

ORIGINAL RESEARCH ARTICLE

Smart mobile clothing redefines fashion through personalization, connectivity, expression, and portability

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Abstract

The smart apparel industry in North America has expanded notably in recent years and this trend is particularly due to increasing interest in wearable technology. These garments are a combination of connectivity, personalization, as well as enhanced functionality aimed at improving performance-related and experiential dimensions, self-expression, mobility, safety, and everyday usability. Due to the pandemic, an accelerated adoption of wearables in medical and safety applications has been observed which has reshaped the connected apparel market. This study explores the attitudes of the consumers toward smart and customized sportswear, focusing on the gap between technological innovation and real-world demand. A survey of 194 respondents was conducted using a mixed-methods research design. The results revealed that there is strong consumer interest in advanced features such as biometric tracking, thermal regulation, and effortless device integration. However, concerns about data security, high costs, and product durability were found to be the main barriers for the adoption. These findings indicate that technological potential alone is insufficient to ensure widespread market acceptance. Although early adopters have embraced these innovations, skepticism about their long-term viability has grown. Furthermore, results showed that consumers have a preference toward a tailored approach and value mobility, convenience, and ease of use over mass-market solutions. They usually search for lifestyle elevation as well as strong purpose-led products. This research shows the significance of mobility and functionality in leading adoption. By innovating with user expectations in mind, smart clothing brands may help reshape parts of the industry and contribute to an evolving relationship between fashion and trust-based personalization.

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1. Introduction

The emergence of smart clothing is a significant development that reflects a convergence of advances in technology and needs of the society. Beyond technological progress, this emergence also raises critical questions related to adoption, usability, and value creation for end users. In this study, the term “smart clothing” refers specifically to

textile-based garments integrating embedded sensors, connectivity, and data-processing capabilities, and is used interchangeably with “smart apparel” when referring to consumer-facing wearables products in the sportswear and lifestyle segments. The trend can be traced back to the 1980s. Early innovations, particularly in aerospace, played an influential role in this evolution. Thermoregulating textiles for spacesuits, as developed by NASA is an example of the way functional fabrics were initially designed for the purpose of specific environmental challenges. This laid the groundwork for further innovations in the field of smart textiles.¹ These initial applications showed that textiles have the potential to interact with their environment. This concept has now been applied to several areas, including healthcare and personal wellness. In the early 2000s, projects such as the Smart Shirt developed by the Georgia Institute of Technology revolutionized the integration of electronics with textiles. In this pioneering work, biometric sensors were incorporated into fabrics. This integration enabled real-time health monitoring and demonstrated that the textiles have the potential to serve as platforms for wearable technology.² With advancements in materials science, the integration of electronics into textiles has further evolved. This has enabled the creation of breathable, flexible, and stretchable fabrics that are essential for wearable applications.^{3,4}

This interdisciplinary collaboration between fields such as medicine, engineering, and computer science has been important for the transformation of clothing into connected systems that not only improve the quality of life while also tackling the challenges of mobility and wellness.³⁻⁴ Today, smart clothing has the ability to provide personalized experiences and meet varied user needs. The synergy between advanced textile technologies and electronic integration has resulted in garments that not only perform traditional functions but also monitor physiological parameters, in addition to adapting to environmental changes.^{5,6}

However, despite these technological advances, large-scale consumer adoption remains limited and uneven across application domains. This evolution shows a trend in design thinking which is quite broad, where co-creation and collaboration between end-users, designers, engineers as well as healthcare professionals are increasingly recognized as essential for the development of innovative textiles that address growing needs of societies.⁷ As the industry is evolving, the focus on sustainability and end-of-life solutions for electronics-based smart textiles will become increasingly important. It needs to be ensured that these innovations make a positive contribution to the user experience as well as to the environment.⁸ The potential

of smart clothing is particularly evident in areas such as healthcare, workplace safety, marketing, and fashion. Over a couple of decades, advances in mobile computing and the miniaturization of electronic components have made these innovations a tangible reality. Smart textiles, particularly the ones that have thermally conductive fabrics, are excellent examples of the functional capabilities of clothing. These fabrics can respond to environmental stimuli, such as temperature changes. This way, they can enhance comfort and functionality of users.

Research has shown that textiles embedded with phase change materials (PCMs) can regulate temperature by absorbing, storing, and releasing thermal energy. This functionality is particularly relevant in domains such as healthcare and outdoor apparel, where thermal comfort and physiological regulation are critical.⁹ The collaboration among several stakeholders, such as researchers, end-users, designers, and manufacturers, has been essential for the creation of smart textiles that are lightweight and comfortable. For example, the development of e-textiles which have sensors and actuators can monitor vital signs, detect falls, or provide feedback for rehabilitation.¹⁰ However, despite excellent potential of smart textiles, the smart clothing industry has a multitude of challenges. Complex questions about manufacturing processes, sustainability, and recyclability arise when advanced technologies are integrated into textiles. In addition, expectations of the consumer related to sustainable functionality, and personalization are putting a lot of pressure on industry processes for adaptation and innovation. Addressing these challenges is important for ensuring that there is long-term affordability and sustainability of smart clothing.

Furthermore, mobility solutions are currently a particularly promising area of application. For cyclists, users of alternative modes of transport such as skateboards as well as scooters, and outdoor sports enthusiasts, intelligent clothing provides the opportunity to combine safety, self-expression, and comfort. Not to mention advanced features such as reflective devices, motion sensors, or textiles with heating or even cooling capabilities. The same goes for clothing adapted for people with disabilities, which could revolutionize the concept of inclusion in fashion.

The economic potential of smart clothing is expanding steadily. Industry forecasts estimate that the global smart clothing market was valued at approximately USD 2.47 billion in 2026 and is projected to reach USD 9.97 billion by 2034, representing a compound annual growth rate (CAGR) of about 15.78%.¹¹ However, compared to the broader wearable technology market¹², smart clothing remains a niche segment, reflecting persistent technological, manufacturing, and adoption barriers. This

demand increase is based on several factors, including advancements in sensor miniaturization, increasing consumer interest in personalized clothing, and greater awareness of the role of clothing in health monitoring and safety. Today's consumers are looking for products that match their lifestyle preferences; however, a detailed investigation of their evolving preferences is highly essential. Therefore, the core research question of this study is focused on understanding consumer interest in connected clothing in the active sports sector as they are the main stakeholders who will decide the future trajectory of advancements in smart clothing based on their preferential choices. The goal is to provide companies with actionable insights related to the development and marketing of personalized smart clothing.

