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Challenges for the Consideration of Ergonomics in Product Development in the Swedish Automotive Industry – An Interview Study

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Abstract
This paper presents an interview study aiming to understand the state of the art of how ergonomics designers work in the vehicle development process within the Swedish automotive industry. Ten ergonomic designers from seven different companies participated in the interview study. Results report the ergonomics designers' objectives, workflow, tools, challenges, and ideal work performance tool. We identify four main gaps and research directions that can enhance the current challenges: human behavior predictions, simulation tool usability, ergonomics evaluations, and integration between systems.

Keywords: vehicle, ergonomics, human-centred design, simulation-based design, digital human modelling

1. Introduction

Studying how a product will affect the potential end-user is essential in product development (PD). Such human-product interaction studies are typically done at relatively late stages of the design process, even though there are benefits to taking action regarding user-related aspects at earlier design process stages (Schröppel et al., 2021). Obstacles towards more proactive ergonomics measures are found to be lack of time, knowledge, methods and tools for consideration of ergonomic issues together with a lack of cooperation and communication between project stakeholders (Broberg, 1997; Falck and Rosenqvist, 2012). Ergonomics design methods and objectives can be applied in many different contexts or application areas, making the ergonomics designers' objectives, workflow, and tools to vary widely. This makes it difficult to identify the kinds of challenges ergonomics designers face and what tools or tool improvements might enhance their ability to meaningfully contribute to the design process at the early stages of PD. Ergonomics designers can use various tools to proactively assess ergonomics aspects at early stages of PD, including physical prototypes, user tests and interviews, and human-product interaction simulations using digital human modelling (DHM) tools. However, these tools and methods can have limitations such as being expensive, time-consuming, difficult to use, and subjective, making it hard to apply insights acquired to other aspects of the design process.

DHM tools are meant to support that product designs fit the users' requirements as soon as possible in the design process when the product exists only as a virtual model, reducing the need for physical prototypes and their corresponding development time and costs (Scataglini and Paul, 2019; Demirel, Ahmed and Duffy, 2021). DHM tools enable to test digital humans (a.k.a. manikins) interacting with a digital product model in a given digital environment, which help to assess and reduce unhealthy or uncomfortable conditions due to design features. Using DHM tools early in the design process is a form of proactive ergonomics assessment since it enables designers to run "what-if" scenarios in the early design phases (Demirel, Ahmed and Duffy, 2021). DHM tools are widely used in the automotive industry for occupant packaging. Occupant packaging consists of organizing space for people and parts of the vehicle to satisfy transport, a clear example of a human-centred design activity (Bhise, 2016). Ergonomics often develop significant constraints or requirements on vehicle design to fulfil the users' interaction needs. Understanding such human-vehicle interactions for developing new vehicles models early in development is crucial to the design process. While computer-aided design (CAD) tools are used to perform most design work, DHM tools are often set apart which creates a challenge to incorporate user aspects through proactive tools in the product development process (PDP). Needs from previous and current research projects motivated to conduct this study (MOSIM, 2018; SVE, 2020; ADOPTIVE, 2021). The development of virtual tools and the consideration of human-centred aspects in product and production development is an important research area for the Swedish industry's (Made in Sweden 2030, 2017). This study aims to understand the state of the art of how ergonomics is addressed in the vehicle development process within the Swedish automotive industry. Our aim is divided into several objectives: identifying ergonomics objectives, methods, tools, the "ideal" tool for the ergonomics designers' work, and identifying challenges for enhancing them. We anticipate that this insight can lead us to see the research gaps in the field and direct future research.

2. Methodology

2.1. Participants and data collection

Semi-structured interviews of active ergonomics designers were used to gain a deeper insight and address the research aim. Ten ergonomics designers from seven Swedish automotive companies participated in the interview study. All of the participants involved in the study are considered experts according to the criteria suggested in Littig (2009), with at least five years of experience and specialized knowledge in the specific domain of ergonomics PD/user-centred PD. Experts with different roles, experiences, and positions within their companies were enrolled in the interview study to gather different perspectives. While all the companies included in the study are from the automotive sector, they focus on different types of vehicles such as cars, trucks, buses, and construction vehicles. The size of the companies varies from 1,000 to 56,000 employees.

