



Ultra-Personalization of Safety Footwear: *Unperceived Opportunities and Perceived Risks*

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There is a rise of digitally fabricated products based on users' data. This approach is known as ultra-personalization. Earlier work on ultra-personalization does not discuss the risks associated with the practice or tools that allow future users to engage in the design process. This work explores the perception of digital tools (mobile/web applications) that allow future wearers to engage in the ultra-personalization of safety footwear. Mass-produced safety shoes are known to have comfort and fit issues making it a necessary case for ultra-personalization. We conducted initial interviews with safety shoe wearers and R&D experts and designed nine concepts of digital tools that allow wearers to engage in expressing their wishes and needs for ultra-personalized safety footwear. The same wearers and experts were invited to review and co-reflect on the concepts. Their reactions and attitudes revealed unperceived opportunities and perceived risks associated with digital tools supporting wearers' engagement in the ultra-personalization of safety footwear. We offer an overview of the identified perceived risks on three levels: product (2), service (5), and production system level (2) and we suggest risk-mitigating approaches. Our paper is relevant to design researchers and practitioners interested in designing and researching digital tools for user engagement in ultra-personalization.

Keywords – Ultra-Personalization, Co-Reflection, Perceived Risks, Unperceived Opportunities, Research through Design, Safety Footwear.

Relevance to Design Practice – This paper describes a process of eliciting perceived risks associated with user participation in ultra-personalization in a context of safety footwear.

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Introduction

There is an increasing number of physical products that are personalized based on an individual user's personal data by means of digital fabrication (e.g., Nachtigall et al., 2018; Sandsjö & Guo, 2018; ten Bhömer et al., 2016; Zhang et al., 2017). This approach is called ultra-personalization (Nachtigall et al., 2020) and its ambition is to offer mass-produced products tailored to individual user needs and wishes. While the users and their needs are central to ultra-personalization most of the work does not discuss ways in which future users can be involved in the design process and the possible risks associated with this involvement.

One of the approaches to engage future users in the design of products that meet their needs is to offer them specially designed digital tools so that they can express their needs. Such tools can transfer a labor-intensive process of capturing heterogeneous user needs (von Hippel, 2001) by shifting activities related to personal need expression and capturing to the hands of users (von Hippel & Katz, 2002). While such tools allow future users to partner with a company in designing an ultra-personalized product, literature on mass customization makes us aware that collaboration between users and a company can be perceived as bearing risk. In this article, we aim to explore the risks associated with digital tools (e.g., mobile and web apps) enabling users to engage in ultra-personalization.

We chose the context of safety footwear as a very relevant case to explore perceived risks associated with digital tools for designing ultra-personalized products. The use of safety

footwear is widely spread across many industries worldwide. Safety footwear is a part of industrial Personal Protective Equipment (PPE) and its goal is to prevent foot injuries. While being essential to personal safety and health protection, footwear is often associated with comfort issues. A large study on user experience with safety footwear confirmed that 60% of women and 45% of men indicate that their safety footwear is either very uncomfortable or not as comfortable as their regular footwear, 58% of respondents indicated that they would pay more for safety shoes that fitted better, and 38% of women and 22% of men were likely to pay a higher price for safety footwear that looked better (Janson et al., 2021). One of the suggested approaches to this issue is customization to improve comfort, fit, industry-specific functionality (Janson et al., 2019), diversity, and inclusion within industrial environments and previous work offer an example of a possible customization procedure (Janson et al., 2022).

To gather perceived risks associated with digital tools for user engagement in the ultra-personalization of safety shoes we conducted an explorative study with seven participants—three

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safety shoe R&D experts and four wearers. We first conducted initial interviews to find design dimensions and opportunities for ultra-personalization and developed nine concepts of digital tools. Each scenario is a snapshot of the future mobile or web applications. These concepts were shown to the wearers and the experts in a co-reflection session. The participants were asked to co-reflect whether they anticipate any challenges with the concepts of digital tools and see any risks. The analysis of the co-reflection session revealed multiple perceived risks in each of the three levels: product, service, and production system level. Four identified perceived risks are inherently associated with digital tools enabling user engagement in ultra-personalization. Along with perceived risks we found that shoe experts and wearers had differences in preferred directions of ultra-personalization (unperceived opportunities from shoe experts' side) and perceived risks (unperceived risks from wearers' side).

The contribution of this work is fourfold:

1. We offer nine concepts of digital tools that support users in participating in the design of ultra-personalized safety shoes.
2. We highlight risks associated with wearers participation in ultra-personation via digital tools.
3. We divide risks into product, service and production system related and discuss implications for digital tools supporting ultra-personalization.
4. We suggest risk mitigating strategies and future research directions.

Background and Related Work

Ultra-Personalization

There is a growing demand for products that satisfy the requirements of individual users (Hu, 2013). As a response to that demand manufacturing paradigm of mass customization emerged

(Pine & Davis, 1993). The aim of mass customization is to satisfy individual user's needs while maintaining mass production efficiency (Wang et al., 2017), where the limitation of mass customization is that customers do not participate in the design phase, instead they are choosing the product or its attributes from the existing solution space (all possible designs that can be produced; Berger & Piller, 2003) which is predetermined by designers (Zhou & Jiao, 2013). An advanced stage of mass customization is mass personalization where the needs of users are intensively integrated into the product design process (Hu, 2013). Emerging digital technologies like 3D scanning and cloud services allow the capturing of large amounts of various personal data and together with advances in digital manufacturing enable multi-stakeholder interaction and product personalization to the level of an individual user. Such product personalization is known as ultra-personalization and is defined as multi-stakeholder Product Service System that employs capabilities of digital fabrication and users' personal data to produce tangible products and intangible services that together can satisfy individual users' needs (Nachtigall et al., 2020).

Sustainability is becoming an important area of concern for society and industry (Medini et al., 2012) and there is a need for fundamental changes in behavior and practice (Brundtland, 1987). Literature discussing mass-customized products (in the mass customization paradigm) sees potential for customized products to be more sustainable although it still cannot say with certainty whether mass customization has a positive impact (e.g., reduction of overproduction, reduction of wasted resources, and longer product lifespan) or negative impact (increase of energy consumption, increase of waste for no return policy, and lack of process optimization) on sustainability (Brunø et al., 2013; Naldi et al., 2023).

Ultra-personalization relies on the flexibility of production processes to fabricate individual products. The level of personalization of ultra-personalized products exceeds the level of customization that is currently conventional in production, and it is expected to become feasible with the implementation of a new production strategy called Industry 4.0 (Torn & Vaneker, 2019).

Examples of ultra-personalized products and services can be found in smart textiles for well-being (Mironcika et al., 2020a; ten Bhömer et al., 2013, 2016) where smart garments (their material properties and design) and interaction with garments can be personalized to each wearer. Another example is 3D printed shoes (Nachtigall et al., 2018) where with a help of digital fabrication (3D modeling and 3D printing) and personal data a pair of shoes were produced considering the wearer's aesthetic preferences as well as the form and movement of her feet. Although the service aspect is not prominent in this example, 3D printed shoes serve as an exemplar of a physical ultra-personalized product.