Thus, the aim of this study is to examine the many facets of smart clothing and to answer a central question: how can these innovations satisfy the growing demands for personalization, mobility, self-expression, and well-being for consumers, while at the same time meeting the industrial and technological challenges they face? This question is addressed through an empirical investigation of consumer perceptions and adoption dynamics. In order to provide a comprehensive understanding, this analysis is based on three main domains: (1) technological innovations and applications which mostly explore the cutting-edge technologies behind the development of smart garments and their practical uses; (2) manufacturing, personalization, and sustainability, examining the challenges and opportunities which are associated with production processes, customization strategies, and eco-friendly practices; and (3) implications for users and market adoption, namely as an assessment of the impact of these advances on end users, particularly in areas such as mobility, physical activity and adaptive fashion.

2. Literature review

The field of smart clothing has been the subject of extensive academic and industrial research over the past two decades. Early studies mainly focused on the integration of sensors into fabrics. It paved the way for advances in health monitoring, athletic performance enhancement, and adaptive fashion. This section discusses the existing literature and identifies research gaps in the domain of smart clothing.

2.1. Evolution of smart clothing technologies

Research on smart textiles initially revolved around the development of electronic textiles (e-textiles). These were capable of embedding conductive fibers in traditional fabric structures. Post *et al.*¹³ introduced the concept of wearable computing by integrating microprocessors into

clothing. This highlighted the potential for real-time data collection and user interaction. This foundational work laid the groundwork for contemporary innovations in sensor-embedded garments, including biometric tracking, environmental adaptability, and connectivity features.

The history of smart clothing can be traced back to the 1990s due to significant technological advancements. The Georgia Institute of Technology's "Smart Shirt," developed by Jayaraman and Park,¹⁴ was a pioneering innovation. It integrated biometric sensors which were capable of real-time physiological monitoring. These early experiments laid the foundation for modern smart textiles. They demonstrated the potential applications of smart textiles in healthcare, military, and consumer fashion. Advances in nanotechnology and flexible electronics have since enabled the miniaturization of components. This flexibility has enhanced the durability, comfort, and functionality of smart garments.¹⁵

Recent research by Fernández-Caramés and Fraga-Lamas¹⁶ highlights how wearable technology is evolving into a more integrated ecosystem, connecting smart clothing with IoT-enabled devices. Companies like Hexoskin and Myant have pioneered health-monitoring garments, reinforcing the link between biometrics and predictive healthcare solutions.

In parallel, the rapid adoption of non-textile wearables such as smartwatches and fitness bands has shaped consumer expectations regarding real-time data access, usability, and device interoperability. However, unlike wrist-worn devices, smart clothing offers continuous body coverage, improved sensor stability, and closer proximity to physiological signals, enabling more seamless and embodied data collection.

This distinction positions smart clothing not as a replacement for existing wearables, but as a complementary and potentially more immersive interface for health, performance, and mobility-related applications.

Research has shown that a purpose-driven approach leading to emotional connection can have a massive impact in shaping customer engagement and behavioral outcomes. Recent empirical research demonstrates that emotionally engaged customers exhibit higher repurchase intentions, greater advocacy behaviors, and increased long-term relationship value for firms.¹⁷ Emotional connection therefore represents a strategic driver of customer lifetime value and customer retention for retailers. Prior research has shown that customer experiences across digital and physical touchpoints influence customer engagement and behavioral outcomes.¹⁸ According to YouGov, 65% of Generation Z consumers report that they prefer brands

that communicate moral values and ethical positioning, and 63% state they are more likely to purchase from brands whose views align with their own. Generation Z therefore expects brands to demonstrate authenticity, social responsibility, and contributions to societal well-being, reinforcing the lifestyle and well-being dimensions associated with smart clothing.¹⁹ These industry-based insights are used to contextualize consumer expectations rather than to serve as primary empirical evidence.

2.2. Applications in health and well-being

Smart clothing has been extensively studied in healthcare applications. Medical research has focused on wearable textiles that monitor vital signs, detect early symptoms of diseases, and provide biofeedback for patients with chronic conditions. Studies by Gao *et al.*²⁰ discuss the integration of sweat sensors in smart garments, allowing non-invasive tracking of hydration levels, electrolyte balance, and stress biomarkers.

Textiles capable of delivering medication transdermally have been developed²¹, offering a potential breakthrough in chronic disease management. Adaptive garments equipped with embedded electrodes can assist in neuromuscular rehabilitation, improving mobility for patients recovering from injuries. Additionally, smart clothing designed for elder care can monitor falls, detect cardiovascular irregularities, and improve the overall quality of life for aging populations.²² These applications illustrate the clinical and therapeutic potential of smart clothing, while also highlighting the importance of reliability, comfort, and long-term usability in real-world contexts.

2.3. Consumer adoption and market trends

While technological feasibility has been a focus, consumer behavior remains an important determinant of commercial success of smart clothing.²³ Studies by Ju and Lee²⁴ highlight skepticism surrounding data security and privacy as major barriers to adoption. Consumers express concerns over how biometric data is stored and used. They emphasize the need for transparent data governance policies. The demand for personalization is a growing trend.²⁵ Brands such as Sensoria and Myant, for instance, have developed garments that adapt dynamically to users' body morphology and movement patterns.

Athletes and fitness enthusiasts increasingly favor smart garments which are capable of providing real-time biomechanical feedback, optimizing training regimens and reducing injury risks. Additionally, AI-based analytics enhance predictive insights which allow users to tailor their activities for optimal results. These trends reported in both academic and industry-oriented studies highlight the

growing importance of personalization and data-driven feedback in shaping consumer expectations toward smart clothing.

2.4. Sustainability and manufacturing challenges

Despite its promising applications, smart clothing presents sustainability challenges. Electronic waste is a growing concern, as traditional textiles are not designed to accommodate embedded circuits and sensors. Research by Fobelets *et al.*²⁶ calls for eco-friendly alternatives, including biodegradable conductive materials and modular electronic components that facilitate recycling. Prahl²⁷ discussed how cradle-to-cradle design principles may help reduce waste and extend the usability of functional garments. Recent research highlights that smart textiles introduce complex sustainability issues related to material selection, manufacturing processes, and end-of-life management, requiring eco-design and circular design strategies, including modular architectures, to mitigate environmental impacts.²⁸

Beyond material selection, sustainability challenges also extend to the full lifecycle of smart clothing, including manufacturing, use, maintenance, and end-of-life management. Unlike conventional apparel, smart garments integrate electronic components that complicate disassembly, repair, and recycling processes. Lifecycle-oriented approaches therefore emphasize modular architectures, where electronic elements can be removed, upgraded, or replaced independently of the textile substrate, reducing premature obsolescence and waste generation.²⁹

Additionally, the development of energy-harvesting textiles capable of generating power from movement or ambient heat could revolutionize the sector, eliminating dependence on external batteries.³⁰ Such solutions not only enhance user autonomy but also contribute to sustainability objectives by reducing battery-related waste and extending product lifespan.

