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Emotional design of medical devices: exoskeletons and post-stroke recovery devices

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Abstract

The paper explores the integration of emotional design elements in the development of medical devices to enhance user acceptance and adherence. It emphasizes the importance of a user-centered approach, acknowledging both functional and emotional needs. The study compares two cases within healthcare design, highlighting the impact of emotional design on users' perception of medical devices. Despite the different stages of development in the two cases, both employed a higher level of refflective design, aiming to create a lasting impact on users' identity using the products.

Keywords: *emotional design, inclusive design, healthcare design, user-centred design, industrial design*

1. Introduction

It is both clinically and technically demanding to design medical devices. However, it can also be a very intimate and emotionally sensitive task. Emotional aspects such as social stress, stigma and shame are well-known barriers in the medical industry (Vaes, K., 2018). Challenges in the healthcare industry increase with the demographical development of a growing elderly population. Moreover, the lack of healthcare workers put increased pressure on the healthcare system. For example, patients with severe paralysis, who normally would live at home, are being hospitalized due to the lack of caregivers (Struijk, L., et al., 2022). This highlights the need for assistive technologies, which could improve life quality (Struijk, L., et al., 2022). However, the adaptation and acceptance of such technologies are not only affected by users' functional needs but also their emotional needs. Using these assistive technologies should not be a hindrance but an empowering experience for users (Kobbelgaard, F. V. et al., 2021). This includes the context of wearable physical assistive exoskeletons, where in some cases, users wanted to show off and be proud of their assistive technology almost as if they were fashion accessories. Because of this, and since the number of developments in bionic devices increased, users should be involved more in an iterative design process and the products can no longer only be designed based on utility alone (O'sullivan, L. W. et al., 2017). A user-centred approach to health communication is important to drive human behaviour changes, whether that is improving adherence to or acceptance of medical devices (Gloyd, M., 2003). This is because medical devices have a long history of 'rejection' (Vaes, K., 2018). In this paper we compare two cases of medical devices, where design was involved at different stages, to see how it was possible to improve users' perception of medical devices in two different product categories using the same methodological approach. The first case entails the development of a protective shell for a 5-DOF (degree of freedom) upper limb exoskeleton designed for

patients with Tetraplegia (spinal cord injuries). The exoskeleton was from the EXOTIC lab from the Department of health science and technology at Aalborg University (Thøgersen, M. B., et. al, 2020). The project built on user requirements (Thøgersen, M. B. et. al, 2022) and users' perception of exoskeletons by Kobbelgaard, F., et al., (2021). Focusing on the impact the aesthetics of an exoskeleton can have on users. The second project concerns the concept development for a physical device, which people who have suffered mild to median strokes can communicate and update medical professionals on their physical and mental recovery after being discharged from the hospital. The involved work was part of the Horizon Europe RESQ+ project anchored at Human Machine Interaction research group at Aalborg University.
The two cases differed in terms of the stage at which design work was involved. In the first case, the designer was included in the later stages of the development with the task of designing the construction and aesthetics of a protective shell for the exoskeleton. In the second project the designer was included in the early design process, also referred to as "The Fuzzy Front End" (Koen et. al, 2002). As prior studies indicate with innovation projects (Laursen et al. 2015), we hypothesise the stage and extent of involvement influences the design contribution to the cases. This paper is structured as a comparative case analysis of two healthcare design cases, focusing on exploring the integration of emotional design elements for increased desirability and increased acceptance and adherence in the use of medical devices. We seek to answer the research question: *How to use emotional design to change users' perception of medical devices?*

2. Design of medical devices

The design and innovation of medical devices have always been led by technology and often driven by clinical requirements. However, despite addressing current health issues, it neglects to focus on considering end users' needs (Dunn, J. L. et al., 2019). In a case study by Dunn, J. L. et al. (2019) they focus on using *Design Thinking principles* (Laursen et al., 2017) together with *Design-led Innovation* to create the Medical Devices Design Innovation Framework (MDDI). The model highlights the importance of emotional design in terms of *desirability* and *human behaviour interactions* involved in the product experience both directly and indirectly. They state that *"Recognising the importance of emotional attachment and the capability of design innovation to promote patient-product connection is critical for long term treatment"*. The same is applicable in the development of the framework for the *Product Appraisal Model for Stigma* (PAMS) by Vaes, K. (2018). This stigma-free design tool was developed to increase user-product attachment, user empowerment and collective well-being by understanding how *product perception* (sensing), *use* (acting) and c*onsequences of product use* (evaluation), influence desirability in the use of medical devices. The model measures these parameters to the product user, bystanders, and culture, understanding how these interlink and creates a tool that allow designers to better understand how stigmatism surrounding medical devices are formed and how to prevent this. Despite having different frameworks, both studies include emotional design as vital for improving the design of medical devices.