Previous work has conceptualized the phases of ultra-personalization. Nachtigall et al. (2019) expanded the theoretical model that captures the phases of ultra-personalized product creation initially proposed by Ahsmann (2016). Nachtigall et al. found that each of the four phases of the theoretical model require multistakeholder cooperation although the authors did not detail how that cooperation can be facilitated.

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Joep Frens is an associate professor at Eindhoven University of Technology. His research focuses on the question of *how to design for open and growing systems*. He teaches courses on (interaction) design on all academic levels and advises a number of PhD students. In the academic year of 2014-2015, he held the Nierenberg Chair of Design at the Carnegie Mellon University School of Design. When he sees a sheet of cardboard he makes a model out of it.

Stephan Wensveen is a full professor of *Constructive Design Research in Smart Products, Services and Systems* at Industrial Design (TU/e). He studied Industrial Design Engineering (MSc, PhD) at TUDelft. In 2002 he joined ID (TU/e). For two years he expanded his horizon on multi-disciplinary design and Participatory Innovation in Southern Denmark. He has always been interested in using the power of design to integrate research, education, and innovation, co-establishing the /d.search-labs (2006), the Wearable Senses lab (2008) and programs around Smart Textile- (2011) and Ultra-Personalized-Product Services (2018). He is co-responsible for canonical examples and approaches to Research through Design. His most recent interest is in the development of designers' competence in *aesthetics of intelligence*.

The described works illustrate the potential of ultra-personalization although they did not extensively touch upon wearers' participation in designing of ultra-personalized products and implication that this participation may bring for design of digital tools for ultra-personalization.

Toolkits for Identifying Users' Needs

The promise of ultra-personalization is to produce physical products and related digital services that would fulfill specific users' needs based on personal data and multi-stakeholder expertise. Thus, individual needs, wishes, personal tastes, and aesthetic preferences of users expressed in different forms of data are at the very heart of the design process. Capturing individual needs of users is a labor-intensive activity in particular if needs are heterogeneous (von Hippel, 2001). One of the approaches for identifying and capturing users' needs is through digital toolkits (also known as toolkits for innovation). Digital toolkits allow mitigating this effort by shifting need-related activities to hands of users (von Hippel & Katz, 2002). Digital toolkits are an internet platform or software application that allows users to design products or services according to their individual needs (Jeppesen, 2005; von Hippel & Katz, 2002). The main difference between the co-creation approaches and tools for innovation is the level of interaction between the manufacturer and the user (Goduscheit & Jørgensen, 2013) which is relatively low for digital tools and this allows to scale the design and production of personalized products. Toolkits differ by the degree of design freedom that they offer to users so that toolkits with a substantial degree of freedom allow users to actively create new products, while toolkits with a narrow degree of freedom may only enable the user to choose components passively from lists that is typical for mass-customization (Prügl & Schreier, 2006). Goduscheit and Jørgensen's literature review showed that most of the studies related to the user toolkits for innovation can be categorized as targeting mass customization. Most toolkits are relatively simple and are based on a few standard modules that offer a limited degree of freedom for users to add new functionalities and new designs to the solution space, and there is a lack of interaction between the users and the manufacturer. In our work, we are interested in digital tools that allow intended wearers to participate in the creation of ultra-personalized safety shoes. These tools should allow a significant degree of design freedom to accommodate a variety of individual needs and allow the intended wearer to express their wishes beyond option selection from a predetermined set of product options which is common in mass customization.

Perceived Risks, Control, and Trust

Consumer behavior is associated with risk-taking (Bauer, 1960) where an outcome of the activity is often uncertain (Sheth & Parvatlyar, 1995). Particularly the perception of risk is a central aspect of consumer behavior and risk can be perceived as painful and produce anxiety (Taylor, 1974). Discomfort and anxiety caused by the perceived risk may prevent consumers from choosing a product or a service (Conchar et al., 2004). Therefore,

it necessary to identify and understand perceived risks to develop risk-reducing strategies. Prior research has identified the different challenges of mass customization. From the perspective of customers, participating in co-design activities is associated with complexity, effort, and perceived risks that limit the success of mass customization (Piller et al., 2005). These challenges are known under the heading of "mass confusion" (Pine & Davis, 1993). The perceived risks of consumers in Online Apparel Mass Customization were further studied by Lee and Moon (2015) who discuss eight dimensions of perceived risks, namely: financial risk ("possible financial loss incurred by purchasing the product"), performance risk ("uncertainty about the performance of products"), psychological risk ("discomfort and anxiety experienced while using and purchasing the product"), social risk ("concern about others' acceptance of purchasing products"), time/convenience risk ("possible time loss and inconvenience caused by purchasing the product"), delivery risk ("worrying delay in the delivery"), additional effort ("uncertainty of additional work"), and return risk ("related to returning finished product").

Ultra-personalization relies on future users' personal data. Developments in digitalization reduced the costs of collection, storage, transmission, and analysis of personal digital data (Goldfarb & Tucker, 2019). At the same time, there are increased privacy concerns (Goldfarb & Tucker, 2012) that may affect future users' willingness to share their data for the creation of ultra-personalized products. There is emerging work that begins to recognize the complexities associated with consumer personal data for ultra-personalization, such as (Mironcika et al., 2020b), and suggests possible approaches to mitigate perceived risks.

For companies, ultra-personalization is asking for new ways of working (e.g., digital fabrication, new fabrication workflows, work automation, new patterns of work, new expertise for employees). The innovation of processes can meet different forms of "resistance to change" as people generally resist to change their work routines and behavioral patterns (Abu El-Ella et al., 2015) and cause perceived risk of unemployment due to automation (Innocenti & Golin, 2022). Increased user engagement in product creation can be associated with a risk of diminished control over company's planning and strategic management because other people or organizations are involved (Hoyer et al., 2010). Moreover, empowering users introduces a risk of complexity which can ask for extra coordination efforts (Hoyer et al., 2010). Engaging users at early stages of the new product development may result in risk of focusing on incremental and not on radical innovation (Hoyer et al., 2010). Besides, because of user involvement, the company's brand management may be affected and bring uncertainty for the company (Pitt et al., 2006). Looking more specifically at company risks associated with the customization of safety footwear, Janson et al. (2022) discuss barriers to the implementation of customization, for example, physical testing versus simulation (a significant effort to set-up the authorized procedure for simulated testing and certification), and new materials (efforts in developing materials and processes including a need for collaboration between software developers and material experts). In our view these barriers can potentially be experienced by companies as risks.

We see digital tools for ultra-personalization as a platform for cooperation between future wearers and the company. Both parties, future wearers and the company, should have confidence that digital tools facilitate cooperation which will allow them to reach their interests. In this we see an analogy with the literature on strategic alliances that concerns how cooperating firms reach confidence in partner’s cooperative behavior, only in our case the cooperation is mediated by digital tools. Das and Teng (1998) discuss that perceived risks, trust and control are related. The perceived risks from cooperation can be mitigated by building *trust* (positive expectations about another’s motives with respect to oneself in situations entailing risk) and introducing *control* (the process of regulating others’ behavior to make it more predictable). In our explorative study we asked participants to reflect on what risks they see with the proposed concepts, as well what they trust/distrust in concepts or want to control to better understand the risks they perceive.

