IETI Transactions on Engineering Research and Practice
http://ieti.net/TERP/

2023, Volume 7, Issue 1, 1-10, DOI 10.6723/TERP.202303_7(1).0001

AN OVERVIEW OF THE ROLE OF ERGONOMICS AND ERGONOMISTS IN CONSUMER PRODUCTS DESIGN

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Abstract Many companies around the world that develop different types of products still do not apply ergonomics at all during this process, or apply it on an intuitive basis. Very few companies are aware of the importance of engaging ergonomists in the design team, as well as the benefits that can be achieved on that basis. With this in mind, this paper aims to point out the role of ergonomics and ergonomists in the design of consumer products. A novel model that refers to the phases of designing a product has been presented, for the purpose of showing how and when ergonomics can be applied during the design process. For each phase, examples have also been given. In addition, the paper identifies potential reasons that have influenced the current situation referring to the insufficient application of ergonomics in the designing of consumer products. This paper could serve as a guide for the implementation of ergonomics and engagement of ergonomists in the process of product designing.

Keywords: Ergonomics; ergonomists; product designing model; design; consumer products.

1. INTRODUCTION

There are still a lot of companies around the world that do not apply ergonomics at all during the product development process, or apply it only intuitively. A very small number of companies understand the importance of including ergonomists in their design teams, and the benefits that can be obtained by doing so. So, it is obvious that there is a lack of publicly available knowledge, which will explicitly show how and when ergonomics can be applied in the consumer products design. For that purpose, this paper will present a concise overview on the topic of how ergonomics can be applied during the design of consumer products.

2. A GLOBAL VIEW AT THE ROLE OF ERGONOMICS IN CONSUMER PRODUCT DESIGN

At the beginning, it is necessary to consider the role of ergonomics in product design on a global level. To this end, we will start from the definition of ergonomics. Zunjic (2017) gives the following definition of ergonomics: "Ergonomics is a multidisciplinary science whose goal is to examine the impact of means of work, conditions of work, processes of work, and products as results of work on humans from the psychological, physiological, anatomical, biomechanical, sociological, organizational and physics aspect by applying the quantitative and qualitative research methods, as well as to adapt the design of the aforementioned elements to humans, with the aim of improving

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comfort, safety, efficiency and satisfaction, which are considered during their interaction with humans" [1].

The relationship between ergonomics and products can be seen from the previous definition. In this regard, it can be noted that one of the most important tasks of ergonomics is to adapt product design to people, in order to improve comfort, efficiency and satisfaction while using the product, taking into account the safe handling of the product. So, in relation to the design of consumer products, ergonomics has the following main goals:

- designing a consumer product from the aspect of comfort while using
- designing a consumer product from the aspect of ease and efficiency of its use
- designing a consumer product from the aspect of safe handling of the product
- designing a consumer product from the aspect of satisfaction due to its use.

Generally speaking, if we consider comfort, then the consumer product from the ergonomic aspect should be designed so that it is adapted to a human with its shape, dimensions, texture, color, etc. In addition, from an ergonomic point of view, a comfortably designed consumer product implies that it does not cause physical, mental, or sensory load or overload of users. The ease and efficiency of use from an ergonomic point of view imply such a consumer product solution that requires minimal time to train users for use, as well as the quick realization of a particular task or the fulfillment of a set goal based on the use of the product. A safe design solution of a consumer product implies the creation of such a solution that will not endanger the safety of the user when using the product, ie which will not lead to injury to the user or damage to his health in any way. Designing warning signs from an ergonomic aspect, related to the use of the product is also a factor to consider. By optimal fitting of aesthetic and ergonomic characteristics of the design solution it can be achieved customer satisfaction. It can be further improved by creating hedonistic design solutions. All the aforementioned ergonomic components of the design solution are often conditioned by each other. When designing, it is always necessary to consider how changing one aspect of the design solution affects the ergonomic aspect of the design solution (for example, whether changing the aesthetic component affects the health and safety of users [2]).

3. APPLICATION OF ERGONOMICS IN DIFFERENT PHASES OF PRODUCT DESIGNING

Consumer product designing is often a complex process, which takes place by certain phases. Since a large number of scientific disciplines are involved in product designing (mechanical design, industrial design, ...), the identified stages of product designing may differ, depending on the point of view that prevails within a particular scientific discipline. Some authors may also have more or less different views on the stages in product design. For example, Mital et al. [3] listed the following stages in product design: initial design, finalized design, models and prototyping, testing models and prototypes, and quality testing. According to Howards et al. [4], four basic phases of the design process can be distinguished - the analysis phase, the generation phase, the evaluation phase, and the communication/implementation phase. However, it often happens that these are terminological and not essential differences when stating the stages of product development. In addition, individual phases per one model may include multiple phases of some other product designing model.

