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Definition of comfort in design and key aspects- A literature review

Saeema Ahmed-Kristensen, Stavros-Konstantinos Stavrakos

Department Of Management Engineering,
Section of Technology and Innovation Management
Technical University of Denmark,
DK-2800 Lyngby, Denmark
skost@man.dtu.dk, sakr@man.dtu.dk

1. Introduction

Everyone pays attention to comfort. Comfort is an important issue in the design of many consumer products, in particular those with physical contact with the consumer, e.g. headsets or chairs. When buying a chair, a bed, even when driving a car, or flying, comfort is taken into account. Industry aims for products which are comfortable in order to stay ahead of competition. Hence, it is important to achieve comfort when designing products.

Discomfort should be prevented in order to allow for satisfactory rates of human performance as well as to reduce any negative effects on the user during the user-product interaction. For example a bus cabin should be designed around the driver so that it facilitates the driver's performance. The environment around an assembly worker or the software environment for an office worker, in the same sense, should be designed in a way which boosts their productivity. A longitudinal study has linked discomfort to musculoskeletal problems and a series of complaints in the back, neck and other body parts. The Second European Survey on Working Conditions [1] which took place in 1996, where a sample of 1000 workers from each member state were interviewed, revealed that back pain (30% of the workers) and muscular pains in arms or legs (17% of workers) are among the most common work-related health problems. Absenteeism due to work-related health problems affects 23% of workers each year (averaging out at 4 working days lost per worker). These health problems strongly relate to postural musculoskeletal discomfort. Reducing discomfort is, therefore, of high importance.

There are three main issues when designing a product to achieve comfort:

- The exact cause of comfort is unknown.
- Comfort relies to a certain extent on subjectivity.
- There is a lack of a comfort design process or approach. [2]

There has not been so far a universally accepted definition of comfort which can be operated, except for mono-disciplinary definitions which reflect, to a certain degree, the background of the researcher.

Various dis - comfort assessment methodologies have been in use. They can be categorized into two types. According to the first type, users are asked directly how comfortable they are. This method is direct if comfort or discomfort is considered to be of subjective nature or a feeling [3]. The second type regards to methods of a more indirect, objective nature. In most cases these methods present an aspect of a user's comfort by measuring a certain value (e.g. pressure, muscle activity, etc.). These methods are less time consuming, they do not require a large sample of users and can be applied at earlier stages of the development process. However, only if correlations between objective measurements and comfort are present, can the objective methods form a useful addition to subjective methods. [4]. The subjective nature of comfort needs to be taken into account when assessing comfort in both, direct and indirect methods of comfort assessment. In both cases, this might hinder the generalization of results.

Although there are a few papers explaining the concept of comfort such as Helander and Zhang [5], De Looze et al. [4], Moes [6] and Kuijt-Evers et al. [7], approaches to comfort which have been developed are mono disciplinary and lack a generalized approach. Hence, there is a need for a generally accepted comfort design process.

This paper will address the aforementioned issues, namely, definitions of comfort and comfort design approaches. A general framework towards the definition of comfort is proposed and the different dimensions strongly linked to comfort are presented. This paper aims to understand the factors that constitute comfort within the context of product design, and understand those that can be influenced through the design of a product. Finally this paper aims to comment on the existing models of comfort assessment and indicate a direction to a more generalized approach.

2. Methodology

The literature was retrieved for the following terms: comfort or discomfort; seating comfort; ergonomics; emotional design; comfort studies; assessment; evaluation; 43 papers were finally chosen. The parts of the papers with similar contexts were joined and qualitative observations were made, which are presented as conclusions at the end of each of the next sections as well as in the discussion (see section 6).

3. General theory of comfort

3.1 Definitions in dictionaries

This section will initially introduce some of the retrieved comfort definitions. It seems that diversity lies in the meaning of the word comfort which is linked to “feelings of relaxation” [8] and “things which bring physical ease or contribute to a state of well-being” [9]. In most dictionaries comfort is also seen as a state where there is “a freedom from pain” as well as comfort is translated as a “convenience of the interior”. In medical dictionaries comfort is described as “a subjective state of well-being in relation to an induced environment including mechanical vibration or shock” [10]. Comfort is, however, commonly associated with terms such as, “assistance, relief, support” [8] and is also seen as “a feeling of freedom from worry or disappointment” [9]. Hence, comfort is associated with the environment and with products which bring bodily ease. Moreover, a physical dimension of comfort is revealed (freedom from pain) as well as an emotional dimension (relief, freedom from worry or disappointment).