Elicitation Steps

We followed three steps to probe and explore perceptions and attitudes toward digital tools that allow wearers to participate in ultra-personalization (Figure 1). In the first step, we interviewed study participants (safety shoe wearers and safety shoe experts) and found initial design dimensions. In the second step, we followed a Research through Design approach (Koskinen et al., 2012) utilizing the design skills of the authors we constructed nine design concepts based on the identified design dimensions to “probe on what the world could and should be” (Zimmerman & Forlizzi, 2014). In the third step, the same participants co-reflected on the concepts during co-reflection session and individual interviews. We have analyzed

the reflections and identified perceived risks. All participants who participated in both studies were invited from a safety footwear manufacturing company interested to explore opportunities of ultra-personalization. The study was reviewed and approved by the Eindhoven University ethics committee and all participants signed informed consent forms. The study was conducted in English and all participants were non-native English speakers.

Step 1. From Interviews to Design Dimensions

In the first interview study we aimed to find out exploratory ultra-personalization directions in the context of safety footwear.

Method

The study included seven participants (Table 1), four wearers with experience of wearing safety shoes (PP4, PP5, PP6, PP7) and three experts in shoemaking, namely a shoe designer (PP1), a podiatrist (PP2), and a shoe engineer (PP3). All participants participated online via a video call. We started by individually interviewing the participants and asking them about their understanding of what personalized safety shoes could be to identify participants’ areas of interest. Participants were asked to talk about their visions on the personalization of safety shoes as well as personal needs and wishes for such shoes and focus less on the current production possibilities. This allowed us to explore participants’ viewpoints in an unrestricted manner with an idea that needs and wishes of wearers might inform development of future production system that allow ultra-personalization. The study was reviewed and approved by the Eindhoven University ethics committee and all participants signed informed consent forms.

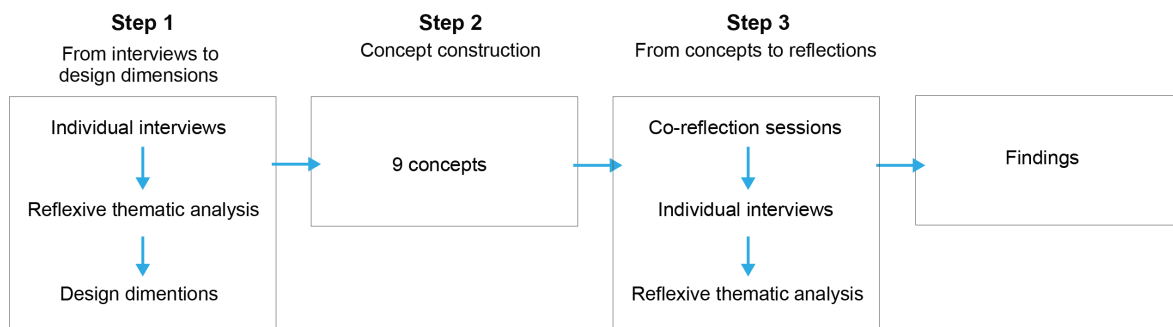


Figure 1. The flow of the explorative study.

Table 1. Study participants.

Participants	Occupation	Gender	Duration of wearing protective footwear
Experts	PP1 Shoe Designer	Male	Occasionally (when visiting the production floor)
	PP2 Podiatrist	Male	Occasionally
	PP3 Shoe engineer	Male	Occasionally (when visiting the production floor)
Wearers	PP4 Logistics manager	Male	Everyday
	PP5 Production engineer	Male	Everyday
	PP6 Shop manager with warehouse responsibilities	Female	Occasionally when working in the warehouse
	PP7 Shop manager with warehouse responsibilities	Female	Occasionally when working in the warehouse

Data Analysis

All interviews were audio-recorded and transcribed. The first author followed the reflexive thematic analysis approach (Braun et al., 2019). She first read and reread the transcriptions to familiarize with the data and made notes. The first author then explored and developed patterns across the dataset and iteratively developed codes that evolved through the coding process. After that, the first author constructed the initial themes that were discussed with the second and the third authors and we collaboratively developed four higher-level themes and gave them names.

Results

From the analysis the following four themes were developed: personalization of visual aesthetics, personalization to the context of use, fit to the body, and feet measurement process.

Two of wearer participants associated ultra-personalization with the look of the shoes and wanted shoes to look “elegant” (PP6-wearer) and “fun” (PP5-wearer). The focus on visual aesthetics informed the first design dimension—personalization of visual aesthetics. With this dimension we envision digital tools that would allow wearers to express wishes related to the visual appearance of shoes. We are particularly interested to explore what risks and opportunities can arise from wearers’ participation in defining the personal visual aesthetics of shoes.

The interviews with shoe experts clarified that different dominant activities, for example, walking, kneeling, or standing require different shoe constructions. Moreover, the environment where activities take place should also be considered for shoe construction (e.g., surface for walking that can require different slip resistance properties of the outer sole to offer the optimal safety). These insights were used for developing the second design dimension—personalization to the context of use.

Participants mentioned the importance of how the shoe fits and feels on wearers’ feet (PP7-wearer: “When I buy my shoes, the first feeling when I put shoes on is very important”, PP6-wearer: “[personalized] shoes should not be heavy”). This shows that participants are looking for particular qualities related to the fit and feel of shoes when they buy them therefore personal wishes for such qualities should inform the design of ultra-personalized shoes. Thus, the third design dimension is fit to the body, and we intend to probe a possibility to include felt physical sensations of wearers into the personalization of shoes.

Four out of seven participants talked about feet geometry and 3D scans that can inform ultra-personalization. With the fourth design dimension, the feet measurement process, we intended to design digital tools that would allow us to continue uncovering perspectives on the body related data and data collection process. We aimed to prompt discussion of who should gather data and with what technology, what are sensitivities related to body 3D data, question trust in captured data, as well as data ownership.

Four design dimensions were used to inform concepts that would further probe participants attitudes towards digital tools for wearers’ participation in the design of ultra-personalized safety shoes. We have constructed nine concepts of digital tools to explore participants’ reactions and attitudes towards such tools.

Step 2. Concept Construction

The first author, who is trained as an interaction designer, in partnership with the second and third authors, created nine concept visualizations, each targeting one of the design dimensions for personalization. Most of the concepts are speculations in a sense that we do not focus on the immediate feasibility of the tools but are rather interested in opening up areas for future research (Auger, 2013) around the perceived risks of personalization. Below we explain the concepts that were used in the second study to prompt discussion about users’ participation in ultra-personalization via digital tools.