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This paper does not aim to go deeper into the issue of differences between individual phases that are present in one or another model of product development. This paper will present a novel product development model, based on the phases applied to the development of a complex system [5]. This model, which is presented in Figure 1, aims to indicate in a concise form how and when the ergonomic approach to consumer product designing is applied at certain stages of product designing. Although the model presented in Figure 1 can primarily be used to develop a complex, multi-component product, it can also be used to develop simpler consumer products. However, in this case, some of the phases listed may not be necessary. In any case, for each individual consumer product, a detailed analysis should be previously performed, on the basis of which it would be determined whether any of these phases need to be omitted.

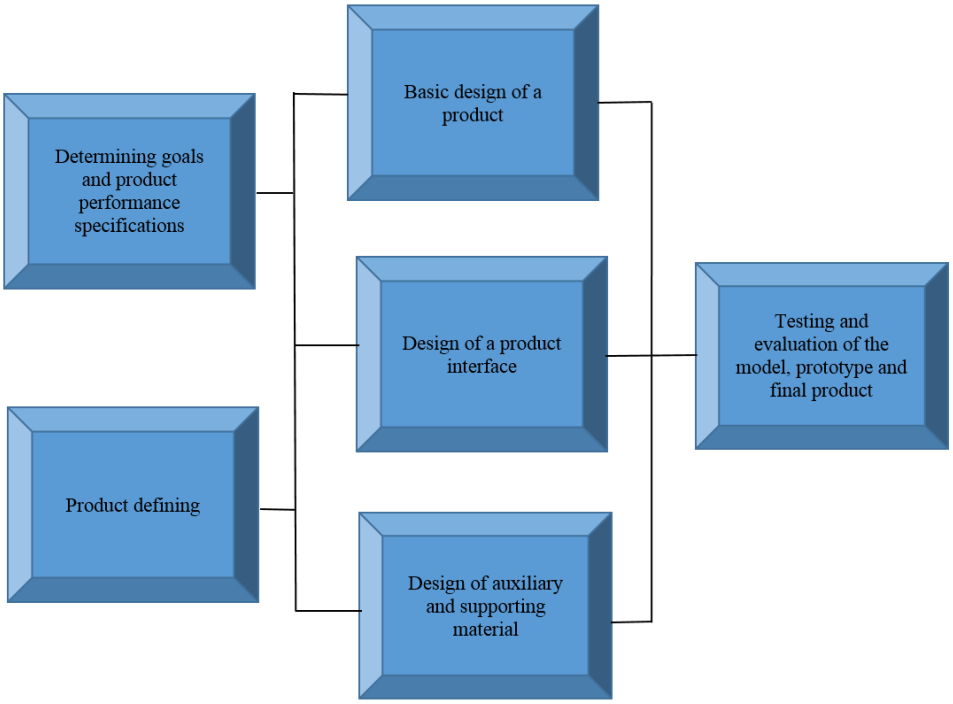

Figure 1. Model of product designing phases.

Although Figure 1 shows the designing process in a clearly structured way, in practice the designing phases often overlap and run in an iterative way. It happens that decisions made in the later stages of the design process represent a modification of decisions made in one of the previous stages of consumer product designing. The next sections will demonstrate how ergonomics contributes to the design of consumer products at each individual phase of the design process. The role of ergonomists during this process will also be considered.

Phase 1 - determining goals and product performance specifications

Before the product is defined in detail, it is necessary to establish the goal of its existence. For example, the goal of a product might be to establish a virtual communication network based on the use of a holographic display between mutually distant work units. Also, it is of essential importance to incorporate ergonomic goals, such as comfort while using a product, ease and efficiency of use of a

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product, safe handling of a product and the health of users, satisfaction produced by a product's use, error prevention, etc., as part of the overall goals of a product.

The specified goals then need to be transferred to the specifications concerning product performance. The performance specification refers to what the product needs to meet in order to achieve the set goal. Generally speaking, for example, a performance specification could be connecting up to 1000 work units, providing support when transferring certain types of confidential information, determining the context in which the product will work, determining optimal and unacceptable environmental conditions in which the product can be used, etc.

Ergonomic specifications for product performance also need to be taken into account in this initial phase of designing. For example, in the case of the development of a new hand tool, ergonomic specifications concerning product performance could include the applicability of use for both right and left-handed users, acceptable contact pressure level on hand, trigger force for the activation of the tool, the allowable temperature of the tool during the operation, etc.