2.1. Emotional design

The involvement of emotional design in industrial design has grown exponentially over the last 20 years. The two main approaches to emotional design are based on the modification of aesthetics or interface, the second being the influence of fluent and engaging interaction (Triberti, S., 2017). Both approaches are applicable in technology design. Pre-existing experience or lack of understanding of a given technology can greatly influence a user's perception of the technology (Triberti, S., 2017). Emotional design has been used in several industries including the healthcare industry before, as medical devices are an integral part of healthcare, however, can seem intimidating and frightening to patients and especially children (Yusa, I. et. al, 2023). Emotional design is described by Don Norman and can be broken down into three categories, *Visceral, Behavioural* and *Reflective level design:*

- The *Visceral* level of design includes emotions of rudimentary meaning, it is a user's core response in evaluating the perception of a given property or object and classifying them based on safety or danger, good or bad, cold and forbidden or warm and welcoming (Norman, D., 2006).

- The *Behavioural* level of design includes emotions tied to the physical interaction and feeling of an object as well as the subjective "feeling of control". However, it is also tied to responses connected to our prediction or expectations, meaning when an object fails to work as intended it provokes emotions on a behavioural level (Norman, D., 2006).
- The *Reflective* level of design includes people's ability to self-examine and evaluate their own actions, understand and monitor progress. The reflective level of design can address users' feeling of pride of ownership, quality and branding which impact users' perception of products. The reflective level of design can sometimes even outweigh the practicality or perceptual responses of visceral and behavioral design (Norman, D., 2004, p. 85).

Emotional design has also been explored in Japanese car manufacturing and product development since the 1990's where the term "Kansei" was coined to represent a feeling in users' response to purchase certain items such as a car, TV or clothing (Mitsuo, N., 2002). Kansei engineering was termed as a method of working to produce new products founded in consumer's emotions and demands. Kansei engineering consists of four parts*:*

- How to grasp the consumers' feeling (Kansei) about the product in terms of ergonomic and psychological estimation,
- how to identify the design characteristics of the product from the consumer's Kansei,
- how to build Kansei Engineering as an ergonomic technology, and
- how to adjust product design to the current societal change or people's preference trend (Mitsuo, N., 1995).

They developed KES the (Kansei Engineering System) which was used to create a database of Kansei words which was constructed based on customers' feeling words used in shops and industry magazines, collected through dialogues with salesmen. Engineers could interpret and convert Kansei words varying levels to physical traits that could be implemented into design requirements (Mitsuo, N., 1995).
Despite being two different approaches to describing emotional design, they both focus on creating a better user experience. Creating pleasurable user experiences with medical devices is an important factor in improving adherence in users (Gloyd, M., 2003).

3. Research methodology and approach

The two cases focused on a similar approach of including emotional design in combination with User-centered design and was based on the literature, analysed in terms of differences and similarities in a comparative case analysis. Focusing on creating a framework for improving acceptance and desirability in medical devices. The comparative case analysis uses insights from interviews held in both cases. Semi-structured interviews were used throughout all of case 1 and was used as the interviews were of an informal nature and it allowed for asking new questions in response to insight from the interviewee (Charmaz, K., 2006 p. 25) As for case 2, a combination of structured and semi-structured interviews was used. The benefit of the structured interview in case 2, was the format's effective way of keeping the interview tightly focused on the target topic of acceptance and desirability, while still being able to have interviewees elaborate further on statements (Alsaawi, A., 2014). In both cases mood boards and products boards were used to generate keyword association banks, similar to the approach in KES.

3.1. Background for Case 1: Exoskeleton protective shell design

The project focused on designing a protective shell for the existing upper-limb exoskeleton (figure 1). The focus was divided into two sub focuses. First part was to create a protective shell that would hide the internal mechanism allowing for users testing the exoskeleton to abstract from the inner workings and decrease the negative associations from users' preexisting attitudes towards robotics and assistive technologies. The second part was an investigation of improvements on the design to increase acceptance amongst individuals with spinal cord injuries for future development. The design project focused on combining mechanical design with human anatomy based on previous work by Kobbelgaard, F. V et al. (2021) on users' expression for discretion in using assistive technologies. Creating a design that would allow for better integration with the body and possibly users clothing articles became the focus after the semi-structured interviews with individuals with spinal cord injuries.