Personalization of Visual Aesthetics

Two participants (PP5 and PP6) expressed wishes for a certain look of the shoes (“elegant” and “fun”). We developed three concepts each aiming to decode such requests into visual shoe designs with the help of 1) algorithms, 2) tools to manipulate the color and patterns of the existing shoe (beyond selection from the predetermined options), and 3) tools to manipulate the dimensions of the shoe.

In Concept 1, we proposed a digital tool that algorithmically generates shoe designs based on the mood boards and keywords composed by wearers (Figure 2). The motivation for this concept lays in a common practice of shoe designers to communicate with clients with a help of mood boards and keywords to build a common understanding about shoes to be designed and produced.

In Concept 2, users are offered an app with a set of design tools to experiment and design their own shoes (Figure 3). Comparing with widely used mass customization tools where users are assembling the product from the list of options, here we are interested to explore the possibility to pass to users specially crafted design tools to allow them to experiment with the design of shoes.

In Concept 3, we build upon the idea of virtual try-on where wearers can see how personalized shoes look on them and can adjust the proportions of the shoes if they wish (Figure 4). This concept was inspired by the fact that people who wear safety shoes frequently find their shoes to be larger than they had anticipated.

Personalization to the Context of Use

From the interviews we found that daily activities and the physical environment where activities and the physical work environment can inform the design of the safety shoes. This means that digital tools should allow for capturing information about daily activities and the physical work environment. In Concept 4, we used an example of the outsole that could be personalized by the app based on the floor images (physical work environment) uploaded by wearers. The design of the outsole is particularly important for the safety of work shoes as the direction and size of the grooves determine for example slip resistance (Figure 5).

In Concept 5, we proposed an app where wearers identify types of their typical activities (e.g., sitting, standing, walking, kneeling, etc.) and activity duration (Figure 6). The motivation for this concept is the fact that different activities require different shoe properties such as foot support, flexibility, bounciness, grip to support climbing leaders and many other elements.

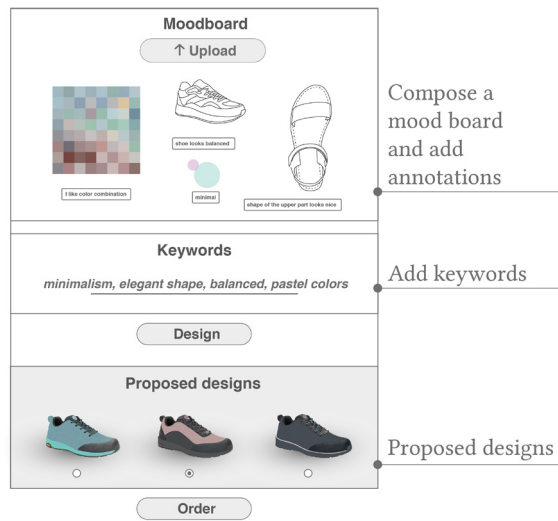


Figure 2. Concept 1. The images of shoes substitute the real images for copy rights reason.

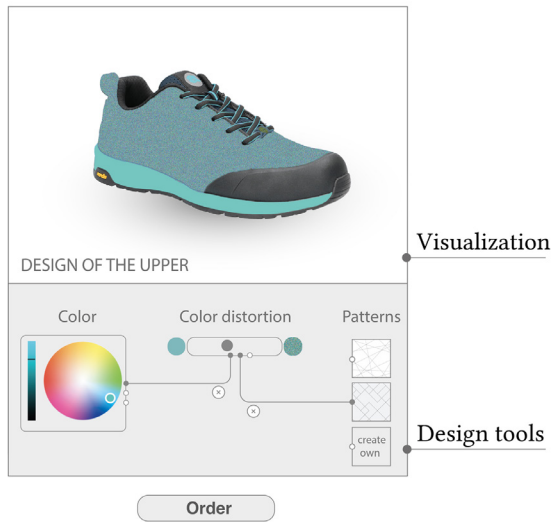


Figure 3. Concept 2.

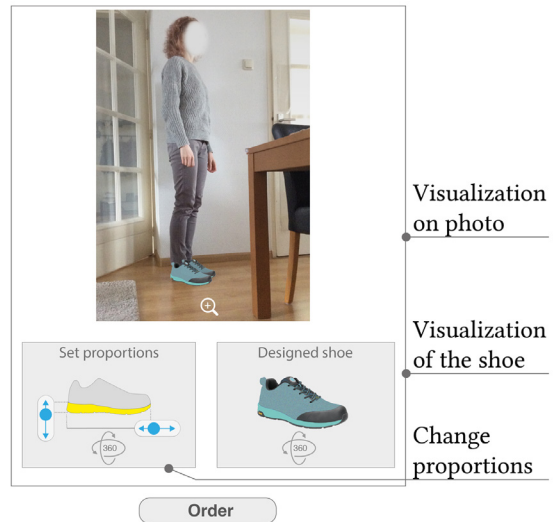


Figure 4. Concept 3.

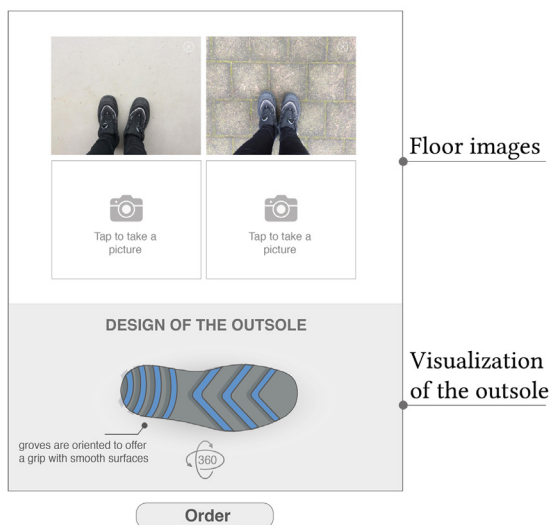


Figure 5. Concept 4.

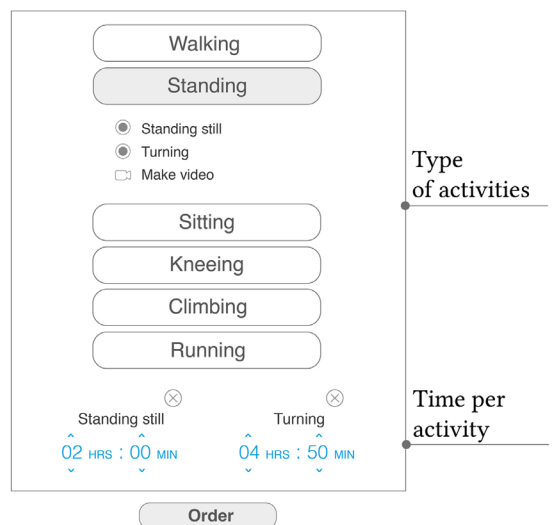


Figure 6. Concept 5.