2.5. Research gaps and positioning of this study

Although there is a lot of recent progress in the field of smart clothing research, there are still several critical gaps which exist. First, there is an urgent need for more studies which combine textile engineering, data science, and human-computer interaction. This could help to improve predictive analytics and adaptability in wearable technology. Second, not much has been done to address the ethical concerns of consumers with respect to their privacy and security. Several in-depth studies are required to further investigate existing regulatory frameworks and consumer protection laws along with the discussion of

their compliance by industries. Furthermore, the economic impact of smart clothing is a complex area of study.

Although the broader wearable technology market is projected to expand rapidly, from USD 96.44 billion in 2026 to USD 231.43 billion by 2034.¹² However, many barriers still hinder the large-scale adoption of smart clothing specifically, including consumer reluctance, high production costs, and the rapid obsolescence of embedded technologies.

Addressing these challenges requires a multidimensional approach that focuses on improved usability, affordability models, and specific marketing efforts. Most importantly, a thorough understanding of consumer behavior, preferences, and expectations is highly essential because consumers are the end users and are the primary stakeholders in the adoption of smart clothing. Strategies for usability and affordability must be based on consumer insights. This will ensure that innovations are aligned with their needs, concerns, and lifestyles.

In response to these gaps, this study adopts a consumer-centered empirical approach to examine adoption drivers, perceived barriers, and expectations related to personalization, connectivity, and usability in smart clothing. By combining survey data with expert insights, the study contributes to the literature by linking technological innovation to real-world consumer demand and market readiness.

This study aims to bridge these gaps and explores consumer behavior to inform the development of more user-centric and sustainable smart clothing solutions. The existing literature shows that there is transformative potential of smart clothing in multiple domains. However, further research is necessary to align technological advancements with user expectations and hence the need for this particular study.

2.6. Research hypotheses

Based on consumer behavior trends and gaps from existing literature, the following hypotheses were formulated to examine preferences for smart clothing:

- Consumers prioritize comfort, fit, and ease of use when considering the adoption of smart apparel over purely technological features.
- Younger adult consumers (18–35) are more likely to adopt smart clothing, driven by familiarity with wearable technology and digital integration. This hypothesis allows for variation within age subgroups depending on perceived usefulness and purchasing power.
- Consumers value personalization in smart clothing

and are more inclined to purchase products that allow for customization in functionality, aesthetics, and performance enhancement.

3. Methodology

This study employed a mixed-methods research design to explore consumer adoption and personalization preferences related to smart clothing, with a specific focus on active sports space. A mixed-method approach was selected to capture both measurable behavioral patterns and deeper qualitative insights into consumer perceptions, motivations, and barriers to adoption. Combining quantitative survey data with expert interviews and secondary market analysis allowed for triangulation of findings and increased the robustness of the results.

3.1. Research design and approach

The research design integrated three complementary data sources: a consumer survey, semi-structured expert interviews, and secondary market analysis. The quantitative component consisted of a structured questionnaire comprising 25 items, including categorical questions, ordinal scales, and Likert-scale measures. These items assessed key dimensions such as perceived technological appeal, price sensitivity, data security concerns, and preferences for personalization and functionality in smart clothing.

To complement the quantitative data, semi-structured interviews were conducted with industry experts specializing in textile engineering, wearable technology development, and sportswear retail. These interviews provided contextual insights into technological constraints, production challenges, and emerging market trends. In addition, secondary data from industry reports, market research publications, and case studies were analyzed to situate the empirical findings within broader economic and technological developments in the smart apparel sector. Prior to full deployment, the questionnaire was pre-tested with a pilot sample of 20 participants to ensure clarity, relevance, and consistency of the items. Feedback from this preliminary phase led to minor revisions in wording and scale alignment, improving the overall reliability and usability of the survey instrument.

3.2. Data collection and administration

Data collection was conducted online over a 20-day period using SurveyMonkey, selected for its accessibility and data management capabilities. Participants were recruited through social media platforms, primarily Facebook and LinkedIn, to reach a diverse audience with varying levels of engagement in active sports and wearable technology. Inclusion criteria required participants to be at least 18

years of age and to have prior experience with, or interest in, sportswear products. Responses that were incomplete or duplicated were excluded from the final dataset.

A total of 194 valid responses were retained for analysis. This sample size is consistent with prior exploratory studies on wearable technology adoption and was deemed sufficient for the statistical techniques employed, including analysis of variance (ANOVA), regression analysis, and cluster analysis. The sample included a broad distribution of age groups and activity levels, allowing for meaningful comparisons across demographic segments.

The sample (Table 1) included respondents from five age groups (18–24, 25–35, 36–45, 46–55, and 56 years and over), with varying levels of involvement in sports and physical activities ranging from recreational to competitive participation. The diversity of the sample provided sufficient variation for the cross-group comparisons reported in Section 4.

Table 1. Demographic profile of the sample (N = 194).

Characteristic	<i>n</i>	%
Age group (years)		
18–24	72	37.1
25–35	74	38.1
36–45	25	12.9
46–55	14	7.2
56 and over	9	4.6
Annual household income		
Less than \$20,000	50	25.8
\$20,000–\$39,999	43	22.2
\$40,000–\$59,999	37	19.1
\$60,000–\$79,999	29	14.9
\$80,000–\$99,999	9	4.6
\$100,000 or more	17	8.8
Prefer not to answer	9	4.6

Notes: Age groups correspond to the five categories used throughout the analyses.

For the qualitative component, semi-structured interviews were conducted with four industry experts ($n = 4$) selected through purposive sampling on the basis of their direct involvement in the smart-apparel value chain. To ensure complementary perspectives, the panel deliberately combined distinct professional profiles: a research-and-development director at a smart-textile manufacturer, a specialist from a technology-transfer center, and experts in textile engineering and sportswear retail. All participants possessed a minimum of five years of professional experience in smart textiles, wearable

technology, or sportswear innovation. Each interview lasted approximately 30–45 min and was conducted online via videoconference during the same general period as the survey data collection. With participant consent, interviews were audio-recorded and transcribed verbatim for analysis. The interview guide addressed adoption barriers, technological feasibility, production and cost constraints, sustainability considerations, and future market trajectories.