Four basic ergonomic activities related to this design phase can be identified. The first is identifying potential users of the product. The second one is identifying all user needs related to the activities they need to perform with the product. Identification of user needs is usually provided through observations, interviews and questionnaires. The needs of users here primarily relate to the requirements in the context of the realization of the task or goal that the product should meet when using it, as well as those needs that are related to optimizing user interaction with the product. As a third activity, taking into account relevant user needs, ergonomists in this phase should participate in forming the final list of goals that should be met by a product. They should strive that basic ergonomic goals should be included. The fourth ergonomic activity in this phase refers to participation in the formation of the overall product performance specification. Here ergonomists should include ergonomic requirements for product performance in a product's list of general specifications.

Phase 2 - product defining

The main activity during the second phase of product designing is to define in detail all the functions that the product needs to perform, in order to meet the set goals and be in accordance with the established performance specification. To support the conceptualization of product functions, a function flow diagram is often developed. The function flow diagram can be considered as a human factor "test and tryout" tool prior to interaction with engineering specialists from other departments [6]. This diagram describes the interrelationships between individual product functions. It is basically represented by squares in which individual functions are written and by arrows that indicate the connection between these functions. Additional function flow diagrams are often made to analyze the subfunctions necessary to execute each function identified in the higher-level diagram. In the case of the development of a virtual holographic projector, some of the basic functions may be the ability to manipulate the size of the holographic display, the ability to zoom in or out of the holographic display, the ability to store holographic display, the ability to control the projector by voice commands or movement, etc.

Ergonomists at this stage should ensure that the identified functions meet the real needs and capabilities of potential users. Some of the functions of the product may not be necessary for the

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users, so investing in their realization would be a missed investment. In order to achieve ergonomic goals, it is important to decide which functions should be included. Ergonomists should be involved in the creation of a list of all functions that are foreseen that a product should have. They need to evaluate every function from the viewpoint of ergonomics and to assess whether any of the functions can be contrary to ergonomic goals. For example, certain modern designs of shoes (aesthetic function) can not fulfill certain criteria of comfort (ergonomic function of a shoe). Ergonomists also should conduct an analysis of whether every of the product functions can cause sensory, mental, or physical stress that is not in accordance with ergonomic recommendations and regulations. For example, in the case of a holographic projector, whether the 3D object display function requires the wearing of special glasses or devices that can cause a sensory load, which may endanger the health or safety of the user after a certain period. Besides, ergonomists in this phase also should specify functions of a product that are necessary for achieving ergonomic goals and specifications. For example, the option of adequate zooming in order to achieve the optimal visibility of an object that is observed from a distance by an optical instrument. In addition, ergonomists need to gather more detailed information regarding the characteristics, abilities and limitations of potential users, which will be used in the next designing phase.

Phase 3 - basic design of a product

At this stage of development, the product begins to take its basic shape. The basic ergonomic activities in this phase are: allocation of functions in relation to the user, hardware or software of the product, specifying the requirements for human performance, analysis of tasks and elaboration of modalities of the use of the product. It is a rare case that the listed four activities are performed only once. They are usually iterative in nature and are performed in accordance with the needs, as the design solution of the product progresses. These activities are described below.

In phase 2, all the functions that the product needs to perform have been specified. Now, the focus is on the subject which will perform these functions. The allocation of the functions is in some cases of optional character, which means that it is left a possibility of optional determination whether a function will be performed by the user or the product itself at a given moment. In adaptive function allocation [7], tasks are dynamically assigned between humans and products rather than being statically assigned. The allocation of functions to a user or product is the result of a consideration of superiority in the performance of a function by a human being on the one hand, or a product on the other. When it comes to experienced users, they are likely to choose to perform many functions by themselves, such as, for example, adjusting the aperture and exposure length when using the camera. However, users who do not have enough experience will probably expect the product itself to perform a certain function for them, such as automatically adjusting the brightness of the image according to the brightness of the environment being photographed.

Function allocation, from the ergonomics aspect, is an analysis based on which it is determined whether a function will be accomplished by a person, product (hardware or software), or some combination of the two. For this purpose, an ergonomist reviews error rates, fatigue, hazards, technological feasibility, human values, ethical issues, and the motivation of people. The solution regarding the allocation of functions may also result from the conducted consideration of the economic justification of the proposed options. There is a general set of ergonomic recommendations that talk about which functions a human is superior for, and when a product (device, machine) has an advantage. In terms of quality characteristics, reliability is a very important factor to consider when

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dealing with complex products [8]. Generally speaking, the more complex the product, the less reliable it is. For that reason, it is important to envisage the possibility of taking control of the product by a human in case of failure or disintegration, as is the case, for example, with modern aircraft for personal use.