Fit to the Body

Two participants (PP6 and PP7) talked about their wishes for a certain fit and feel of the safety shoes. We made two scenarios related to the fit and comfort of ultra-personalized shoes that allow 1) an explanation and a dialogue around shoe design decisions, and 2) capturing felt sensations of fit and comfort when wearing ultra-personalized shoes. In Concept 6, we explore a possibility of a dialogue about the personal fit of shoes between users and a company (Figure 7). Via the app the company proposes shoe construction based on 3D data of the user and the user can ask a question and add suggestions about fit elements.

In Concept 7, a user can reflect on the felt sensations on her feet while wearing a pair of shoes and together with the desired sensations capture that information in the app (Figure 8). Such a tool can be used to understand ultra-personalized shoe feels and capture data for the design of the next shoe.

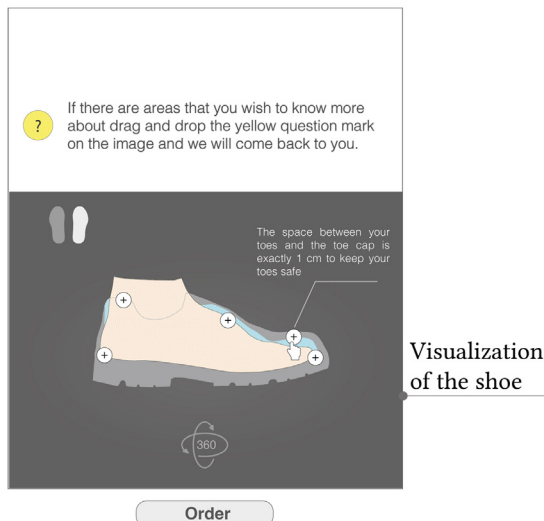


Figure 7. Concept 6.

Feet Measurement Process

Four participants talked about foot geometry and 3D scans for ultra-personalization. We developed concepts to explore perceptions of different foot 3D scanning approaches 1) 3D scanning with the help of mobile phones to offer self-measurement for future wearers, and 2) 3D scanning by professionals with dedicated 3D scanning technology. In Concept 8, feet are being photographed by wearers with the help of an app (photogrammetry) (Figure 9). Lastly, in Concept 9, data is being captured by a dedicated 3D scanner located with shoe distributors (Figure 10).

Step 3. From Concepts to Reflections

In the second interview study, constructed concepts were used to explore and elicit participants' perspectives on the proposed concepts of digital tools for users' participation in ultra-personalization.

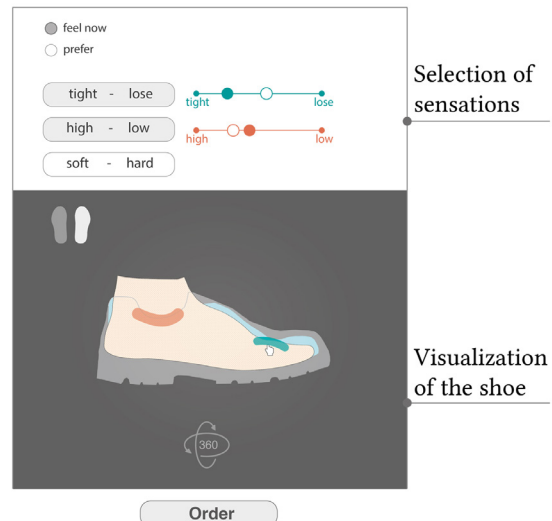


Figure 8. Concept 7.

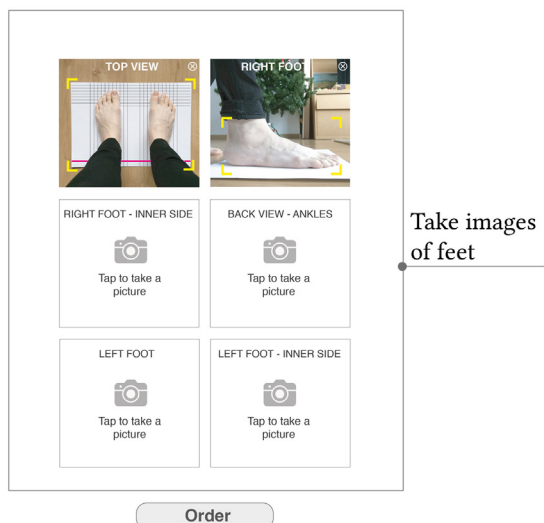


Figure 9. Concept 8.

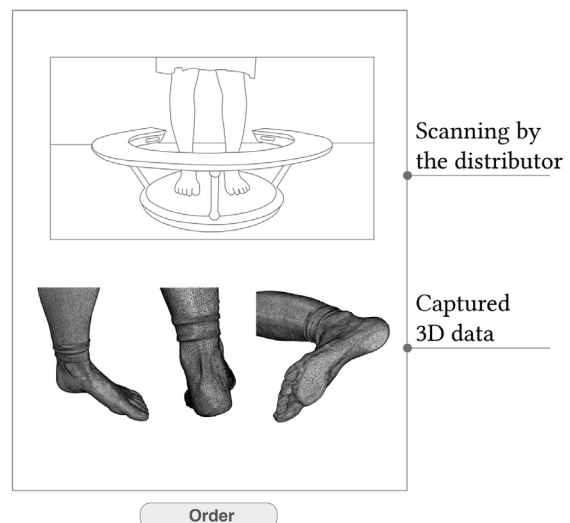


Figure 10. Concept 9. The image of the scanning process substitutes the real image for copy rights reason.

The same eight participants who were interviewed in Step 1 gave feedback on the concepts in two sessions: 1) an online group co-reflection session where the participants could exchange perspectives towards concepts, and 2) online individual interviews where the participants shared more nuanced attitudes and reactions on each of the concepts. Our main interest for the reflections is in the risks that the participants perceive, related issues of control and trust and whether perspectives of future wearers and R&D experts differed.

Method

In the online co-reflection session the researcher first introduced nine concepts, after that each participant chose two or more preferred concepts to comment on and individually commented on them for 30 minutes. Participants were asked to tell whether they perceived risks with any concept, what they trust and distrust in the concept, and whether there was something in the concepts that they wished to control. That was followed by the group discussion where each concept was discussed.

Individual follow-up interviews were set to elicit more detailed personal attitudes towards each concept. Participants were asked to reflect on whether they saw any risks with each of the concepts, and if there are elements that they trust or distrust and wish to control.

Data Analysis

First, we have identified which concepts were selected as preferred ones by each participant to find which design dimensions our participants found relevant. Second, the first author transcribed and analyzed the co-reflection session and follow-up interviews which resulted in rich data consisting of nearly 12.5 hours of audio recordings. Similarly, as in Step 1, we followed the reflexive thematic analysis approach (Braun et al., 2019). The first author familiarized with the data and made notes. Then she developed patterns related to perceived risks. After that, the first author constructed the initial themes that were discussed over multiple meetings with the second and the third authors and we collaboratively developed nine themes and then grouped them into three higher-level themes. Third, we were interested in identifying who from the participants were represented in each of nine identified themes. The first author revisited the coded data and counted number of sentences per each participant per each of nine themes.