3.3. Ethical considerations

This study was conducted in accordance with established ethical research guidelines. Informed consent was obtained digitally from all participants prior to data collection. Participation was voluntary, and respondents were informed of their right to withdraw at any time. All survey responses were anonymized, and no personally identifiable information was collected. Interview data were treated confidentially and reported in aggregated form to ensure participant privacy.

3.4. Data analysis

Quantitative data analysis was performed using SPSS software. Descriptive statistics were first used to summarize consumer characteristics and overall response patterns. Chi-square (χ^2) tests were conducted to examine relationships between categorical variables, such as age group and level of interest in smart clothing adoption. ANOVA was employed to compare mean differences in interest levels and willingness to pay across demographic segments. Where significant effects were identified, post-hoc comparisons were conducted to determine group-level differences. A standard multiple linear regression, with all five predictors entered simultaneously, was used to identify the key predictors of interest in smart clothing. The dependent variable was the respondent's level of interest in adopting smart clothing, measured on a 7-point Likert scale. The predictors were operationalized as follows: age (treated as an ordinal variable across the five age bands), income band, prior familiarity with wearable technology, preference for personalization, and level of data-security concern. Prior to estimation, the standard assumptions of linear regression were verified, including linearity, normality of residuals, homoscedasticity, and the absence of multicollinearity (assessed via variance inflation factors).

In addition, cluster analysis was applied to segment respondents based on shared preferences, attitudes, and adoption intentions. A k-means cluster analysis was performed on five standardized variables central to adoption: interest in smart clothing, data privacy concern, preference for personalization, willingness to pay, and prior familiarity with wearable technology. A three-

cluster solution ($K = 3$) was specified and the algorithm converged after four iterations; this solution was retained as the most interpretable and parsimonious. Its robustness was supported by an analysis of variance on the cluster centers, which identified willingness to pay as the strongest discriminating variable ($F(2,191) = 500.58, p < 0.001$), while prior familiarity with wearable technology also differed significantly across clusters ($F(2,191) = 7.08, p = 0.001$).

This approach enabled the identification of distinct consumer profiles and provided a foundation for the market segmentation reported in section 4.5. Qualitative interview data were analyzed following Braun and Clarke's six-phase thematic analysis. Transcripts were first read repeatedly for familiarization, then coded inductively; codes were subsequently grouped into candidate themes, which were reviewed and refined against the full dataset. Coding was carried out manually by the research team through iterative comparison and discussion of emerging themes. The analysis yielded four overarching themes (adoption barriers, usability expectations, data privacy concerns, and sustainability challenges) which were used to contextualize and enrich the quantitative findings.

4. Results

This section presents the results of the consumer survey and provides insights into purchasing behaviors, preferences for smart textile features, concerns related to connectivity and data privacy, and segmentation patterns underlying distinct user profiles. The results are organized to empirically test the three research hypotheses formulated in section 2.6 using descriptive statistics, inferential analyses, and segmentation techniques. The results are structured to address comfort and usability (H1), demographic differences in adoption (H2), and the role of personalization in consumer preference (H3).

4.1. A gradual but promising adoption

The emergence of smart apparel reveals that there is both curiosity and caution. While most respondents (96.39%) already own active sportswear, purchasing habits are still based on tradition. They favor specialized physical stores over digital platforms. This inclination shows the irreplaceable nature of the tactile experience that consumers seek to feel the texture, assess the elasticity, and ensure the perfect fit. These are the elements that e-commerce has yet to fully replicate. When choosing athletic apparel, Figure 1 shows that the priorities are clear: comfort comes first (78.87%), followed by fit (53.37%) and brand reputation (30.85%). The relatively lower emphasis on brand reputation suggests that functional attributes currently outweigh symbolic or brand-related considerations in purchasing decisions for smart clothing.

Despite the convenience of online shopping, several barriers continue to limit adoption. Uncertainty about size and fit (72%), coupled with the inability to physically interact with the product (68%), remains a significant barrier. These findings indicate structural limitations in current digital retail environments for smart apparel. Technologies such as 3D fit simulators and augmented reality interfaces could be employed to transform digital storefronts into immersive and trusted domains.

4.2. Smart textiles and developing potential

The appeal of innovation is evident as respondents show a strong preference for textiles that enhance comfort as well as functionality. Attributes such as elasticity (72.54%), quick drying (71.14%) and odor resistance (64.44%) are highly sought after (Figure 2). This shows a desire for garments that seamlessly adapt to the needs of the body.

In contrast, features such as compression (43.23%) and aerodynamics (42.48%) garner less enthusiasm. These

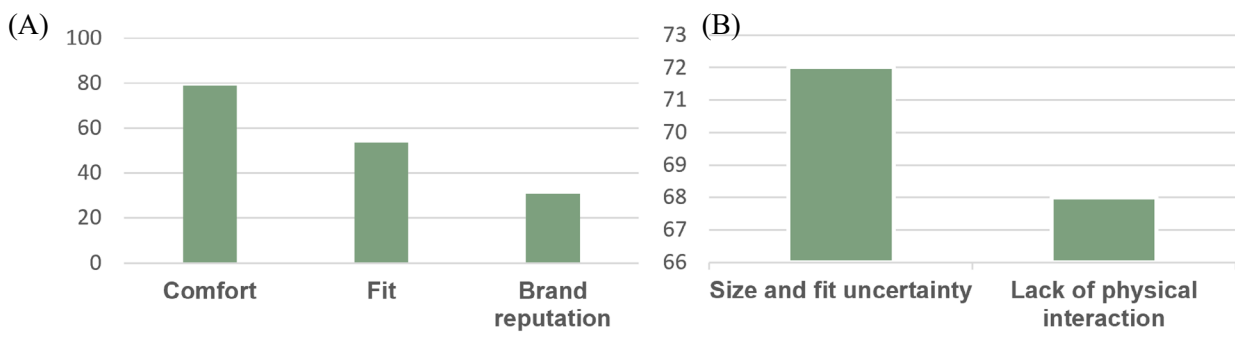


Figure 1. Consumer priorities when selecting products and perceived barriers to online shopping ($n = 194$). (A) Relative importance of product attributes, measured as the percentage of respondents selecting each criterion. (B) Main barriers to online shopping, measured as the percentage of respondents reporting each concern.

findings provide empirical support for Hypothesis H1, confirming that comfort- and usability-related attributes are prioritized over more technologically advanced features. Personalization emerges as a defining expectation as 65% of respondents expressed a preference for sportswear shaped to their specific morphology, aesthetic tastes and specific functional needs, whether for high-intensity training or urban mobility. This result directly supports Hypothesis H3, highlighting personalization as a key driver of consumer preference in smart clothing. In addition, an impressive 73% of consumers cited environmentally friendly materials as the main factor in their purchasing decisions. This commitment to sustainability shows a critical imperative for brands: innovation must not only advance technological performance, but also align with ethical and environmental values.