Semi-structured interviews, lasting between 60-75 minutes, were held online via a video meeting tool (Zoom). The interview topics were pre-determined and specified by an interview guide consisting of open and closed questions and follow-up questions. All the interviews were video and audio recorded for data analysis. The interviewer also took notes during the interviews to record additional information about the context, clarifications, and observations during the online meetings. The interview topics and purpose of the study were described to the participants, and they were given the opportunity to consent to participate in the study as per Swedish law and the Declaration of Helsinki. The interviews were conducted between May and June 2021.

2.2. Interview guideline

An interview guideline was developed to direct the interview conversation to discussions covering the research objectives and ensure consistency and comparability across interview sessions (Meuser and Nagel, 2009). The interview was divided into five phases. Phase one aimed to create a comfortable environment for the interviewees. The study's goal was explained to the participants, the consent form reviewed, and the interviewees introduced themselves. The second phase focused on understanding the main goals and objectives of the interviewees' position and their departments within the product development process (PDP). Phase three addressed the workflow or methodologies that ergonomics designers follow to achieve those goals and objectives. Phase four involved identifying all of the tools used by ergonomics designers in their work. Phase five consisted of imagining and describing an "ideal" tool to support their work. At the end of the interview, participants could give feedback, additional comments and ask questions.

2.3. Data analysis

The deductive procedure described by Mayring (2014) was followed for analyzing the qualitative content. This procedure consists of four steps: 1) data preparation; 2) definition and revision of categories; 3) data codification, and 4) interpretation of results. All the recorded material was transcribed for further analysis in the first step. Discussion categories were based on the research objectives and interview phases of the interview guide: Objectives, Workflow, Tools, Ideal tool, and Challenges (Mayring, 2014). Next, the transcribed interview content was coded, and the data were sorted into a table to compare information across participants and discussion phases. Following this, a horizontal analysis of the data made it easier to identify the patterns and reported challenges.

3. Results and interpretation

3.1. Objectives

When discussing their aims and objectives, most of the interviewees (n = 8) used the word "balance" to describe the purpose of their work. According to one interviewee, *"The ultimate goal or objective we have is to balance things instead of having the best one thing because if they are the best in one thing, they are bad in all the others and we have to find a balance between all of them"*. The data analysis of the interview results made it possible to identify and divide the different "things" they have to balance into internal and external balancing relationships. Internal balancing involves balancing among the various distinct ergonomics aspects affecting the end-user. External balancing involves balancing between ergonomics and the various non-ergonomic aspects in PD (safety, aesthetics, manufacturing, materials, etc.). The process of balancing involves identifying the specific limits of identified requirements as well as the relative ranking and/or weight of each requirement. Following the funnel concept developed by Clark and Wheelwright (1993), the PDP has three steps: Predevelopment, Development, and Production (Figure 1). As illustrated in Figure 1, ergonomics designers primarily perform internal balancing during the predevelopment phase and external balancing during the development phase.

Defining what counts as an appropriate balance (both internal and external) is critical for most designers. In most cases, designers adhere to a set of company-defined requirements or objectives to assess the success of internal and external balancing processes. The priority and definition of ergonomics requirements vary by company. Some focus on the study of physical and cognitive ergonomics by different groups, while others address physical and cognitive ergonomics by the same ergonomics group. In ergonomics, "*the requirements are closely connected to the experience of the customer and product user*." Visibility, driver sitting posture, roominess, comfort, life use, and ingress-egress are some examples of ergonomics aspects covered during internal balancing by the fulfilment of requirements. Regardless of the ergonomics aspect, requirements may include ergonomics standards as specified by regulatory bodies and/or internally defined ergonomics standards derived from internal company research and design history. Legislative bodies may also set ergonomics requirements (e.g., visibility or other safety standards). All of these requirements are assembled into a set of company-defined requirements. Thus, designers indicated that by accomplishing the company-defined requirements, legal and acceptable products are realized, ensuring no physical damage to users and a minimum standard for comfort and user experience for end-users.