Findings

Below we list our findings about the concepts that participants preferred, the distinction of perceived risks between experts and wearers, and the overview of the perceived risks on three levels: product (2), service (5), and production system level (2).

Preferred Concepts

During the first 30 minutes of co-reflection session participants were asked to select two or more preferred concepts out of the nine and comment on them. Table 2 shows which concepts were selected by participants.

Table 2. Preferred concepts chosen to comment by participants.

Design dimension	Concept number	Participant
1 Personalization of aesthetics	Concept 1	P5 – wearer P6 – wearer
	Concept 2	P6 – wearer
	Concept 3	P7 – wearer
2 Personalization to the context of use	Concept 4	P2 – expert P3 – expert P4 – wearer
	Concept 5	P1 – expert P7 – wearer
3 Fit to the body	Concept 6	P3 – expert P5 – wearer
	Concept 7	P3 – expert
4 Feet measurement process	Concept 8	P2 – expert P3 – expert P5 – wearer
	Concept 9	P1 – expert P2 – expert P4 – wearer

What is striking in Table 2 is that three of the four wearers preferred concepts that allowed for the personalization of visual aesthetics, while none of the experts expressed a preference for this design dimension. This can point to an unperceived opportunity for the shoe company. The other three design dimensions were chosen by both shoe experts and wearers, and this indicates an interest by wearers and experts and a perceived opportunity that those dimensions offer for ultra-personalization.

Distinction of Perceived Risks between Experts and Wearers

In total 109 sentences from transcribed audio were identified as associated to perceived risks. Perceived risks on product level represented 20 sentences or 18%, perceived risks on service level represented 75 sentences or 69%, perceived risks on production system level represented 14 sentences or 13% (Table 3).

From the data (Table 3) we see that some perceived risks (P1, S5) were commented on by both shoe experts and wearers. Other perceived risks (P2, S1, S3, S4, PS1, PS2) were commented only/mostly by shoe experts, and S2 mostly by wearers. The categories of risks commented only by experts relate to design and production of safety footwear. The data shows that two experts, particularly PP1 (Shoe Designer) and PP2 (Podiatrist), on average see more perceived risks compared to wearers.

Perceived Risks

We have identified risks associated with wearers’ participation in ultra-personalization via digital tools. Since ultra-personalization delivers tangible products, intangible services and it is enabled by the production system, we grouped risks that are related to product, to service and to production system levels.

Table 3. A summary of perceived risks categories and distribution of coded sentences (n = 109).

Perceived risks	Participants	shoe experts			wearers				Total	Commented by
		P1	P2	P3	P4	P5	P6	P7		
Product		10 (50%)			10 (50%)				20 (18%)	
1 Lack of experiential information about fit and feel		3	3			5		5	16	Experts + wearers
2 Multi-dimensionality of design as a risk for ultra-personalization			2	2					4	Experts
Service		49 (65%)			26 (35%)				75 (69%)	
1 Risk of sharing the control over decision making		13	3		3				19	Mostly experts (16 from 19 comments)
2 Risk for participation		1	2		2	7	3	2	17	Mostly wearers (14 from 17 comments)
3 Risk of not understanding wishes via digital services		6							6	Experts
4 Risks related to data		11	7	3	2		4		27	Mostly experts (21 from 27 comments)
5 Risks related to ways of communication		2	1					3	6	Experts + wearers
Production System		14 (100%)			0				14 (13%)	
1 Risk of automating experts' skills		5	2						7	Experts
2 Strict regulations as a risk for ultra-personalization		2	5						7	Experts
Total		43	25	5	7	12	7	10	109	

Risks on a Product Level

Although the goal of the co-reflection was to reflect on digital tools participants voiced several uncertainties related directly to the ultra-personalized products.

P1—Lack of experiential information about fit and feel. Participants have mentioned that there is a risk that ultra-personalized safety shoes will not meet their expectations regarding the appearance of shoes (PP5-wearer: “Now I am going to design the shoe and there always will be—ah, that’s not a color that I wanted, the sole is not what I expected”) and the fit to the body (PP2-expert: “I can imagine someone who kneels a lot and get a stiffer [personalized] shoe [can say]: I do not want this shoe because I want it to be more flexible”). These perceived risks result from the expectations formed by a digital visualization of the ultra-personalized safety shoes and a lack of physical experience with the product.

P2—Multi-dimensionality of design as a risk for ultra-personalization. Ultra-personalizing shoes in multiple dimensions could create a risk of conflicting parameters (PP2-expert: “For example, someone says I walk a lot, and I kneel a lot. For walking I would like to see more toe elevation and a stiffer outsole. But if this person needs to kneel you don’t want a stiffer sole because it needs to flex more, so that would conflict”). Therefore, choices should be made to balance requirements (PP3-expert: “That is a matter of making the choices in the development”).

Risks on Digital Service Level

There are multiple risks on the digital service level associated with wearers’ participation in ultra-personalization via digital tools.

S1—Risk of sharing the control over decision making. Decision making via digital tools is seen as a risk by both expert participants and wearer participants. Wearer participants stated that they might not have the competencies to take decisions related to the fit of the shoes (PP4-wearer: “I am not sure that the end-user is the person who tells R&D how the shoe must fit, or when it is giving enough support to his feet. I think there is something for the designer to figure out and not for the end-user”). Expert participants admitted that the design of the shoes should not be concluded by wearers (PP1-expert: “If I look at the app then the risk is how [it] is now presented [referring to the Concept 7] is that you let the customer make a conclusion what the shoe should be”). Several strategies were proposed to mitigate this risk for example, introducing limitations to designs (e.g., offer certain color pallets to ensure visual aesthetics, and limit areas that can be modified by wearers), carefully formulating questions to wearers that allow a company to preserve control over design decisions (PP2-expert: “Instead of asking where the shoe should be higher ask where do they feel pressure”).

S2—Risk for participation. There are several risks that can be seen as barriers to participation in ultra-personalization via digital tools. Participants mentioned that tools require digital

skills that they might not have (PP7-wearer: “I am not doing that, I am not an internet guy”, PP6-wearer: “I am the person who is not very good with computers”). There are concerns that digital tools will require efforts that wearers would not be willing to spend (PP7-wearer: “I do not think that everybody wants to give much time to buy shoes”, PP2-expert: “Knowing people they do not want to click many times, they do not want to answer many questions”). Moreover, some participants perceive personalization as an unwanted abundance of choices to select from (PP5-wearer: “The more colors you have more difficult it is to make a choice”). These reactions point out that digital services as well as skills and effort they ask from wearers may be perceived as a barrier for participation in ultra-personalization.