4.3. Connectivity and consumer skepticism

Smart clothing promises a deeply integrated user experience, but connectivity remains a double-edged sword. Figure 3 shows the most compelling features-activity tracking (77.72%) and real-time physiological monitoring (68%). It demonstrates a strong appetite for garments that go beyond passive wear to become active health and performance companions. However, enthusiasm wanes for features that seem less immediately practical, such as oxygen level tracking (37.31%). These patterns suggest varying levels of perceived usefulness across connected features. This indicates a need for clearer communication about the tangible benefits of advanced sensors.

Beyond functionality, trust was found to be a significant

barrier. The average level of confidence in the ability of the manufacturers to protect personal data is alarmingly low (3.45/10). Top concerns include the unauthorized use of biometric information (65%) and opaque privacy policies (57%), revealing an underlying fear of digital vulnerability. These results indicate a significant level of consumer apprehension regarding data governance in smart clothing. To increase the rate of adoption, brands must prioritize transparency and implement strong security measures. It will reassure consumers that their data is not only collected responsibly but also protected ethically. While smart textiles present exciting possibilities, cost and market saturation is still an important challenge as one industry expert emphasized:

“The main obstacle to the widespread adoption of smart clothing remains its production cost. The industrialization of these technologies is still in the optimization phase, but as demand grows and manufacturing processes improve, we will see cost reductions, making these products more accessible to the general public.”

Additionally, the overwhelming presence of tech products in the market has resulted in consumer fatigue, making adoption rates uncertain. The same expert highlights this challenge:

“There are too many products on the market right now! What is really necessary? People are overwhelmed by their environments. The key is to simplify decision-making. Smart clothing must offer real added value, like saving time and enhancing

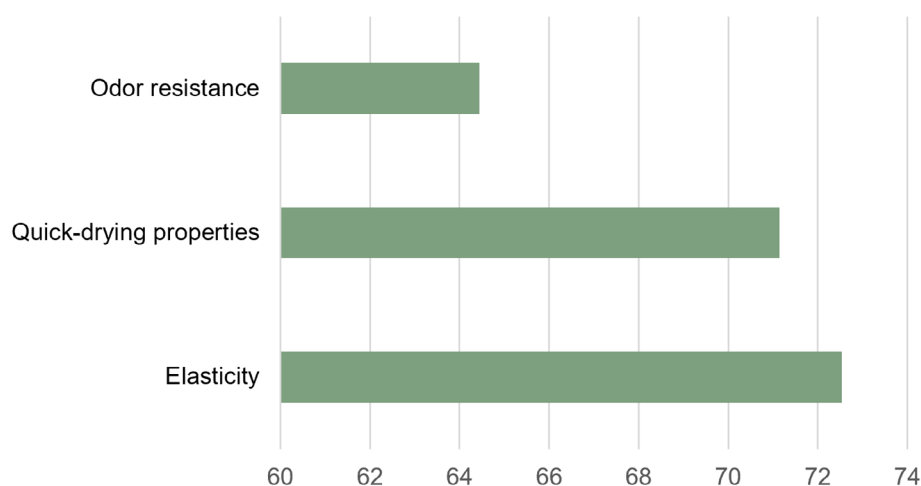


Figure 2. Participants' interests in smart textiles attributes ($n = 194$). Values represent the percentage of respondents indicating interest in each textile property.

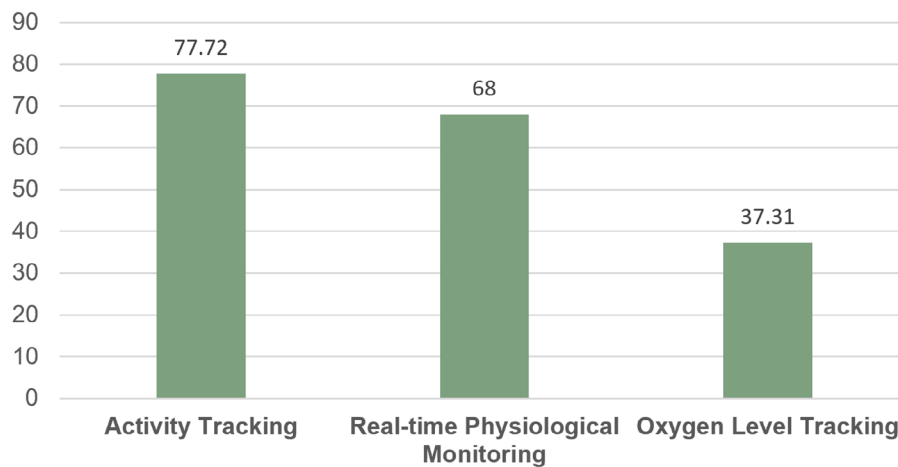


Figure 3. Most desired features in smart clothing ($n = 194$). Values represent the percentage of respondents selecting each feature.

efficiency in everyday life.”

Another key development is the integration of smart textiles with the Internet of Things (IoT), which is transforming garments into fully interactive tools. According to an R&D Director at a smart textile manufacturer, the future of smart clothing is destined to be even more dynamic:

“The interconnection between smart textiles and IoT is turning clothing into interactive tools. In the next few years, we will see garments capable of regulating body temperature, analyzing posture, and even interfacing with our everyday connected devices.”

These findings highlight that consumers prioritize practicality, simplicity, and tangible benefits when considering the adoption of smart clothing. And it reinforces the need for easy-to-use and seamlessly integrated functionality.

4.4. Statistical analysis of key variables

Quantitative analyses revealed the demographic dynamics which impact the adoption of smart clothing. A chi-square test of independence revealed a statistically significant association between age group and high interest in smart clothing (a score of 5 or higher on the 7-point scale), $\chi^2(4, N = 194) = 21.87, p < 0.001$. The 25–35 age group showed the highest proportion of elevated interest (51.4%), compared with 16.7% among 18–24-year-olds and only 11.1% among respondents aged 56 and over. Consistent with this, mean interest was highest in the 25–35 group ($M = 4.54$) and lowest among the youngest ($M = 3.42$) and oldest ($M = 3.33$) respondents (overall $M = 3.98$ on the 7-point scale). This points to pronounced generational differences in

perception and readiness. Economic considerations also influence adoption patterns.