Along with ergonomics requirements, non-ergonomics requirements are often defined and may cover many aspects of product design, including aesthetic, safety, production, and material standards. The requirements that apply to the design process can also vary depending on the PD area and level. For example, roominess and visibility are considered more heavily in assessing the balance in the predevelopment phase. In contrast, cost and manufacturing limitations are given more weight later in the development phase. Applying requirements to assess balance can be complex for certain ergonomics aspects, so some designers indicated that they report their results by "*describing consequences instead of certain decisions"* in ergonomics. Instead of focusing on how each requirement was met and balanced, they report the design consequences of fulfilling or not fulfilling the requirements.

3.2. Workflow

Figure 1 presents a typical ergonomics designers' workflow characterization based on the interviews. Such characterization and the terminology consist of an author's interpretation. However, interviewees validated it in a workshop session weeks later to the interview sessions. This workflow describes the steps of ergonomics designers through the different product design phases, where the most relevant steps are the internal and external balancing (Figure 1). Not all of these steps involve ergonomics designers. However, based on interview comments, ergonomics designers consider the decisions made at most of these steps to impact or constrain the ergonomics of the product. For example, when the PDP begins with the project or product definition, this work is typically done by the marketing team. The type of vehicle, intended use and users, and styling are likely to affect ergonomics requirements and decisions. However, ergonomics designers do not typically have a significant role in this step. They have a more prominent role in the following steps, though their role may vary depending on numerous factors.

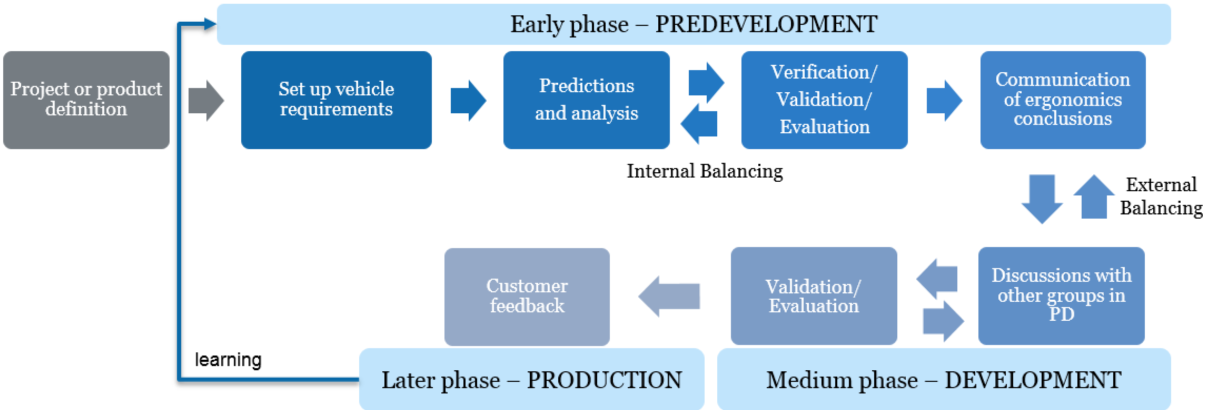

Figure 1. Ergonomics designers' work in the product development phases

Some projects aim to develop an entirely new product from scratch, though it is more common for a new product to be built on or modified by a previous or existing product. That means ergonomics designers would start directly in the external balancing at the development phase. This limits the ability of ergonomics designers to test new methods and explore novel designs. Instead, ergonomics designers often must work from existing designs and requirements, adapting and improving what is already there. Regardless of how novel a new product is, once defined in the first step of the development process, the ergonomics group sets and prioritizes the vehicle requirements accordingly. Once the ergonomics requirements are defined, ergonomics designers make predictions using simulation tools, previous studies, user testing, and analyses relating to the ergonomics aspects as a part of the internal balancing process. These predictions may be based on designs and models in progress and reference designs when the product is an update to an existing/previous product. As a part of this step, ergonomics designers ensure that ergonomics requirements, especially those with higher priority, are considered and ranked or weighted to achieve good ergonomics and user experience according to the vision defined by the product definition. This balancing process is accomplished iteratively by verifying, validating, and evaluating the consequences of various weightings and prioritizations of candidate requirements. Following the definitions from ISO standards (ISO 11064-7, 2006), verification involves testing and confirming that the product meets the defined requirements and may be done by simulation or user testing. Once verified, the ergonomics designers build prototypes and engage in user studies or make simulations to validate, which consist of confirming that meeting the requirements has the expected consequence or intended application (ISO 11064-7, 2006). Finally, the results of the verification and validation processes are evaluated to determine how well the requirements are met and how well meeting the requirements results in the expected user experience/ergonomics outcomes. Designs, simulation methods, and occasionally requirements are updated until evaluation indicates that a desirable ergonomics balance has been achieved. The ergonomics requirements results achieved during these processes are then communicated to the rest of the areas involved in the PD. Here in the medium phase,