S3—Risk of not understanding wishes via digital services. Wishes and needs of wearers should be well understood by shoe experts before translating them into ultra-personalized designs (PP1-expert: “If they like a tight fit then you need to know why they like to have a tight fit there. Because it looks nice, or because a wearer wants to have a grip for stability. But if you only ask if they want it tight or loose then maybe they will choose the wrong option [referring to the Concept 7]”). Participants experts raised their concern whether the motivations behind wearers’ wishes can be well understood via digital tools. Besides gathering wearers’ preferences for ultra-personalized shoes, digital tools should also gather motivations for wishes and this requires analyzing wearer’s requests and asking follow-up questions to build a common understanding of what wearers wishes and needs are and what is feasible to produce. For digital tools to be able to do such an inquiry it is necessary to translate expert knowledge of shoe construction and material behavior into digital tools. Translating the skills of shoe professionals into digital tools is perceived by expert participants as (PP1-expert) “too complex” and there is a risk of not fully understanding wearers’ wishes and that will result in producing shoes that do not fit wearers’ expectations.

S4a—Risks related to data: Process and tools for data gathering by wearers. There is a clear advantage of using digital tools for capturing wearers’ data, which includes body geometry data, activity data, and data related to the context of work, as data collection can be done at a time and location convenient to wearers. At the same time, participants foresee a risk of getting incomplete or wrong data (PP6-wearer: “When there are no good measurements you can get wrong shoes”, PP1-expert: “If you ask wearers how much they walked and they give an estimation, so the data is an interpretation of themselves and not a real data”). Wearer participants used an analogy of prescription glasses where measurements are done by professionals suggesting that personal body-related data should be gathered by professionals (PP5-wearer: “When you buy the pair of glasses then the measurement is done by professional people and not with the tool like this [referring to the Concept 8]”). To diminish risks associated with data collection participants proposed automating data collection with a help of built-in sensors to collect activity-related data (PP1-expert: “It actually would be best to monitor people, track them with the watch or the sensor in the shoe, measure what are

they doing and then make it immediately personalized up to the person”), as well as to develop guidance within apps to support self-measurement to prevent mistakes (PP1-expert: “you need to give good guidance on how to scan, if they do not follow then you get the wrong outcome”).

S4b—Risks related to data: Privacy. Another risk around data collection is data privacy and wearers’ perception of gathered data. In proposed concepts experts lacked considerations around who should have access to the data and how that may affect wearers’ willingness to participate in ultra-personalization (PP2-expert: “Because does the employee wants to know that the employer is tracking their movement all day?”). Moreover, personal data may be perceived as highly sensitive (PP2-expert: “And people might not want to share the picture of their bare feet”) and this may hinder wearers from sharing it.

S5—Risks related to ways of communication. From the interviews we see that risks may arise from a lack of communication between a company and wearers. For example, experts mention that they might not fully understand the wishes of wearers and they need to know motivations for wishes to make personalized shoes (PP1-expert: “If a wearer wants to have loose laces it could be that they are lazy to lace up [...] or because they feel too tight and the foot is pressed down and deformed when walking because of the stiff leather and the foot is suffering”). Wearers commented on several concepts that they want to know more about design decisions before deciding to buy shoes (PP7-wearer: “I really want to know how they are doing this otherwise I won’t buy these shoes”). These examples suggest that to decrease the risk of misunderstanding between a company and wearers it is necessary to build digital services that support good communication. During interviews when reflecting on different concepts participants mentioned that digital services for ultra-personalization should allow them “to explain” (experts–PP2, PP3), “to let know” (expert–PP3), “to inform” (experts–PP1, PP3), “to give/share information” (experts–PP1, PP2), “get information” (expert–PP1, wearer–PP4), “to listen to” (expert–PP1), “to go into a dialogue” (expert–PP1), “to ask” (experts–PP1, PP2), “to suggest” (expert–PP1), “to comment on” (wearers–PP4, PP6), and this suggests that services should support these ways of communicating.

Risks on Production System Level

When talking about digital services for ultra-personalization participants were reflecting on the existing production system and implications that ultra-personalization would have on it. This shows that certain risks associated with future digital services can be rooted in the current capabilities and capacities of the production system and processes. Both categories of perceived risks were derived from expert’s quotes.

PS1—Risk of automating experts’ skills. To scale the design and production of personalized products certain processes of shoe creation need to be automated. Participants perceived that some skills of experts cannot be automated, and automation will lead towards the loss of product quality. For example, automation of shoe design is seen as a risk. A talent of a designer is in

identifying trends and finding the right time to introduce trends into a product and this is very important for trend-sensitive markets. Expert participants believe that such skills cannot be automated (PP1-expert: “[Referring to the Concept 1], I think these features [...] are almost impossible to put in the algorithm because it is quite difficult to put this on paper as it is not always that straightforward. [...] Algorithms cannot do that because fashion is still controlled by humans”). Another risk with expert skill automation is that the role of the expert can be taken by the technology and this would affect the expert’s willingness to participate in creating automated systems (PP2-expert: “[The device] could potentially take over my job. [...] I would not be developing it [this device] if I knew that the company does not have a job for me anymore”). Moreover, algorithms are seen as a big risk since experts do not have experience with automation (PP1-expert: “If I look at this option in general [referring to the Concept 1], is this tool then the algorithm itself would be a big risk [...] Because we are footwear developers and not [software] developers”).

PS2—Strict regulations as a risk for ultra-personalization.

Safety work shoes need to comply with certification requirements and changing one part of the shoe requires a re-certification of the full shoe. Existing rigid product certification requirements can influence the design freedom for ultra-personalization (PP2-expert: “There are regulations and this is something we need to conform to”, PP1-expert: “Since regulations are very rigid to deal with nowadays it makes no sense to look into opportunities there”). As a solution to rigid regulations expert participants see an opportunity to increase product range that is pre-certified and use them to assemble shoes that better match wearers’ requirements (PP2-expert: “We would need to make pre-certified outsoles with different ways of patterns in the outsoles which they [wearers] can choose from”). Another risk is with the lack of possibility to test every new shoe model as regulations currently require poses an extra risk (PP2-expert: “[With ultra-personalization] you will always have shoes that were never tested before, so creating an individual shoe for someone without testing is always a risk”).

Discussions and Future Directions

Unperceived Opportunities

We found differences between wearers’ and shoe experts’ preferences for what to ultra-personalize. When we asked participants to choose preferred concepts to comment on only wearers selected concepts from *personalization of visual aesthetics* design dimension. This indicates that shoe experts do not see an urgency in this design dimension and do not give it a high priority. This divergence of interests is particularly interesting as it shows that a company may have unperceived opportunities for ultra-personalization. Companies should be aware that unperceived opportunities may exist and develop tools that can help them to identify those opportunities. For example, digital tools could have the possibility for wearers to rate various future directions for ultra-personalization or allow wearers to offer suggestions for what they wish to ultra-personalize and why.

Unperceived Risks

Our data shows that shoe experts (particularly PP1 and PP2) perceive more risks associated to user participation in ultra-personalization. This suggests that perceived risks can be expertise related. Design and production processes require specific expertise that wearers generally do not have, and they may be unaware of possible related risks. Wearers might desire certain product properties that can be unfeasible for design and production. This may lead to frictions between what is desired by wearers and what can be produced by a company. Therefore, expectations and wishes of wearers need to be balanced with a help of digital tools. These tools can educate wearers about the design possibilities as well as possible risks if they request something that is beyond what is possible to produce.

