The building layout influences the organization. -Decreasing walking distances for the workers. -Placement of rooms in relation to each other. 	High fidelity of the overall department layout. Affording a helicopter view of the department and activities taking place.	<ul style="list-style-type: none"> -Interior layout supports work tasks. -Building shape influences the room shapes. -Numbers of each room type for covering the work tasks taking place. 	Low fidelity of the layout of individual rooms. Do not afford exploration of single rooms, due to rooms being 'black boxed' into cardboard boxes.
<i>Organization</i>	<ul style="list-style-type: none"> -Psychosocial conditions are influenced by work organization. -Organization of work is influenced by building layout. -Team formation is influenced by the organization and building layout. -Division of labor is a part of the work organization. -Work organization is influenced by effective coordination. 	High fidelity of the overall building layout and functions. Affording a helicopter view of the relations and coordination between functions. Easy configuration of rooms.	<ul style="list-style-type: none"> -Efficient organization is influenced by relation to external functions. -Efficiency of work is influenced by the organization of activities in advance. 	Low fidelity of relations to external functions outside the department. Do not afford exploration of tasks not predefined, such as the social relations in ongoing team formation.

Table 4: The evaluation possibility of the subgroups of the three dominating work system entities, and the influence of the media attributes. (Two column table)

	Full-scale mock-ups	Table-top models
<i>Technologies & tools</i>	<ul style="list-style-type: none"> - Movement of equipment/components (Hignett et al., 2010; Villeneuve et al., 2007) - Dimensions of equipment and furnishing (Hignett et al., 2010; Steinfeld, 2004) - Work posture (Hallbeck et al., 2010) - Operation task time (Paquet and Lin, 2003) - Usability of tools and products (Paquet and Lin, 2003; Watkins et al., 2008) - Furnishing and equipment (Peavey et al., 2012) 	<ul style="list-style-type: none"> - Communication technology (Ruohomäki, 2003)
<i>Space</i>	<ul style="list-style-type: none"> - Depths, heights and positions (Bligård et al., 2014; Hignett et al., 2010; Peavey et al., 2012; Steinfeld, 2004; Watkins et al., 2008) - Usability of workstations (Paquet and Lin, 2003) - Physical requirements (Paquet and Lin, 2003) - Room dimensions and layout (Peavey et al., 2012; Villeneuve et al., 2007) - Materials (Peavey et al., 2012) - Interior designs (Persson et al., 2014) - Space sizes and planning (Steinfeld, 2004; Watkins et al., 2008) 	<ul style="list-style-type: none"> - Plant layout (Daniellou et al., 2014; Riis, 1996) - Depths and relative heights (Bligård et al., 2014) - Spatial provision required (Ewenstein and Whyte, 2007)
<i>Organization</i>	<ul style="list-style-type: none"> - Distraction in work (Peavey et al., 2012) - Cognitive workload (Paquet and Lin, 2003) 	<ul style="list-style-type: none"> - Work activities (Ruohomäki, 2003) - Human interaction (Ruohomäki, 2003) - Division of work and production schedule (Forssén-Nyberg and Makamäki, 1998; Ruohomäki, 2003; Savolainen, 1997) - Communication and cooperation (Forssén-Nyberg and Makamäki, 1998; Riis, 1996; Ruohomäki, 2003) - Unnecessary repetition (Ruohomäki, 2003) - Team reactivity (Daniellou et al., 2014) - Resources that are allocated (Daniellou et al., 2014) - Interdependence between departments (Forssén-Nyberg and Makamäki, 1998; Riis, 1996)

Table 5: Identified ergonomics conditions of existing studies of full-scale mock-ups and table-top based simulation.
(Two column table)