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the development of the product starts. Ergonomics designers discuss and test different possible solutions until a balance between ergonomics and the rest of the PD areas is achieved. All these new possibilities are validated and evaluated again before the later phase of production starts. At this point, the work of ergonomics designers is considered finished. The final products are subjected to user tests, which provide input information for the ergonomics team to learn from for future projects (Figure 1).

The time to perform the entire PDP can vary from 3 to 10 years, depending on the type of vehicle and project definition. While changing or improving a specific feature of a product can be done quicker, developing a new product from scratch requires more time since many more requirements and ergonomics aspects need to be considered and tested. The time involved in identifying and balancing ergonomics requirements is affected by the length of the PD cycle and the size of the ergonomics design team. Interviewees reported a different number of people involved in the ergonomics groups, ranging from 3 to 19 persons. Typically, no single person on an ergonomics team is specialized in all the required tasks, and thus different individuals have different skills and areas of expertise in the process such as simulations, interviews, or user tests.

3.3. Tools

Table 1 indicates the types of design, development, analysis, and measurement tools mentioned in the interviews and the number of interviewees that indicated using each. In the interview context, a tool was presented as an instrument that can enhance the efficiency of a task (Martin, 1997). While this definition might lead to understanding technology or methods also as tools, they were included since interviewees reported them as instruments enhancing a task. These tools are used during the internal and external balancing to make predictions, analyses, and the corresponding validations.

Table 1. Used tools in the ergonomics product development

Tool	Common use descriptions	Freq.
Physical prototype	Physical prototypes allow the designers and users to interact with an idea or concept and test for ergonomic issues. Ergonomics designers also test the impact of product features on ergonomic aspects like roominess.	10
DHM tool	DHM tools simulate human product interactions in a virtual environment. Ergonomics designers test several ergonomic aspects (visibility, driver position, and reachability, among others) with manikins of different anthropometry.	10
Virtual Reality	Virtual reality uses computer technology to create an immersive simulated environment. Ergonomics designers test different ergonomic aspects of the vehicle cabin, mainly visibility, roominess, and user behaviour in different environments.	7
CAD software	CAD software is a technology for the design and technical documentation of 2D and 3D physical components. They are used for studying clearance considering the interior vehicle geometries. Rendering techniques are also used for the study of light reflections (visibility).	6
Camera	Cameras capture visual images. They are used for study documentation.	5
Motion capture	Motion capture consists of recording the movement of people or objects. It is used for studying specific tasks like the ingress-egress of vehicles.	4
3D Scanner	3D scanners measure the 3D surface shape of physical objects. They are used to capture the eye point position, body posture, and size to make validations. They are also used for comparisons of competitor products.	3
Driving simulator	Driving simulators allow creating a driving experience by placing the drivers in virtual environments with a physical control interface. They are used to analyze ergonomic aspects and driving behaviours in different vehicle models scenarios.	3
User tests	User testing of actual products provides the evaluation of developed products. Interviews, statistical analysis, and correlations are some of the methods used.	3
Vehicle Compliance	Complimentary CAD software for automotive compliance design. Ergonomics designers use it to ensure visibility standards.	2
Image-editing software	Editing and manipulation software helps ergonomics designers with user behaviour analysis (cognitive aspects).	1