3.2 Definitions in the scientific literature

Comfort has been linked to the term “discomfort” since the first attempt to operationally define comfort as “the absence of discomfort” [11]. Slater defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and the environment [12]. Richards [3] states that comfort is the state of a person that involves a sense of subjective well-being in reaction to an environment or a situation. In regards to the subjective nature of comfort Vink et al. [2] states that “Comfort is a subjective experience. For Passenger 1 on a long distance flight, back discomfort is of great importance. Passenger 2 wants a reduction in noise and Passenger 3 needs more space.”

Two contrary positions on a definition for comfort seem to support the need to involve the individuals actively in the assessment of comfort experience: Comfort is seen as an attribute or as an achievement. Before comfort was materialized in the 1920’s, early definitions saw comfort as a state of mind; later, comfort came to be considered to be an attribute – of food, furniture, clothing, or the indoor climate – and this way, it became commoditised [13]. If comfort can be technically specified, then controlling comfort consists only of controlling technical parameters. Following a period of energy-intensive mechanical systems, responsibility for achieving comfort was placed on the technology rather than the occupants.

[14]. These technical approaches to comfort provisioning involved comparatively unstructured ideas about building users [15] seeing individuals as passively moving through tightly specified, technically – controlled spaces rather than actively engaging with those spaces in order to practice comfort in a mixture of technical and non-technical ways [13].
A contrary position views comfort as an achievement. This view recognizes that individuals have the ability to choose from a range of technologies and practices in order to achieve comfort, seeing this as positive, in contrast to 'comfort-as-attribute' approaches that tend to view individual agency as a risk to be minimized and managed [14]. Individuals may devise their own strategies to manage comfort, which may not overlap with those that mechanical engineers and designers have provided for [14]. The 'comfort-as-achievement' view sees comfort as being "personally idiosyncratic, culturally relative, socially influenced and highly dependent on temporality, sequence and activity" [13], where individuals may choose to manage their comfort in different ways and may feel differently about different ambient conditions [15]. This contrasts with the 'comfort-as-attribute' view which assumes that comfort is a more-or-less uniform physiological property.
Hence, it seems that comfort is (1) a construct of subjectively defined personal nature, it is (2) a reaction to the environment and that (3) comfort is affected by factors of various nature (physical, psychological and physiological).

3.3. The Dis (continuum) of comfort

Comfort is not a well-defined concept yielding an on-going debate in the literature. The debate stresses on the difference between comfort and discomfort. Several researchers [11], [16], [3], [17], [18], seem to be making a distinction between two different states of comfort, that is, the absence of comfort and the presence of comfort, in which comfort is defined as the absence of discomfort. This does not necessary entail a positive effect [19]. In fact according to Bishu et al [18], in particular for seating design, "the goal of the designers is to reach the state of absence of discomfort, where the working individual is oblivious of the fact that he or she is seated." In his study, Richards [3] has suggested that the fact that people rate their subjective responses across the entire continuum indicates that positive discomfort is part of a bipolar dimension that can be attributed to characteristics of design.
This statement is supported by a number of papers in hand tool evaluation studies in which comfort is measured in terms of discomfort [20], [21]. In hand tools comfort is mainly determined by functionality and the physical interaction between the user and the product. As discomfort factors are present in hand tool use, comfort may be dominated by discomfort [22]. In their study, Kuijt-Evers et al. [22], factors having the closest relationship to comfort were identified among 40 descriptors, such as good fit in hand, functional, easy to use, reliable, etc. These factors were clustered. The statistical analysis showed that 6 comfort factors were distinguished: functionality, posture and muscles, irritation and pain of hand and fingers, irritation of hand surface, handle characteristics and aesthetics. These factors explain 53.8 % of the variance. In the use of hand tools it was concluded that the same descriptors relate to both comfort and discomfort.
Two studies in the design of seats support the above statement. A comfort study [23] carried out to evaluate the comfort of a passenger seat for a new type of bus and a comfort study [24] was carried out to compare two different track seats (with and without suspension) when changing driving postures. Both studies have used a multistage comfort scale (MSC), Electromyograms (EMG) and general posture analysis. It was concluded that comfort and discomfort can be seen as two opposites on a continuous scale. This stems from the fact, that people frequently and naturally distinguish ordered levels of their subjective responses across the entire continuum from strongly positive to strongly negative [3]. The same principle underlies the graded scales [25], which have been used to evaluate seats.