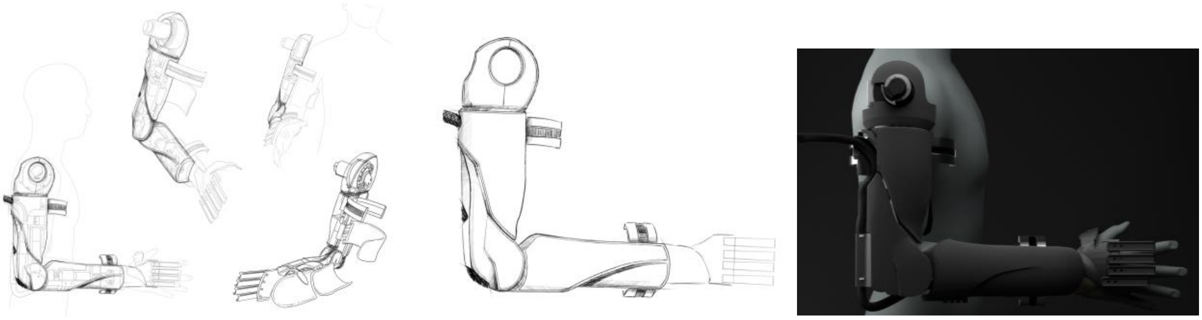

Figure 1. Protective shell for exoskeleton

Throughout the project, nine users of varying levels of SCI were interviewed, with the inclusion of one medical professional working as a rehabilitation expert who was also physically affected by SCI. The emphasis for the project was to interpret the users' feedback on their perception of the existing exoskeleton and understand how a design could improve the acceptance of assistant technology among a range of different users. Understanding how form and materials could positively affect the likability of the exoskeleton and create a feeling of empowerment. Through a range of ideations including human anatomy in combination with mechanical design, the focus became finding a balance that improved users' desire for wearable assistant technologies.

3.2. Background for Case 2: Post-stroke recovery device

The case focused on allowing medical professional to gather additional information during the recovery to track and interfere in case of decreasing health, while being able to evaluate the effectiveness of their current care. In creating a physical device, patients in recovery post stroke could answer questions regarding their physical and mental health, by allowing patients to report on their wellbeing at a convenient time while at home. The problem it tried to solve, was to see if it was possible to increase adherence in relaying this information to medical professionals by creating a physical device instead of relying on a digital product. The device had to include voice assistant technology. The focus for the design project became understanding users' perception of medical devices, the negatives and positives associated with different product categories and investigating how the inclusion of emotion design could improve the experience of using the device and if this could lead to greater adherence. These ideas were then developed using Design Thinking methodologies (Laursen et al., 2017) to generate three possible concept directions for a physical device. Throughout the case project ten users of varying levels of post-stroke implications were interviewed. Analysing quotes from the interviews, the overall emphasis for the concept directions was, that by not looking like a medical device the user would have a smaller barrier to using the device which would increase adherence.

3.3. Concept overview

The following section list a brief overview of each of the concept directions developed. Each focusing a different approach to increased adherence and acceptance of medical devices.

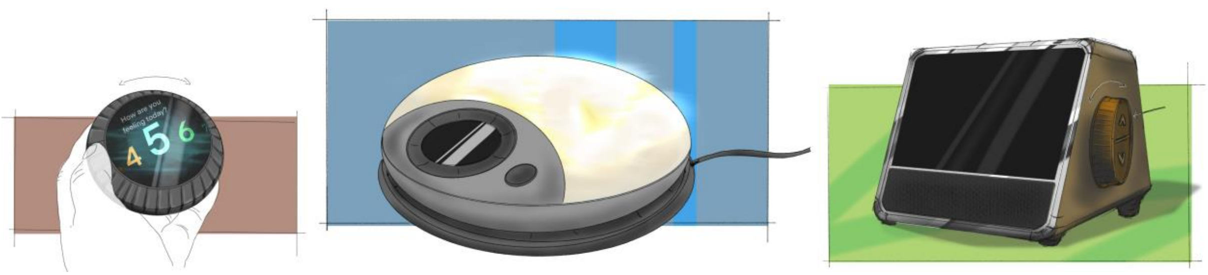

Figure 2. Concept directions left: concept 1; middle: concept 2; right: concept 3