Work system entities	Subcategories of identified ergonomics conditions: Conditions influencing the well-being and performance of the future work system.	Numbers of transcribed sequences					Possibility for evaluation by the simulation participants
		Case 1	Case 2	Case 3	Case 4	Total	
Case study 1: Full-scale mock-ups							
Work Practice	- The work practice today	2	0	0	2	16 (6%)	Low
	- The room restricts the work practice	0	0	0	2		Low
	- The room supports efficient work practices	0	1	6	3		High
Participants	- Worker which are not central participants influence as well	0	0	2	3	7 (3%)	Low
	- The key participants are the main users	1	0	0	1		High
Information	- Discrete information sharing is required	4	0	0	0	8 (3%)	Low
	- The right information has to go to the right people for increased efficiency	3	0	1	0		Low
Technologies & Tools	- Efficiency of work is influenced by the number of tools per room	0	5	4	4	84 (32%)	Low
	- Execution of work is influenced by placement of technology within the room	2	3	5	4		High
	- Execution of work is influenced by the dimensions of the tools and technologies	0	0	2	6		High
	- Efficiency of work is influenced by the types of tools within the room	1	11	7	0		Low
	- Work posture is influenced by the tools and technologies	12	1	6	5		High
	- Efficiency of work is influenced by supporting tools for logistics and distribution of labor	4	1	1	0		Low
Space	- Quality of work is influenced by noise level	3	0	0	3	117 (45%)	Low
	- Psychosocial conditions are influenced by the room layout	4	0	0	0		Low
	- Work practice is influenced by room shape	6	1	1	16		High
	- Physical conditions are influenced by light inflow	2	1	2	0		Low
	- Work practice is influenced by dimensions of interior	3	0	8	1		High
	- Room layout and functions are influenced by external rooms' shapes and functions	2	2	0	0		Low
	- Work posture and practice is influenced by room layout	2	2	12	10		High
	- Area utilization is influenced by arrangement of interior	7	11	18	0		High
Organization	- Division of labor influences the rooms' layout	13	0	0	3	27 (10%)	Low
	- Organization of work tasks for obtaining efficiency	0	6	1	4		Low
Total						259 (100%)	
Case study 2: Table-top models							
Work practice	- Utilization of spare time for key work practices	2	3	5	1	52 (16%)	Low
	- Work practice frequency influences the work system	2	1	0	0		Low
	- The work practice today	1	0	2	4		Low
	- The time needed for work tasks	9	2	2	1		Low
	- People have personal preferences to work tasks	2	1	0	6		Low
	- Disturbances of work practices is decreasing the efficiency	1	2	5	0		High
Participants	- Number of special participants needed for the optimal quality of work	1	0	1	0	8 (2%)	Low
	- Experience of the participants needed in certain situations	1	1	0	1		Low
	- Different participants have different authority	0	0	2	1		High
Information	- Room layout support of informal communication	0	1	5	1	42 (13%)	High
	- The basic information needed in the work	0	7	3	3		Low
	- Information needed in unintended situations	8	0	5	9		High
Technologies & Tools	- The sufficient types of tools within the rooms influence the efficiency	1	3	3	1	34 (11%)	Low
	- Technologies for managing the overall patient flow	0	3	0	1		High
	- Technology functions supporting key work	0	1	1	2		Low
	- Existing system problems are decreasing the efficiency	3	0	1	1		High
	- Team formation supporting tools for effective collaboration	6	2	1	4		Low

Space	- The building layout influences the organization	6	4	6	2	57 (18%)	High
	- Decreasing walking distances for the workers	2	3	2	2		High
	- Interior layout supports work tasks	2	3	4	0		Low
	- Building shape influences the room shapes	0	1	2	0		Low
	- Placement of rooms in relation to each other	5	1	3	1		High
	- Numbers of each room type for covering the work tasks taking place	2	2	4	0		Low
Organization	- Psychosocial conditions are influenced by work organization	0	5	10	5	130 (40%)	High
	- Efficient organization is influenced by relation to external functions	4	1	0	0		Low
	- Organization of work is influenced by building layout	3	16	11	4		High
	- Team formation is influenced by the organization and building layout.	8	7	6	0		High
	- Division of labor is a part of the work organization	9	3	8	9		High
	- Efficiency of work is influenced by the organization of activities in advance	2	3	2	1		Low
	- Work organization is influenced by effective coordination	5	4	1	3		High
Total						323 (100%)	

Table A.1: Results from the analysis of the two multiple case studies. (Two column table)