Opposing to the theory of seeing comfort and discomfort as two extreme states on a continuous scale ranging from extreme discomfort through a neutral state to extreme comfort, several studies have questioned the intuitive assumption of comfort/ discomfort as a single dimension on a continuous scale. These studies [26], [27], [28], argue that comfort and discomfort are affected by distinctly different variables, and assessment of comfort and discomfort should hence be based on different types of criteria [27]. In the study of Zhang et al. [29], the identification of these variables was the primary goal. Descriptors of feelings of comfort and discomfort were solicited from office workers and validated in a questionnaire study. 104 respondents provided descriptors of the feelings they experienced when they felt comfortable (e.g. agreeable, at ease, calm) or uncomfortable (e.g. fatigue, cramped, restless) in a seated workplace. Secondly, to validate these descriptors, another group of 34 participants was asked to rate these descriptors on a 5-points scale, from 'very closely related to comfort/discomfort' to 'not related at all'. From this study, 43 descriptors emerged. 21 descriptors related to discomfort and 22 related to comfort. The participants rated the similarity of all 903 pairs of descriptors, and the resulting similarity matrix was subjected to multidimensional scaling, factor analysis, and cluster analysis. Two main factors emerged, which were interpreted as comfort and discomfort. Feelings of discomfort are mainly associated with pain, tiredness, soreness and numbness. These feelings are assumed to be imposed by physical constraints and mediated by physical factors like joint angles, tissue pressure and circulation blockage. Comfort, on the other hand, is associated with feelings of relaxation and well-being [30]. It was concluded that siting comfort and discomfort were identified as independent entities associated with different factors: discomfort is related to biomechanics and fatigue factors, whereas comfort is related to a sense of well-being and aesthetics. Comfort and discomfort need to be treated as different and complementary entities in ergonomic investigations.

In a later study involving 20 and 37 subjects respectively, Zhang et al. [31] issued a checklist for evaluation of chair comfort, and discomfort was analyzed in two field studies. In the first study two groups of subjects, ten secretaries and ten managers, evaluated two groups of ten chairs. Subjects assessed each chair three times during a workday using three different types of scales. Analysis of variance demonstrated that discomfort was related to fatigue accumulated during the workday, but it was not related to chair design. Since discomfort and comfort are based on independent factors a reduction of comfort does not necessarily bring about feelings of comfort. In fact, from their independence it would follow that there is no connection between the two entities [31].

In addition, low values of discomfort factor scores were associated with a full range of values of overall comfort ratings from 1 to 9, while comfort ratings decreased sharply with increasing discomfort scores. This indicates that, when discomfort factors are present, comfort factors become secondary in the comfort/ discomfort perception (hence, discomfort has a dominant effect, [31]. Paul et al. [32] propose the nurturing/pampering paradigm, indicating the need for different strategies for reducing discomfort (nurturing) and increasing comfort (pampering) in the work place. This could provide a unifying focus for ergonomists and designers.

In conclusion, there was little consensus on whether comfort and discomfort should be regarded as being a bipolar continuum or as composing of two experiential dimensions but the theory of Helander and Zhang [31] convinced us that there was a division or discontinuity between comfort and discomfort scales. However, both comfort and discomfort should be addressed since discomfort seems to be more tangible, hence, easier for the individual to express. Lastly, since comfort is related to a sense of well-being and aesthetics, an important message is expressed, that aesthetic and emotional design matter and should be linked to the concept of comfort.

4. Underlying Factors of comfort and discomfort

This section will investigate the context of a series of papers which have a specific addition to new knowledge in the field of comfort and highlight issues to be taken into account when striving for comfort.

4.1 Context and type of activity

Ellegast et al. [33] aimed to evaluate the effects of four specific dynamic chairs on erector spine and trapezius Electromyograms (EMG), postures/joint angles and Physical Activity Intensity (PAI) compared to those of a conventional standard office chair. All chairs were fitted with sensors for measurement of the chair parameters (backrest inclination, forward and sideward seat pan inclination), and tested in the laboratory by 10 subjects performing 7 standardized office tasks and by another 12 subjects in the field during their normal office work. All chairs were compared to a reference chair. The comparison of all specific dynamic chairs with the reference chair revealed no significant effect for any of the muscles. By contrast, the tasks performed strongly affected the measured muscle activation, postures and kinematics. The standardized tasks performed in the laboratory had a significant impact on the posture of the different joints, whereas no significant differences were found for the chairs and for the comparison of the specific dynamic chairs to the reference chair. The characteristic dynamic elements of each specific chair yielded significant differences in measured chair parameters, but these characteristics hardly affected the body dynamics of the subjects sitting on the chairs. The results of the study emphasize that many aspects of workplace design, such as variability of tasks should be considered in order for musculoskeletal disorders to be prevented [33].