A one-way ANOVA ($F(4, 189) = 6.82, p < 0.001$), with Levene’s test confirming homogeneity of variances ($p = 0.227$), revealed significant differences in willingness to pay across age groups. Post-hoc Tukey tests indicated that respondents aged 25–35 exhibited the highest willingness to pay (mean = \$145.35, SD = \$51.21). It is significantly higher than that of younger respondents aged 18–24 (mean = \$109.67, SD = \$45.40), $p < 0.001$. These findings reveal the importance of targeted pricing strategies that appeal to value-conscious as well as premium-seeking consumers. As illustrated in Figure 4, interest in smart clothing follows a clear age gradient, peaking in the 25–35 group ($M = 4.54$) and declining among both younger (18–24) and older respondents. Considered together with the willingness-to-pay results reported above, these findings provide only partial support for Hypothesis H2: although age significantly influences both interest in and willingness to pay for smart clothing, the effect is not uniform across the broad 18–35 range posited in the hypothesis. Engagement is concentrated in the 25–35 cohort, whereas 18–24 respondents were comparatively less favorable. The 25–35 cohort therefore represents the most strategically relevant segment for market engagement, while the comparatively lower engagement among the youngest consumers warrants further investigation.

To identify the relative contribution of these factors, a multiple linear regression was estimated with level of interest in smart clothing as the dependent variable (see section 3.4 for model specification). The model was statistically significant and explained 38.7% of the variance

in interest ($R^2 = 0.387$, adjusted $R^2 = 0.371$; $F(5, 188) = 23.73$, $p < 0.001$). Preference for personalization ($\beta = 0.247$, $p < 0.001$), prior familiarity with wearable technology ($\beta = 0.252$, $p < 0.001$) and income ($\beta = 0.278$, $p < 0.001$) were significant positive predictors, whereas data-security concern was the strongest predictor overall and negative in direction ($\beta = -0.353$, $p < 0.001$). Age did not emerge as an independent predictor once the other variables were controlled ($\beta = 0.032$, $p = 0.625$), even though it was associated with interest at the bivariate level. These findings suggest that interest in smart clothing is shaped less by age alone than by preferences for personalization, prior familiarity with wearable technology and income, and (negatively) by concerns about data security, reinforcing the barriers identified in section 4.3.

4.5. Market segmentation and mobility integration

The cluster analysis described in section 3.4, performed on the standardized preference and attitudinal variables, yielded a three-cluster solution that best balanced interpretability and parsimony. The resulting segments differed primarily in willingness to pay and in prior familiarity with wearable technology, while remaining largely similar on interest in smart clothing, personalization preference, and data-privacy concern. They together accounted for the full sample (49%, 40%, and 11% of respondents, respectively). Cluster centers for the variables included in the k-means analysis, together with the corresponding ANOVA results, are reported in Table 2.

Each of these segments has unique motivations and concerns regarding smart clothing adoption:

Mainstream Pragmatic Adopters (49%, $n = 95$)

- The largest segment: respondents with a mid-range willingness to pay (approximately \$144) and a mid-range prior familiarity with wearable technology, who appear to weigh advanced functions against cost.

Price-Conscious Skeptics (40%, $n = 77$)

- The most price-sensitive group: they report the lowest willingness to pay (approximately \$77) and the lowest prior familiarity with wearable technology, prioritize comfort and durability over connectivity, and show the strongest reluctance to adopt, driven primarily by cost considerations.

Enthusiastic Premium Adopters (11%, $n = 22$)

- Consumers with the greatest familiarity with wearable technology and the highest willingness to pay, prepared to pay a substantial premium (approximately \$214) for advanced connected features.

Apart from personal fitness, smart clothing presents several possibilities for urban mobility. A notable 71% of respondents advocated for reflective textiles for the purpose of enhancing cyclist and pedestrian visibility, while 68% endorsed integrated safety sensors. These insights suggest that there is an opportunity for brands to extend innovation beyond performance wear, incorporating safety-based applications that align with various lifestyle needs. These findings highlight heterogeneous expectations toward

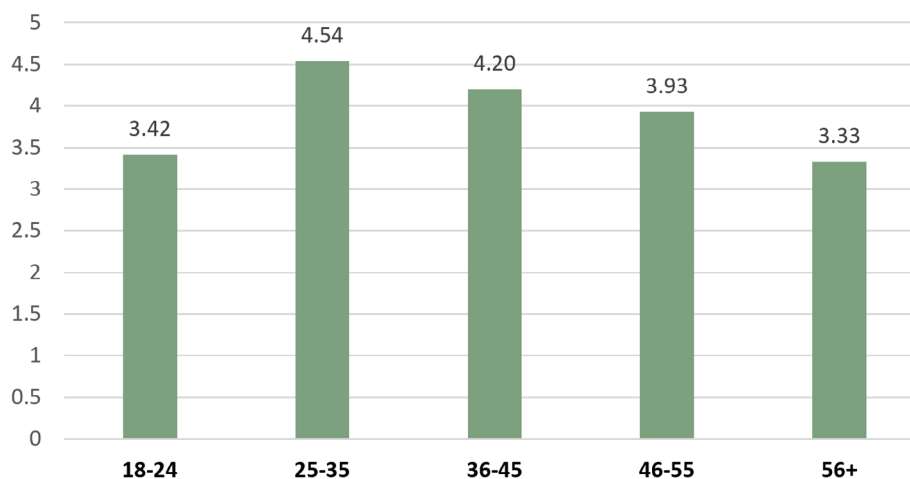


Figure 4. Mean interest in smart clothing by age group ($n = 194$). Bars present descriptive mean interest scores on a 7-point Likert scale. The inferential test of the age-group association was conducted on a dichotomized high-interest indicator (a score of ≥ 5 on the 7-point scale) and was statistically significant, $\chi^2(4, N = 194) = 21.87$, $p < 0.001$. Differences in willingness to pay across age groups are reported separately in the text (one-way ANOVA, $F(4, 189) = 6.82$, $p < 0.001$).

smart clothing, indicating that adoption dynamics are not uniform and are shaped by differentiated motivations, constraints, and perceived value across consumer segments.

4.6. The convergence of connectivity, expression, personalization, and performance

Smart clothing is characterized by the integration of digital technologies within textile structures, resulting in garments that combine connectivity, personalization, and functional performance. Survey results indicate that respondents do not perceive these dimensions as isolated features, but rather as interconnected attributes contributing to overall garment value. Smart textiles embed sensors capable of monitoring physiological data, while adaptive fabrics respond to environmental conditions such as temperature and movement. These combined functionalities were consistently associated with enhanced usability and perceived relevance across usage contexts.

Beyond functional performance, respondents reported that smart clothing supports forms of self-expression linked to lifestyle, activity level, and personal comfort preferences. Customizable design elements and adaptive features were frequently cited as enabling garments to better align with individual needs, particularly in relation to mobility, training intensity, and everyday wear. In addition, sustainability-related attributes, such as durable materials and responsible design, were mentioned as reinforcing perceived product value.