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3.4. Ideal tool

The interview ended with a focus on identifying key features of an ideal tool for ergonomics designers. All the interviewees indicated that such a tool should be easy to use and flexible across various human anthropometries. Some visualized an improved DHM tool as the ideal tool, while others preferred a tool overlapping the digital and physical world to allow for user tests with physical prototypes. Interviewees who indicated that their ideal tool would be a DHM application agreed that such a tool would need improved usability, more accurate predictions, and additional functions relative to existing DHM tools. Suggested additional features included predictions of forces and seamless integration with motion capture and virtual reality (VR). Interviewees who indicated a preference for a combined digital-physical tool described a tool capable of combining basic physical prototypes with more detailed digital models, named VR or augmented reality (AR) tool as an example. This would allow for changing various details of the digital representation while maintaining some physical interactions. Such a setup would also allow for more flexibility in user testing different design concepts and environments.

Beyond the ideal tool's form (hardware/software), most interviewees indicated that a good integration between systems (motion capture - DHM - VR/AR) would be important. The interviewees agreed that the ideal tool would allow them to study and analyze a candidate user's entire movement or activity sequence with different measurement and simulation methods. The same visualization and analysis tool could be used for both simulation and direct measurement. This would also allow for direct comparisons between simulated and real data. Thus, they could import motion capture recordings from VR or real user-product interaction into the imagined DHM tool and see the recorded motion applied to different anthropometries and body shapes. In essence, interviewees expect from such a DHM tool more reliable testing and analysis of different ergonomic aspects while considering human physical diversity. Relatedly, interviewees also suggested integrating the ergonomics tool with VR to immerse people from other departments in the product under development to help them see and experience the ergonomics insights first hand. Having ergonomics evaluation methods is another feature suggested by some for the ideal tool. Ergonomics evaluations would rate how good or bad different ergonomic aspects are for the end-users, decreasing the need for validating predictions based on simulations and accelerating the design iterations. Lastly, some of the participants also mentioned the ability to consider cognitive aspects in the process. Some of the interviewees indicated that cognitive aspects of users likely have a large impact on physical product interactions. As such, they believe that the ability to consider cognitive aspects in the ideal tool could contribute to a more proactive and holistic ergonomics design process.

3.5. Challenges

The ergonomics designers were also asked about the different issues or challenges they face during the PDP within the Swedish automotive industry. The indicated challenges are categorized and described in Table 2, along with the number of interviewees identifying each challenge. The reported challenges could be divided into interdepartmental communication issues and tool development issues. Both groups affect the workflow of PD.

4. Discussion

4.1. Ergonomics in product development

With this interview study, we aimed to understand the state of the art of the Swedish automotive industry when considering ergonomics within the PDP. Several interviewees described a workflow that is similar to the design process proposed by Cross (2021). Cross' four-stage model, consisting of the main activities: exploration, generation, evaluation, and communication, can be interpreted in the context of ergonomics design. During exploration, ergonomics designers seek to understand the project definitions and define and balance requirements. Generation includes producing proposals for solving and fulfilling the product requirements. Ergonomics designers feed into this stage by producing, evaluating predictions of ergonomics requirements and balancing them as applied in simulations or results from user tests. Evaluation includes verifying and validating the predictions and evaluating results relative to the project definitions and previously selected internal balances. Finally, communication involves both

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Table 2. Identified challenges in ergonomics product development