In a similar context, Groenesteijn et al. [34] investigated the effect of office tasks on posture and movements in field settings, and the comfort rating for chair characteristics and correlation with type of task. Computer work showed the lowest physical activity, together with upright trunk and head position and low backrest inclination. Conversation shows the highest activity of head legs and low back together with the highest cervical spine extension. In contrast, desk work provoked the most cervical spine flexion and showed the second lowest activity. The telephoning tasks showed medium activity and the highest kyphosis. Conversation showed the highest backrest inclination. Positive comfort relations were found for computer work and a “swing system” chair, for telephoning and an active longitudinal seat rotation, and for desk work and a chair with a three-dimensionally moveable seat. Hence, positive comfort correlations were found among different types of activities and different types of chairs.

Hence, the type of task plays an important role when investigating comfort. It is necessary to define the context and the type of activity when assessing comfort.

4.2 Product Form, Memory and State

Vink [2] indicates that “discomfort is mainly related to physical characteristics, whereas comfort is related to experience, emotion, unexpected features, and luxury”. In her study Kamp [35] describes the contour of three different car-seat designs, including a light weight seat, and the recorded corresponding emotion and tactile experience of 21 persons sitting in the seats. The seats were all deliberately covered with white sheets so that the participants are not influenced by the appearance of the seats and focus on the seats’ sitting comfort. For the rating of emotions the Emocard method was applied. This is a nonverbal self-reporting method developed by Desmet et al. [36] based on the circumplex of emotions created by Russell [37]. This circumplex is based on two dimensions; ‘pleasantness’ and ‘arousal’. The 16 Emocards are placed on eight distinct places on this circumplex. Participants can express their emotional responses to the seats by marking the face that best indicates their response. Results show that the new light weight car-seat concept rated well on experienced relaxedness, even with the lack of a side support. Of all participants, 19% had neither a

pleasant nor a negative feeling, although the arousal level was high. This would mean that people were surprised by the actual feeling of the seat. Before they sat down, they expected to experience a different feeling. An important finding is also that hard seats with rather high side supports are rated sporty and seats that are softer are rated more luxurious [35].
This study shows that individuals estimate comfort based on contour, sporty or luxurious feel and appreciation. They also assess the products depending on their current state. Moreover, they have a preconceived notion of comfort based on past experiences with similar products. Hence, the product memory of the individual creates a comfort expectation.

4.3 Sensory impact

Among the various papers which have investigated the Human Computer Interaction, Aarts et al. [38] and Cook et al. [39] introduced the Ambient Intelligence system (AmI), which refers to electronic systems embedded in everyday environments and are sensitive and responsive to people in a seamless, unobtrusive, and often invisible way. In the context of AmI, Aarts et al. [38] identified the issue of suggestion, that is, when the Ambient Intelligence system suggests to the user to perform a certain task at opportune moments. In their study De Korte et al. [40] investigated the use of different types of non-obtrusive feedback signals in order to change unhealthy behavior of office workers. Thus, four different feedback systems were selected to remind the computer users to rest their hand from the mouse when they do not use it, since sustained lifted hand and finger behavior for a long period of time can develop repetitive strain injury [41]. Two of the feedback systems were two types of vibrations in a computer mouse and the other two were visual signals, a small screen appearing at the corner of the screen and a full screen, transparent signal visible on the computer screen. Notable differences between types of feedback were seen, relating to comfort and task satisfaction. The 24 participants rated the feedback system which does not interfere with their primary task as the most effective. The feedback system which activates another sense than the one used for the execution of the primary task creates a better sense of comfort.
Hence, the impact on the senses should be taken into account when designing comfortable products. Stimulating a different sense can alter the comfort experience.