The futuristic system of allocating functions (which is becoming more and more a reality) could take place automatically, in the way where the control unit of the product could itself recognize when the user is overloaded, sleepy or underloaded, and in accordance with that to allocate to the user the control over the functioning of the product, or switch it to the product itself (such as in the case of a driver drowsiness detection system in a passenger car). With the above in mind, it is up to the ergonomists to make an expert decision on the allocation of functions, covering the aforementioned aspects.

Once the ergonomists included in the design team have completed the identification of the functions to be performed by the user related to the use of the product, the next step is to specify the human performance requirements required to perform those functions. Such items as the level of intelligence, speed, power, the time needed to achieve safe and efficient use of the product, customer satisfaction and the like should be specified.

The general procedure for the task analysis consists in making a list of all the tasks that need to be performed, in order to satisfactorily achieve all the functions performed by the user when interacting with the product. Each task is further broken down into the steps necessary to complete each task individually. Each step is then analyzed to determine details such as: the stimulus that initiates the step, the decisions that a person needs to make to successfully complete the step, the necessary actions during the step, the information necessary to implement the step, feedback after the completion of a step, potential sources of error or stress, as well as establishing criteria for evaluating performance. A procedure that can help ergonomists to conduct task analysis can be found in [9]. In addition to the above, ergonomists should determine critical tasks, perform an assessment of the difficulty of execution, assess the necessary knowledge and skills for the intended operation of the user, as well as the time required for his/her training to use the product.

Conducting the described analysis is essential, in order to ensure that the product is operational and suitable for maintenance, ie efficient and safe to use. Task analysis is the starting point for designing the human-product interface, writing instructions for use, determining personal requirements, developing training programs, ie for completing the design solution and product evaluation.

Elaboration of modalities and anticipation of options regarding product use is extremely important for product design, because the intended use of the product will determine which design solutions will be built into the final product solution. This consideration is also important from the aspect of safety, because it is not enough just to predict how the user will use the product, but it is necessary to anticipate the possibility of misuse of the product, or its use in an inappropriate way. Ergonomists should perform an analysis of the potential misuse of a product and introduce the designers' team to the notion of product liability. Foreseeability of misuse and abnormal use of products was considered in detail in [10]. In such situations, it is necessary to provide safe design solutions that will reduce the likelihood of unsafe use of the product, or completely eliminate such a possibility. For this purpose, approaches such as exclusion design (which practically prevents the user from using the product inappropriately), prevention design (which makes inadequate use of the product difficult but does not

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completely exclude it) and fail-safe design (which provides for the activation of additional mechanisms to prevent damage in the event of inadequate use of the product). As part of this activity, the ergonomic design of warning signs and text warnings related to the use of the product is carried out.

Phase 4 - design of a product interface

The interface represents those parts of the product with which the user interacts when using the product. This term is most often related to the parts of the product that are used to manage, ie control the operation or condition of the product. It is understandable that simpler products have simpler user interfaces. However, with more complex products, such as a passenger car or a personal plane, the interface elements can be numerous and complex. If inappropriate design solutions are made in relation to the user at this stage, he will be permanently exposed to additional stress and discomfort, while the performance of using the product may also be reduced.

Ergonomists usually work closely with designers on the same team at this stage to design the interface. Ergonomists at this stage suggest various alternative design solutions that are in line with the possibilities and limitations of people. In addition, they assess the implications for people's performance when the design solution is proposed by experts from other scientific and engineering fields. Ergonomic design solutions are usually not given in the form of a detailed project, but usually contain a set of certain specifications. For example, ergonomists suggest the area in which the control should be placed, specify its dimensions, suggest the shape and determine the force required for activation, while it is up to the constructor to accomplish and implement such a solution. During interface design, ergonomists perform four primary design activities: obtaining and interpreting human factors and human performance data, forming interface design proposals for a product, conducting an attributive evaluation of proposed design solutions, and conducting a detailed user performance study for a selected product interface solution.

From the standpoint of human – product interaction, every part of the product with which a user can be in contact requires ergonomics attention. For example, if a user can touch any part of the product, this requires ergonomics designing and assessment. Examples are cockpits of cars, planes, and other transportation means. Considering that in cockpits and cabins a driver or passenger can be in a contact with any element of the physical space, cockpits and cabins need to be designed from an ergonomic viewpoint. One of the big issues that could arise in this phase of product designing is the relationship between ergonomics, safety and aesthetics [2]. In today's world, aesthetics is often overemphasized, resulting in poor ergonomic design of the interface. To avoid such a situation, it is recommended that an interface element should be designed first from the ergonomics standpoint, and then it can be shaped aesthetically, without losing ergonomic characteristics.