Qualitative insights from expert interviews further illustrate this convergence. According to an expert from a technology transfer center,

“The future of smart clothing will soon be based on the fusion of the physical and digital worlds. A major transformation is underway! Thanks to augmented

reality and connected textiles, clothing will no longer be passive objects but true interactive interfaces that enhance the user experience. What we know today will soon be obsolete. We are witnessing a convergence that paves the way for a more immersive fashion experience.”

Taken together, these findings indicate that consumers associate smart clothing with a combination of connectivity, personalization, and performance-related benefits, rather than with isolated technological functions. This convergence emerged as a recurring pattern across survey responses and expert perspectives, providing an empirical foundation for the integrative framework discussed in the following section.

5. Discussion

The results of this study highlight a fundamental paradox. While consumers clearly acknowledge the strong potential of smart clothing, concerns about usability, cost, and privacy are the main factors behind non-adoption. These observations directly reflect the empirical results presented in section 4 and are discussed here in relation to hypotheses H1–H3. Adoption therefore appears contingent on the ability of brands to establish trust and support self-expression. Brands with strong brand legitimacy and established emotional connections with consumers—particularly within the sportswear and technology ecosystems—may benefit from a competitive advantage in attracting early adopters. However, overcoming adoption barriers requires a gradual and highly targeted approach based on consumer education, affordable innovation, and transparency, as suggested by findings related to price sensitivity, usability expectations, and data privacy concerns.

Table 2. Final cluster centers and analysis of variance from the k-means three-cluster solution ($N = 194$)

Variable	Cluster 1 — Price-Conscious Skeptics ($n = 77$; 40%)	Cluster 2 — Enthusiastic Premium Adopters ($n = 22$; 11%)	Cluster 3 — Mainstream Pragmatic Adopters ($n = 95$; 49%)	$F(2, 191)$	p
Interest in smart clothing (1–7)	4	4	4	0.41	0.664
Data-privacy concern (1–7)	4	4	4	0.86	0.425
Preference for personalization (1–7)	5	5	5	0.18	0.832
Willingness to pay (USD)	76.7	213.7	143.9	500.58	< 0.001
Prior familiarity with wearable technology (1–7)	3	4	4	7.08	0.001

Notes: Likert variables are reported on a 7-point scale; willingness to pay is expressed in U.S. dollars. The cluster solution converged after four iterations. Consistent with SPSS guidance, the ANOVA statistics are reported for descriptive purposes only, as cluster membership was assigned to maximize between-cluster differences.

5.1. The gap between intention and adoption

There was found to be a significant gap between expressed interest of consumers in smart clothing and its actual adoption. This gap is consistent with the empirical results presented in section 4, which highlight strong interest in functionality and personalization alongside persistent concerns related to price and trust. Although social image and aesthetics are important and appealing reasons, economic and practical considerations continue to prevent adoption among masses. Consumers perceive the cost ranging from \$150 to \$300 as prohibitive, compared to their acceptable price range of \$50 to \$99. These findings partially explain why hypotheses related to comfort and personalization (H1 and H3) are positively perceived, yet not fully translated into purchase behavior. This price gap could be streamlined with the help of adapted business models, such as rental systems, modular functionality, subscription plans, or tiered offerings. These strategies are presented as exploratory managerial implications rather than empirically tested solutions. This could facilitate broader market penetration. With respect to privacy concerns, transparent communication and clear regulatory frameworks are quite important to reassure consumers that there would be strong security and ethical handling of their data, a factor that emerged as a key barrier to adoption in the results related to data protection and consumer trust.

5.2. The challenge of functionality and comfort

Our findings are consistent with previous research, emphasizing that ease of use takes precedence over a lot of technological sophistication. This observation directly supports hypothesis H1, which posits that comfort and usability are primary drivers of consumer interest in smart clothing. Smart textiles must not just function as technological gimmicks; rather, they should establish themselves as practical tools that enhance daily life without there being a steep learning curve. Gesture control, haptic feedback, and voice interfaces could be employed as critical breakthroughs for the purpose of adoption. These elements are discussed as prospective design implications informed by expert interviews and existing literature, rather than as empirically validated adoption drivers measured in the present study.

In addition, portability and comfort were found to be at the forefront of consumer expectations. Lighter electronic components, breathable materials, and optimized flexibility are the main levers for convincing users. Advances in miniaturization are an important way to combine technological sophistication with portability without compromising aesthetics, thereby addressing both functional and experiential expectations identified among

respondents.

History shows that wearable innovation follows a recurring pattern: initial skepticism leading to gradual mainstream adoption. Seatbelts which were once considered superfluous are now an important safety standard. Smart clothing could follow a similar trajectory, under certain conditions and over time. However, it needs to be ensured that adoption is based on clear use cases and measurable benefits, as suggested by the results of this study. The current hype for artificial intelligence (AI) may also speed up the adoption of smart clothing.

Furthermore, awareness campaigns should highlight the tangible benefits of smart clothing, such as increased safety for cyclists and motorcyclists, in line with the mobility- (and safety-) related expectations identified among respondents. It should provide evidence and benefits of real-time physiological monitoring for athletes or adaptation of thermal comfort to changing environmental conditions. Initiatives such as free trials and demonstrations which are highly interactive could be important for overcoming initial skepticism, particularly in the early phases of adoption.

5.3. Key levers for enabling the transition to smart clothing

Finally, widespread adoption of smart clothing requires more than technological advancements. It requires that smart clothing be aligned with consumer expectations, industry standards, and sustainability goals. These dimensions emerge consistently from the quantitative and qualitative results presented in sections 4.1 to 4.5. [Figure 5](#) shows several main levers which must be activated to ensure a seamless and sustainable transition. Thus, success in this evolving market relies on several fundamental pillars, including miniaturization and aesthetics, durability and ease of care, consumer education and awareness, regulatory framework and privacy, interoperability and connectivity, accessibility and affordability, and sustainability and circular economy.

These levers directly reflect the primary adoption barriers identified in the results, particularly those related to comfort, cost, usability, trust, and long-term value. The core of the diagram emphasizes “self-expression, performance, and well-being,” underscoring that smart clothing should go beyond mere technology to provide added value in terms of comfort, identity, and functionality. Future research should quantitatively assess the full lifecycle impacts of smart clothing, including energy consumption, carbon footprint, and end-of-life management, in order to better evaluate the environmental trade-offs associated with embedded technologies.