Concept 1: Works on a design in comparison to existing smart home devices. Including an interaction that could be used for answering several types of questionnaire structure. Testing how effectively you can answer questions of varying complexity. The decision landed on a rotational dial concept, that allowed users to answer questions in levels or scroll through pre-configured answers. The design includes portability for a focus on ease of use and for users with limited mobility. **Concept 2:** Focuses on creating an emotional attachment like a pet or friend, that you trust in giving personal answers to. Working of the principles of using touch and sense for interaction. It works on breaking down the barrier of disclosing about illness. Therefore, it is like having a medical companion you also feel responsible for. **Concept 3:** Works on being more relatable in the home, making it less visible and more recognizable in both visuals and interaction. Creating a centralized hub and making the area in which users interact with the medical device more discrete.

4. Comparative analysis

As for evaluating the use of emotional design, both cases with have a direct comparison using the three levels of emotion design, *visceral level*, *behavioural level* and *reflective level* (Norman, D., 2004). In case 2, the final output was three conceptual directions whereas the case 1 the final output was a single conceptual direction, however, these are all compared according to the criteria and not direct comparisons between the concepts. The concepts were developed based on qualitative data gathered through semi-structured interviews in both cases.

4.1. Approach

In both cases, word association exercises were used to get an understanding of users' perceptions and attitudes towards a range of different product categories including medical devices in contrast to common electronic devices and clothing items. This was working of the principles of *Type I* keyword databasing used in KES *(Kansei Engineering System)*, to establish parameters to compare users' "feelings" towards a product with the design elements used for each product.

4.2. Case 1 Exoskeleton protective shell design approach

In case 1, semi-structured interviews were held with individuals who have suffered spinal cord injuries of varying ages, to understand the pre-existing perceptions and attitudes toward assistive technology. In these interviews, the individuals were first presented with existing solutions followed by the concepts developed in the project focusing on including human anatomy into the styling of the protective shell. The individuals interviewed included eight men and one woman, with varying levels of SCI. All participants were recruited through public requests of interviewees through private and public Facebook pages. This includes the public Facebook page of Danish SCI organisation RYK. Two individuals were interviewed in their homes, to compare and investigate the context of living for individuals with SCI. Six individuals were interviewed during their visits to a rehabilitation clinic. One of the individuals was the owner and practising rehabilitation expert of this clinic, who was affected by SCI themselves. The process of case 1 was as followed:

1. Research on current solutions: The first phase of the project focused on gathering information of existing solutions, analysing the market, and mapping functionality and aesthetics of assistive technologies, varying from full body exoskeletons to assistive branches for rehabilitation. From this research three mood boards were created of visual representation of designs consisting of *1) Hardshell/ enclosed 2) Hybrid 3) Softshell/soft body*. These were purely for visual representation and was shown in conjunction with existing exoskeletons. From these three design directions were created based on the research and mapping of reference images.

2. First interview with users: Six interviews were held in the first round, consisting of three individuals with varying levels of SCI, two people with varying levels of immobility due to stroke and one medical professional with SCI. The interviews followed the same structure: 1) Questions on opinions and existing knowledge of exoskeletons without reference images, 2) Presentation of project and existing exoskeletons with feedback, 3) Presentation of mood boards and reference images with feedback, 4) Presentation of design directions and feedback on design choices. Accompanied with a summary of quotes from the interviews:

1. *"...it could be very appropriate if the exoskeleton expressed mobility, but also like strength in a way."*
2. *"...when I see those big ones, it's like, all I can think of is it me or the machine that has the power."*
3. *"See now, I would prefer if I could literally wear it under a jacket when I go out to like a restaurant or something, it's enough that my wheelchair screams 'I'm sick, look at me' but then again it needs to be small enough..."*
4. *"...I think the mechanics look very Iron Man-like and that's too much for me, but I like the idea of it looking like my actual arm... maybe I could even exchange the bicep so it looks like I have bigger biceps, that would be pretty cool. Include that, so people can customize it to their liking, I like that idea..."*

This structure was maintained in order not to influence users and let them give feedback on existing designs before showing the potential design directions. From the interviews a word bank association consisting of 7 keywords based on users' emotional connection to the presented material was created along with a mapping of design features, material, surface, and colour preferences. The keywords were created from single words or sentences such as "*...I want it to be discrete, not too big and fit me perfect...*" became "*fit like a sleeve*" resulting in the word "*sleeve*" for the word association bank.
Despite the quotes from the interviews seeming ambiguous, the job of the industrial designer then becomes interpreting and converting these requests to work with the reflective level of design, to ensure the design includes solutions for latent needs.