Phase 5 - design of auxiliary and supporting material

In this design phase, attention is focused on the planning of supporting and supplementary material that will provide support for achieving the planned performance related to the use of the product. Instructions for installing, assembling, and maintaining products, as well as accessories, programs, and training tools are included. Almost all complex products require some training and documentation to help users of a product. An example of documentation that contains guidelines for product handling are instructions for use. It is especially important that the design of additional and

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auxiliary material, such are user manuals, is based on ergonomic principles. If this is not the case, poorly designed product instructions can cause reduced performance when using the product, and even lead to accidents. In this phase, ergonomists should ensure that supporting materials are designed in accordance with ergonomics principles. Some of them, for example for the quick start guides, have been given in [11]. Manuals and instructions for use should fulfill requirements concerning readability, legibility and visibility. They should be designed in accordance with the abilities of the population that will use such material.

Phase 6 - testing and evaluation of the model, prototype and final product

In the context of product development, evaluation involves systematic measurements related to the product being developed (basic design, interface, procedures, auxiliary material), for the purpose of verifying that the functions that should be performed are actually being performed. In essence, almost every decision made during product design involves some sort of assessment, such as, for example, deciding whether to use a visual or auditory signal in a given situation. In almost all cases, systematic evaluation is necessary until the end of the development phase, ie until production begins.

In this phase, ergonomists should undertake an ergonomic assessment of a model, prototype and final product, using ergonomics methods. Some of these methods can be found in [12]. Assessment should be conducted with the same category of people who need to use a particular product, such as retirees, people who have a driver's license, people with disabilities and the like. The evaluation criterion should be relevant to the operational use of the product. Usually, the criteria include performance related to the use of the product, physiological effects, accidents, health effects, the time required for training, product satisfaction, opinions and attitudes. Often, several criteria can be used for evaluation at the same time. Special attention is paid to the design of the experimental procedure, which should correspond to the real circumstances as much as possible. In this regard, testing should be performed in conditions close to those in which the product would otherwise be used.

4. CONCLUSION

In this paper, it is presented a novel model that refers to the product designing phases. This model is based on the model that is applied in designing complex systems. Despite their structural similarities, these models serve different purposes. The purpose of the model presented in this paper was to present how ergonomics can be applied in the various stages of the development of the product, and to clearly show what is the role of ergonomists in the development of a consumer product. This new model is presented in a graphical form. Contrary to the validation of statistical and numerical models, there are no developed specific methods for the validation of graphical models (especially those that are given in the form such as this model). However, in accordance with the purpose of this model, it can be said that its logical validity has been confirmed, because it is explained how ergonomics can be applied to each phase of product designing, and what is the role of the ergonomists in each phase. In addition, examples were presented in the context of each phase.

As mentioned, the presented model of product design by phases clearly shows that in each phase of designing, ergonomics has its role. It is logical, then, to ask the question, why is ergonomics rarely applied in practice for designing consumer products? In connection with this issue, it should be said that large companies have recognized the importance of ergonomics, especially in the automotive and

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aerospace industries, so that, today are very rare companies in these industries that do not apply ergonomics in their work. In the mentioned branches of industry, ergonomics has, among other things, become synonymous with user comfort. However, in other industries, ergonomics is much less used when designing consumer products.

One of the main reasons for such a situation is that ergonomic activities in the previous period were based primarily on the assessment of various effects on a person, in the case when he interacts with an object or environment. In addition, ergonomics fosters a multidisciplinary approach, so, much of the ergonomic activity is focused on non-productive activities, such as health, education, or service activities. For this reason, a large number of ergonomists do not have at their core technical education, which is important for effective integration into the design team. On the other hand, in many technical faculties, ergonomics is not studied as a subject within the offered curricula, which is an additional problem, which should be given due attention in the coming period.

The International Ergonomics Association (IEA) has recognized the importance of this issue. IEA formed a special working group called "Ergonomics in Design for All" (EinDfA). In addition, the Federation of European Ergonomics Association (FEES) has adopted a strategy for the promotion of ergonomics, which includes, among other things, employees, companies, as well as educational institutions. There are also certain international projects that are dedicated to the further development of ergonomics. One such project is the CEEPUS project, dedicated to the development of ergonomics along the Danube region. Two authors of this paper have participated in this CEEPUS project. It is to be expected that efforts and strategies in this area will be further developed, so that product users and society as a whole can benefit fully from the application of ergonomics.

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