4.4 Neighboring body surface

Franz et al. [42] describe the design of a neck-/headrest to increase car comfort. Two studies were undertaken to create a new comfortable headrest with neck support. In experiment one, neck- and headrest data were gathered using 35 test subjects. The pressure distribution, stiffness of the foam material and position of the head and neck support were determined. In experiment two a full adjustable final headrest with adjustable neck support was constructed and tested with 12 subjects using a new adjustable headrest under virtual reality driving conditions. Experiment two showed that the headrest with the new/adjustable neck support was favored by the majority of the subjects. 83% were satisfied with the stiffness of the material. 92% were satisfied with the size of the neck- and headrest. All subjects mentioned that the neck support was a great comfort benefit in calm traffic conditions or during driving on the motorway. The back side of the head, the neck and the shoulder area all need different foam characteristics. This study shows that it is important to use the right material for each area. The neighboring/ contacting surface needs to be investigated when deciding the material characteristics.

4.5 Discomfort and physical loading

Among the many comfort studies which link discomfort to physical loading, Kee et al. [43] investigated the relationships between subjective measures of discomfort and objective measures related to the assessment of postural stresses based on literature survey. Objective measures included posture holding time, Maximum Holding Time (MHT), torque at joints, Lifting Index (LI) and compressive force (CF) at L5/S1. The major relationships identified in this literature survey were the following: 1) postural discomfort linearly increased with increasing holding time, and holding force, 2) whole body discomfort was inversely linearly proportional to the MHT, 3) body-part discomfort was related to objective measures such as torque at the relevant joint, 4) discomfort was strongly linearly related to LIs and CFs, and 5) the discomfort measured with the magnitude estimation was linearly related to that measured with Borg CR10. Thus, it is thought that discomfort might be used as a measure for quantifying postural stresses.

In a similar context, Zenk et al. [44] conducted an objective assessment approach which evaluates the concept of "optimal load distribution", based on the identification of a close relationship between the pressure on the seat and the discomfort felt by the person sitting. The results indicate that in the seat position with the pressure distribution corresponding to the most comfortable posture the pressure in the intervertebral disc is lowest.

Hence, if the physical load forced on the user is kept down to low levels and the exposure of users to the load lasts for a considerable amount of time then their response can relate to objective measures. There is a strong connection between discomfort and physical dimensions.

5. Existing models of comfort assessment

A frequently cited model regarding sitting comfort and discomfort is the one shown in Figure 1 by De Looze et al. [4]. The discontinuity between comfort and discomfort is presented in this model. The left part of this theoretical model concerns discomfort. According to Zhang et al. [30], physical processes underlie discomfort. De Looze et al. [4] make use of the terms 'exposure', 'dose', 'response' and 'capacity' as the main issues. According to Armstrong [46], exposure refers to the external factors producing a disturbance of the internal state (dose) of an individual. The dose may evoke a cascade of mechanical, biochemical or physiological responses. The extent to which external exposure leads to an internal dose and responses, depends on the physical capacity of the individual.

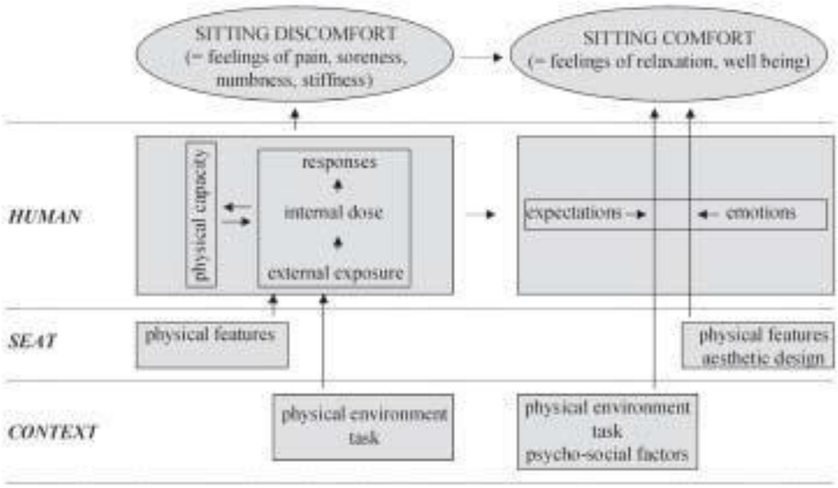

Figure 1. Theoretical Model of comfort and discomfort and its underlying factors at the human, seat and context level