	Challenge	Description	Freq.
Tool development issues	DHM tool gaps	Inaccurate predictions of human posture require the need of validations.	10
		DHM tools usability, they are not easy to use, time-consuming.	10
		Limited measures of human posture and environment interactions.	3
	Evaluation methods	Lack of driver ergonomics evaluation methods.	4
	Need of ergonomics knowledge	CAD and design knowledge and skills are insufficient. Knowledge and experience in ergonomics are needed as well.	3
	Willingness for simulation work	Difficult to find the people willing to do the simulation work due to the usability of these tools and reliability.	2
	Tools providing objective data	Ergonomics requirements can depend on subjective assessment by ergonomics designers. Objective methods are needed.	1
	Workflow steps - consuming iterations	Ergonomics designers have to validate all the predictions from either simulations or user tests information, which can be time-consuming and slow the process down.	1
Communication issues	Difficulty reporting ergonomics conclusions	Ergonomics designers often struggle to report and explain the ergonomic issues to other departments. They have to communicate these issues easily enough for a non-ergonomics expert without losing key insights that come with specialized knowledge.	10
	Ergonomics consideration early in the PDP	There is a need to consider human aspects early in the projects to give feedback to the rest of the PD areas. However, ergonomics designers may be involved later in the process.	3
	Planning vs. flexibility	The ergonomics group needs to plan activities but keep flexibility. Planning always changes. It is difficult to find a balance.	3
	Interdepartmental communication	Misunderstandings between departments about the project or product definition in the predevelopment phase can lead to mismatched ergonomics requirements.	2

reporting and discussing ergonomics issues to other PD areas. While several studies indicate a lack of design method's applied in engineering design practice (Vredenburg et al., 2002; Birkhofer, Jänsch and Kloberdanz, 2005; Geis et al., 2008; Eisenmann and Matthiesen, 2020), within the companies represented by the interviews, there seemed to be some adherence to company defined design methodologies for ergonomics PD which map onto more traditional academic PDP models.

While ergonomics designers' work and workflow are built on general product design methodologies, interviewees highlighted the differences in considering and studying ergonomics in PD and production. In PD, the study of ergonomics relies a lot on subjective predictions and interpretations of user-product interaction. In the context of vehicle design, the subjectivity is due, in part, to a lack of established evaluations methods for vehicle ergonomics. In contrast, in production ergonomics, the assessment of physical workload is typically defined by established ergonomics evaluation methods. One interviewee explained, *"we understand more the cognitive capacities that assembly line workers can do in labour, whereas I would say here* [in PD] *we are not as worried about how frequent they are doing things in a vehicle, it is more about finding comfort."* As described by one of the interviewees, *"ergonomics in PD is softer, it is more luxury,"* it is about improving human-product interactions focusing on comfort and user experience. These comments imply that ergonomics evaluation methods are not independent of the general design context and that currently, most objective ergonomics evaluation methods are designed for production design.

Identifying objective ergonomics assessments for product design may be complicated because companies, at least those involved in the study, had very different approaches to ergonomics in PD. One notable distinction is that some of them consider both physical and cognitive aspects together, whereas others separate these ergonomics domains. This kind of division can, for example, change the definition of the term comfort between companies and even across ergonomics design groups within companies. While ergonomics designers focusing on physical aspects may define comfort in terms of biomechanical

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loads, those combining cognitive and physical ergonomics considerations may further define comfort according to the feeling of safety experienced by the end-user.

4.2. Main gaps as improvement opportunities

Based on the interviews, we identify four gaps or research directions for improving ergonomics designers' work based on the reported challenges and desired ideal tool, focusing on DHM tools.

4.2.1. Human behaviour predictions

The lack of realistic and accurate human predictions in DHM simulation tools leads to time-consuming validation during PD. This makes ergonomics designers rely on their own experience for predictions and simulations, which introduces an unspecified level of subjectivity and bias into the results. Sometimes ergonomics designers manually specify postures that may provide the insights needed but are difficult to reproduce. In other cases, designers specify many postures (as a way of simulating a movement sequence), and then DHM tools can predict manikin transitions between these postures, often based on some definitions of ergonomics optimization (Zhu, Fan and Zhang, 2019). Both of these processes can be difficult, time-consuming, and subjective. Often these predictions are "good enough" but do not necessarily reflect actual human movements (Lämkull and Zdrodowski, 2020; Demirel, Ahmed, and Duffy, 2021). More reliable human product interaction predictions would accelerate the consideration of ergonomics in the PDP, resulting in better user experiences and helpful input for other departments, such as vehicle safety. Human product interaction predictions, including driving postures, may be improved by improving current posture prediction methods or identifying new posture prediction methods within DHM tools.