3. Design changes and second interview with users: Changes were made based on the interviews, and the design directions were chosen to be a hybrid solution with a mix between hard shells resembling human anatomy, swap ability for individual panels for customizability and integration of flexible material to resemble more natural movement of parts as in correlations with the findings Kobbelgaard, F. V et al. (2021) made on natural looking movement of mechanical parts in their research. The changes were then presented to a second round of users, including 3 users from the project's user board. A voting system was also used to rate which design aspects, based on aesthetics and functions, were to be included in future development. Where each design aspect would receive a vote if the participant agreed with the inclusion of the design aspect.

Table 1. Participants response to questions on design aspects

Design Aspects	Responses out of 9 participants
Inclusion of human anatomy improves coherence with user	9
Mat plastic look	9
Interchangeable panels for customizability	7
Interchangeable panels of fabric or other materials	4
The inclusion of metal for accenting panels	5
Coherent colour schemes	6
Colour for accenting panels	3
Grey/ black as the predominant colour	9

4.3. Case 2 Post-stroke recovery device approach

In case 2, interviews were held with elderly individuals in Czech as part of a larger interview phase to understand the target groups perception of varying products. The interviewees' insights and physical posture were analysed to understand their attitudes towards both medical devices and as well as common electronics. This was followed by a round of interviews with three individuals who have suffered from a median to mild stroke.

1. Research on current solutions: The first phase of the project was establishing a mapping of current solutions. The project was focused on using voice assistance to support any potential solutions. However, the design focus was testing if a possible physical solution for a device could improve adherence with users over a digital solution. We wanted to understand user's perception of different products to analyse emotional reactions and potentially draw connections between latent needs and emotional connections to products. Alongside a list of questions, a mood board was made of various products, including medical devices. Both to understand if different product triggers positive emotional responses we could use, as well as confirm and understand the stigmatism surrounding medical devices.

2. First interview with users: The interviews were held in Czech consisting of 7 individuals, where they were interviewed and shown the product images. All the interviews where film, and a combination of their answers and body language was analysed to determine their responses.
The main takeaway from the first interview were as followed:

1. Complexity of devices might have a larger influence on elderly users
2. Medical devices can be associated with an illness
3. All individuals had a joyful reaction to stuffed animals, resembling childhood or resemblance to pets

3. Design direction and interview: Following the interviews, a word association bank was created based on emotional responses to the products. However, at this time in the process there were little to no requirements. The projects focus was exploring options for increasing adherence, resulting in a continued use of the device to answer questions post recovery. Since there was no knowledge on type, quantity or repetition of the questions that needed to be answered on this device, we decided to use this as the framework for one design direction. Meaning that one of the directions focused on a device that could answer the most complex questions with as little interaction as possible, while still being a physical device. Secondly, discretion became a design direction to account for the stigmatism. Lastly, integrating a "friend" like or "pet" like might as well increase adherence which was concluded from the reaction to stuffed animals during the interviews. These became the basis for the three concept directions shown in **Figure 2.**

4. Second interview with users: Following the creation of the concept directions, interviews were held with three individuals who had varying levels of post-stroke implications. The interviews focused on questions on medical routines, perception of medical devices and questions regarding a physical solution. The interviews followed the same structure: 1) Questions on medical routine post-stroke, 2) Questions on medical devices, 3) Presentation of design directions and feedback on design choices. Accompanied with a summary of quotes from the interviews:

1. *"...it [is] pretty difficult for me to hold anything with my right arm, so it has to either be stationary or I should be able to use the entire device with one hand in my lap."*
2. *"I have a "sickness" corner, it is where I go when I do my medical routines, it has to be that way…"*
3. *"… I just want to feel normal, I go in and out of the doctors and that’s that… I don’t want to be reminded all the time that I'm sick… and medical devices do that so I don’t want to use them [end up in a pile]"*

The same interview procedure was used for the case 2 as for the first case. Likewise, a word association bank was also created from the interviews. There were several words that was present for case 1 as well as case 2. Most of the similar words focused on discretion and users being less affected by their current medical condition and feeeling, as they described, more "normal".

5. Discussion and conclusions

The following section uses the three levels of emotional design by Don Norman and are compared based on statements made by users throughout the interviews in the project. This focuses on the key points and insights that moved the project forward towards the resulting output.