With regard to sitting, it could be said that the physical characteristics of the office seat (e.g. form, softness), the environment (e.g. table height) and the task (e.g. the performance of VDU activities) expose a seated person to loading factors, which may concern forces and pressure from the seat on the body and joint angles. These external loads may yield an internal dose in terms of muscle activation, internal force, intra-discal pressure, nerve and circulation

inclusion, and skin and body temperature rise, provoking further chemical, physiological and biomechanical responses, leading to discomfort [4].
The right part of the model concerns comfort, i.e. feelings of relaxation and wellbeing. At a context level, not only the physical features are assumed to play a role, but also psycho-social factors like job satisfaction and social support. At a seat level, the aesthetic design of a seat in addition to physical features may affect the feelings of comfort. At human level the influential factors are assumed to be individual expectation and other individual feelings or emotions [4]. The dominant factor of discomfort, as suggested by Helander and Zhang [31], is illustrated by the horizontal arrows pointing from the left (discomfort) to the right (comfort) part.
Moes [6] has identified 5 phases to describe the experience of sitting discomfort (see Fig. 2). I – interaction, E _ effect in the internal body, P - perceived effects, A - appreciation of the effects and D – discomfort.

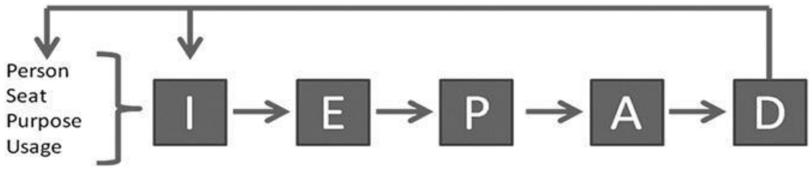

Figure 2. The comfort model by Moes (2005)

Moes [6] also describes that this process is dependent on the person, the seat, the purpose and why the seat is used. Moes [6] also comments on the dependency between the interaction and the assigned task, which is aligned with the previous conclusions drawn by looking into the papers by Ellegast et al. [33] and Groenesteijn et al. [34].

6. Discussion

6.1 Definitions of comfort

The main conclusions by looking into the various comfort definitions and the literature debate on the existence of a continuum between comfort and discomfort is that comfort is subjective, that there is a strong reaction to the environment and that comfort has a multidimensional context (physical, physiological, psychological). On the other hand, it seems that there lies a discontinuity among comfort and discomfort. Feelings of discomfort are mainly associated with pain, tiredness, soreness and numbness. Comfort, on the other hand, is associated with feelings of relaxation and well-being [30]. When referring to comfort the term “environment” entails both physical and psychological dimensions of comfort whereas in discomfort the focus is on the physical environment. In this context a definition of comfort should entail the nature of subjectivity and the term “environment” as it reacts with the individual on a holistic level (physical, psychological, physiological) to achieve comfort. The discomfort definition should also entail the individual and the physical dimension of the environment as it seems that there is a stronger link to discomfort.

6.2 Existing models of comfort

By comparing the two models it is evident that De Looze et al. [4] refer to both comfort and discomfort whereas Moes [6] presents discomfort as being the only final phase of the comfort experience. De Looze et al. [4] also present comfort and discomfort as two disconnected entities leaving space for different approaches in the comfort and discomfort experience. Moreover, De Looze et al. [4] show explicitly the discomfort experience consisting of a series of physical processes. In that respect Moes [6] also presents a more clear linear process in the experience of discomfort. On the other hand, Moes [6] does not refer to the physical environment whereas in the model by De Looze et al. [4] the physical environment is explicitly shown. Both models, however, do not describe at all or not well enough the experience of achieving comfort and this agrees with the authors' previous conclusion that more emphasis should be given on the emotional dimension of comfort and that knowledge should be gained in the impact of aesthetic design on the context of comfort.

7. Conclusion

The main conclusions which derived from the literature review stress on the importance of the assigned task and the context activity when assessing comfort. Comfort estimation is also based on the product form and the appreciation to the product. Comfort expectation as well as the memory of previous products and the state of the participants affect the assessment of comfort. Stimulating a different sense can alter the comfort experience. Choosing the right material by looking also into the neighboring surfaces could affect the overall feeling of comfort. There is also a strong connection between discomfort and physical dimensions.

A discontinuity between comfort and discomfort has been observed. Comfort is linked more to feelings of well - being and relaxedness whereas discomfort is strongly linked to a more physical dimension, that is with feelings of tiredness and pain. This is also reflected in the models which were observed, in which the physical dimension of comfort is explained in a satisfactory way. However, the comfort experience is underestimated in the existing models. Therefore, an emphasis should be given in the emotional dimension of comfort as well as in the subjective nature of comfort. This could improve the understanding of the comfort experience and lead to the designing of more comfortable products.

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