4.2.2. Simulation tool's usability

While DHM tools can provide critical human factors insights into PD, they have limited usability. According to various studies, some DHM tools in engineering design may be unstandardized, complicated to use, not trustworthy, or time demanding systems for the development of the study of human interactions (Ranger, Vezeau and Lortie, 2018; Lämkull and Zdrodowski, 2020). Interviewees involved in this study echoed these earlier findings and stated that current simulation tools are time-intensive, requiring ergonomics designers to spend considerable time using them. The time-intensity of these tools reduces the willingness of others outside and inside of ergonomics design groups to learn the tools. This can hinder the development of cross-departmental communication channels based on existing DHM tools. Improving the usability of DHM tools would likely make them more accessible for proactive ergonomics assessment and correspondingly increase the number of DHM tool users within companies (Högberg, 2009). This could, in turn, reduce the time it takes to perform both internal and external balance processes.

4.2.3. Ergonomics evaluation methods

As mentioned above, ergonomics evaluations methods typically assess ergonomics in production development or running production. However, there is a lack of corresponding objective methods within vehicle development, and evaluation relies on internal validations based on each company's internal user testing and simulations. These simulations provide company-specific and often subjective visualization and measurements of user-product interactions. New methods and improvements to existing methods for objectively evaluating different vehicle ergonomics aspects (driving sitting posture, comfort, reachability, among others) would accelerate the ergonomics designers' work by reducing the time spent on validations and increasing the quality (e.g., in the form of increased reliability and validity) of the evaluations performed as well. Once new or improved objective methods are available, integrating these methods within DHM tools would assist ergonomics designers in finding successful design solutions at stages of the design process where the vehicle is only available as a CAD model. Such functionality would further make it easier to report ergonomic issues to other actors within PD by having the ergonomics evaluation methods to clarify the degree to which a specific system or component design does not fulfil ergonomic requirements. Further, objective methods in simulations would make it easier

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and quicker to compare potential changes, both during a specific product design process and across design processes.

4.2.4. Integration between tools

The integration between tools such as motion capture, DHM, and VR/AR, was commonly mentioned as a feature in an ideal tool. Studying the same case of user-product interaction across different design tools would improve studies and analysis performance, especially relating to communication of ergonomic issues to other departments in PD. *"The best communication is to have each person that's involved in the project experience the ergonomic issue."* That could be done by deploying simulated cases within the virtual world (e.g., using VR). In addition, importing motion capture data into DHM tools would be another way of improving human behaviour predictions and representations by building on behaviours recorded during actual user interactions with previous models or physical mock-ups. Motion capture data may provide data for building up knowledge about human behaviour. The main limitation of motion capture is the lack of integration with CAD software, high costs for high accuracy systems, and inflexibility for setting up the systems in the user or the use context (Demirel, Ahmed and Duffy, 2021). So future development in this area may be particularly valuable for supporting the PDP.

4.3. Possible limitations and future follow up

The data generation and analysis were done by a sole author, which might involve bias in the study to some extent. However, the preliminary results were discussed during a workshop with most interviewees and other researchers for validation. In order to avoid influence in the interviewees' answers, the questions were formulated as open as possible. Still, there might have been some differences in how the interviewees define different concepts, such as verification and validation. Further discussions will continue in future research project workshops when aspects such as how to handle unfulfilled requirements and long term strategies to incrementally change the design could be covered.

5. Conclusion

Results from the interview study with ten ergonomics designers show that balancing between ergonomic aspects and with other product development aspects of the product design process are their primary objectives. In addition, the involved companies follow design methods when addressing ergonomics in PD. The most reported tools were physical prototypes, VR, and DHM tools for analyzing ergonomics aspects in the vehicle development. The reported challenges are divided into interdepartmental communication issues and tool development issues, both affecting the workflow of ergonomics designers in PD. Lastly, we identify four main gaps and research directions that can enhance the current challenges that ergonomics designers face: human behaviour predictions, simulation tool usability, ergonomics evaluations, and integration between systems. While addressing these challenges is no small task, we hope that understanding what challenges active ergonomics designers face can shape and direct future research and development of DHM and other design tools to support the development of more ergonomic design effectively.

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