Known and New Perceived Risks

Five perceived risks associated with digital tools for user participation in ultra-personalization (P1, S1, S2, S4a, PS1) were previously discussed in earlier works on consumer behavior, online shopping, mass customization, human-computer studies, new product development, organization, and management studies. Table 4 offers an overview of identified risks and similar risks found in the literature.

Five perceived risks (P2, S3, S4b, S5, PS2) appear to be inherently related to ultra-personalization. From these, four risks (P2, S3, S4b, PS2) were commented only/mostly by shoe experts and one risk (S5) was commented by both wearers and shoe experts. From our explorative study we see that experts perceive most of the risks that were not identified earlier.

More Diverse or Personalized Digital Tools

In our work we found that all wearers referred to perceived risks related to participation in ultra-personalization via digital tools. This suggests that digital tools should be designed to fit various interests of wearers, different skills, and the amount of time and effort that they wish to spend on ultra-personalization. Future work should explore whether digital tools should be designed to be more diverse and to what extent or whether there is a need to personalize these tools for each user.

Approaches to Mitigate Perceived Risks and Future Research Directions

Augmenting Digital with Physical (for P1)

Without experiential information about fit and feel it is hard for wearers to assess whether designed shoes fit them. Product fit uncertainty (Hong & Pavlou, 2014) and lack of touch and feel of products (Kim & Krishnan, 2015) cause a big number of product returns. AR and VR technologies for virtual assessment of fit are found not to be effective yet (Chu et al., 2022). To mitigate the perceived risk associated with the lack of information about fit and feel we see a need to augment digital design of ultra-personalized

Table 4. An overview of the perceived risks.

Identified perceived risks	Similar risks identified by earlier works	Commented by
Risks on product level		
P1 Lack of experiential information about fit and feel	Performance risk The possibility that a product proves disappointing when the product does not match the purchaser's expectation (Jacoby & Kaplan, 1972)	Experts + wearers
P2 Multi-dimensionality of design as a risk for ultra-personalization	Not identified earlier	Experts only
Risks on service level		
S1 Risk of sharing the control over decision making	Risk of diminished control Risk of diminished control over the project because other people or organizations are involved [Hoyer et al., 2010].	Mostly experts
S2 Risk for participation	Time/convenience risk Time/convenience refers to the possibility of a time loss caused by wasted time and inconvenience during the online purchase process (Forsythe et al., 2006; Forsythe & Shi, 2003). Additional effort Additional effort refers to the uncertainty of additional work during the online apparel mass customization purchase process (Lee & Moon, 2015).	Mostly wearers
S3 Risk of not understanding wishes via digital services	Not identified earlier	Experts only
S4 Risks related to data	a. Privacy risk Concern for the theft of the private information, or simply its misuse by the company collecting it (Featherman & Pavlou, 2003). b. Process and tools for data gathering by wearers Not identified earlier	Mostly experts Mostly experts
S5 Risks related to ways of communication	Not identified earlier	Experts + wearers
Risks on production system level		
PS1 Risk of automating experts' skills	Perceived risk of being replaced by a machine or an algorithm Perceived risk of unemployment due to automation (Innocenti and Golin, 2022).	Experts only
PS2 Strict regulations as a risk for ultra-personalization	Not identified earlier	Experts only

shoes with physical experiences. Colors and materials of ultra-personalized products could be accessible to wearers in dedicated experience centers. We also envision a new type of experience products that will allow to pre-test physical sensations of ultra-personalized product and assess its the fit to the body. For example, modular garments with adjustment possibilities to allow wearers to adjust the garment's fit before the ultra-personalized garment is produced. For products made from harder materials, for example shoes, we envision creating a variety of modular and/or adjustable parts (e.g., Greci et al., 2012) that can be assembled and tested for personal fit.

Offer an Opportunity for a Dialogue (for P2, S3, S5)

A lack of communication between the company and wearers is perceived as a risk in ultra-personalization via digital tools. Shoe experts want to have the opportunity to follow up the request of

wearers to propose a specific design. The wearers want to stay informed about the decisions for shoe personalization and ask questions if something is not clear. This suggests that tools for ultra-personalization should include dialogue possibility for co-designers. We envision that a dialogue could be supported via chatbots (conversational software agents with automation capabilities). Future work should explore the extent to which chatbots can support the communication with a prospective wearer during ultra-personalization and whether human operators (human-in-the-loop; Cranor, 2008) are necessary to take over the communication if needed.

Educate Wearers (for P2, S1, PS2)

Ultra-personalized products should be created in balance with what is desired by wearers and what can be produced by a company. Wearers often are not experts in design and production

and may not know what is possible and why. Digital tools should be designed such that they educate wearers (in accessible ways) about the design opportunities to manage their expectations of what and how artifacts can be ultra-personalized.

Automatic Certification (for PS2)

Rigid certification requirements apply to safety footwear. A change in only one shoe element requires recertification for the full shoe and that is a time and cost-demanding process. One of the possible approaches to this limitation is “automatic certification” proposed by (Ellena et al., 2018). We see a need to further investigate opportunities for automatic certification for ultra-personalized products.

Co-Design Data Gathering Tools

The broad range of risks related to personal data for ultra-personalization is asking for a careful attention. Tools designed for data collection should be trusted by a company and by wearers. When designing and using data gathering tools company should be aware of wearers’ various attitudes towards data gathering tools and processes (e.g., Mironcika et al., 2020b). Future work needs to explore the wearers’ perceptions related to various types of personal data and how those personal perspectives can influence design of data gathering tools.

Limitations

The concepts of digital tools for ultra-personalization were presented as visualizations and participants were not able to interact with envisioned digital tools. Participants would likely have mentioned new risks or provided a more detailed explanation of the risks mentioned if they had the opportunity to interact with fully developed digital tools.

The study was conducted in collaboration with a company that designs and manufactures safety footwear and is interested in exploring the possibilities of ultra-customization, so we cannot exclude positive expert bias.

The explorative study focused on safety footwear that is subject to strict safety regulations. Such regulations do not apply to everyday footwear and perceived risks identified in this study may not apply to everyday footwear. Furthermore, the study was carried out with one company and seven participants. Nevertheless, participants’ contribution in terms of effort resulted in a significant amount of data that offered us diverse insights.

Conclusions

In this work we have explored perceived risks associated with digital tools that allow user participation in ultra-personalization in the context of safety footwear. We have created nine speculative concepts of digital tools for the ultra-personalization of safety shoes to probe participants’ attitudes toward such digital tools. Participants co-reflected on the concepts during session and then in individual interviews. We have found a number of perceived

risks associated with digital tools on product (2 risks), service (5 risks), and production system levels (2 risks). From those perceived risks five were identified as inherently related to ultra-personalization and were not discussed in the literature earlier. Along with perceived risks we found that shoe experts had unperceived opportunities and wearers unperceived risks. Based on the identified perceived risks we have proposed risk mitigation approaches and future research directions.

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