Visceral level of design
Case 1: Exoskeleton: Through interviews with users and the use of mood boards and product boards, the focus on the visual aspect of the became combining the mechanical design with human anatomy to create greater coherence between user and the assistive technology. Use of both harder materials such as plastics and softer materials such as fabrics could give a better understanding of parts that move and part that do not.
Case 2: Post-stroke device: Working with varying levels of discreteness, could breaking the taboo of medical devices being frightening and uninviting. Worked with creating more homely and related products could improve this. Comparable to other electronic devices that do not create a sense of negativity in the comfort of home. Work on making it look inviting in different ways, using lighting and senses, uses of retro aesthetics to address elderly users as well as size reflect portability.

Behavioural level of design
Case 1: Exoskeleton: Based on the previous work Kobbelgaard, F. V et al. in terms of designing for the behavioural level of design, there is great importance in designing a mechanical exoskeleton that moves naturally in a biological manner (Kobbelgaard, F., et al., 2021). However, this can also be transferred to the design of the visceral level, with the inclusion of materials of shapes that form fluent motion when the mechanical parts are activated.
Case 2: Post-stroke device: Focusing on solving for the simplest interaction with the highest level of complexity. Universal recognised interaction, to investigate that interaction corresponds to the expected use of the device.

Reflective level of design
Case 1: Exoskeleton: With assistive technologies, there is often a negative association towards the use of "powerful" mechanical devices that "overpower" the users and give them the sense of losing control. This distances the users more towards wearable technologies. However, by focusing on UCD and analysing how design can improve users feeling of inclusion, control and most importantly "proudness" in using these wearable assistant technologies, the likelihood of a greater acceptance improves.
Case 2: Post-stroke device: The negative association of medical devices could be the biggest mistake in medical device design. Including designs that challenge the perception of it being a device that is more than a household object. There needs to be a focus on balancing between not highlighting illness yet a sense of necessity, otherwise it just becomes another medical devices that becomes neglected.

This study should be seen as a preliminary examination or investigation of including emotional design in the design of medical devices at different phases of the design process. Both cases have not been further developed, which creates a major pitfall in terms of validating the expectations of the users with the execution and final design of each product in each case study. However, this investigation establishes a design framework for applications in future work. Giving a comparison of some of the expected outcomes and differences included this approach to two cases with different phases of the design process. A major consideration in terms of the aesthetic design of the products is determined by the geographically affected preferences of users and in Denmark where this study found place. Where most people tend to more muted and simplistic colour schemes and designs. Therefore, this would benefit from looking at the effects of different design directions across the world.
Despite the two cases being in different phases of the design process, with case 1 being at a later stage including a fully working mechanical prototype, and case 2 being at the early stage also known as the "fuzzy front end", both cases included the same theoretical approach. Working at a higher level of emotional design, as Don Norman describes as the reflective level of design, the objects, and products we design can have a lasting impact on users' identity. However, working with reflective design can create the biggest difference in whether a product becomes a successful product or not. However, is not tangible without the involvement of both the behavioural and visceral level of design. Nevertheless, through the projects we found that the visceral level and behavioural level of design can more easily be determined by working from the reflective level down. Both projects worked on solving problems associated with the reflective qualities of product, whether it is a product that makes you proud to use,

empower you or removes your fear of always being associated with an illness. Design innovation advocate the use of user-centered design is used in early product development (Dunn, J. L., 2019). This could possibly be helped, by analysing and understanding the products reflective level of design. In both cases, this approach resulted in the inclusion of additional theory such as the KES to strengthen the understanding of users' perception of existing products to interpret users' emotional responds to select product categories. This results in tangible parameters that can be converted to design criteria or latent users' demands and wishes. As explained by Triberti, 2017, emotions are by product of stimulus and is influenced by previous emotional states or pre-existing experiences and contextual factors. Therefore, it is important to involve users in a comfortable environment to allow them to correctly reflect, which in turn could yield greater insights in making successful products. In both cases, there was great emphasis on this to ensure the participants could give highly reflective insights that could be analysed. Working in the medical industry developing devices that could greatly impact people comes with a challenge, where the safety of participants is priority leading to longer development time. Therefore, the extend of the study is very limited and should be considered as preliminary work in constructing a framework for including emotional design in medical device development. Working at a reflective level, proved through user feedback, to not only increase acceptance amongst users but also increased user interest in involvement with the projects. For future avenues of research, this comparative study shows a potential framework for improving medical device development by working with the reflective level of design first.

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