The successful adoption of smart clothing depends on a combination of technological innovation, user-centered design, and consumer trust. These dimensions are directly derived from the empirical findings presented in the results section and synthesize both quantitative and qualitative insights. As this market evolves, brands must address important factors that influence consumer acceptance, usability, and long-term viability.

The following pillars summarize the key dimensions shaping the transition toward smart mobile clothing:

- Self-expression, performance, and well-being: smart clothing should enhance both personal identity and functional benefits. Whether improving athletic performance, safety, or everyday comfort, brands must

present these garments as an extension of the self, not just another technological gadget. A dimension strongly supported by consumer expectations related to comfort, personalization, and perceived usefulness.

- Miniaturization, attributes and aesthetics: prioritizing sleek design and seamless technology integration is essential to making smart clothing both visually appealing and comfortable for daily wear. The challenge lies in embedding advanced functionality while maintaining a lightweight and stylish appearance.
- Durability and ease of care: consumers expect washable and durable garments that maintain their integrity over time. The development of removable electronic modules and water-resistant fabrics is crucial for product longevity and ease of maintenance.

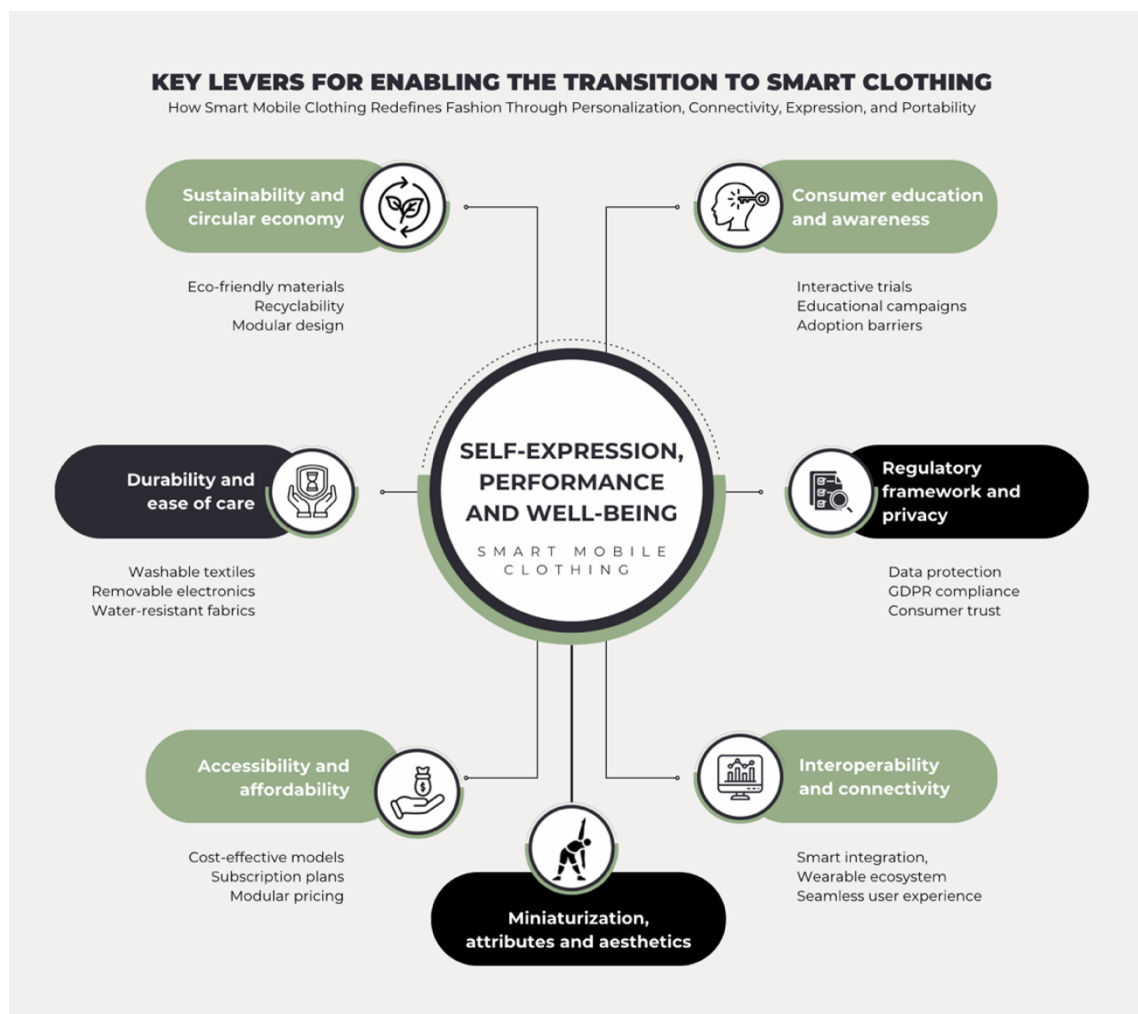


Figure 5. Key levers for enabling the transition to smart clothing

- Consumer education and awareness: Adoption is closely linked to consumers' understanding of smart clothing benefits. Demonstrations, interactive trials, and clear communication may help reduce uncertainty and narrow the gap between expressed interest and actual adoption.
- Regulatory framework and privacy: as smart textiles collect biometric and behavioral data, establishing strong security and privacy regulations is necessary. Adhering to global data protection standards (GDPR, CCPA) will be a key factor in building consumer trust, a critical barrier consistently emphasized by respondents.
- Accessibility and affordability: overcoming cost barriers requires affordable business models, such as modular pricing, rental options, or subscription plans, to make smart apparel accessible to a broader audience, responding directly to the price sensitivity revealed in the statistical analysis.
- Interoperability and connectivity: for a better user experience, smart clothing must seamlessly integrate with existing wearable tech ecosystems (smartphones, fitness trackers, smartwatches). This will enhance connectivity and ease of use.
- Sustainability and circular economy: as consumers become more aware of their environmental impact, brands must focus on eco-friendly materials (e.g., PFAS-free textiles), recyclability, and modular design to reduce waste and extend product life.

By working on these factors, the smart apparel industry can overcome adoption barriers and can increase consumer trust. Overall, these findings indicate that hypotheses H1 and H3 are strongly supported, while H2 is partially supported, reflecting differentiated adoption dynamics across consumer segments. These findings suggest that, beyond a passing trend, smart clothing may be contributing to a longer-term evolution in the relationship between textiles and technology. Recent research further highlights the accelerated convergence of AI, adaptive materials, and wearable sensing systems, contributing to the emergence of increasingly intelligent and multifunctional textile ecosystems, while also emphasizing persistent challenges related to scalability, privacy, sustainability, and commercialization.³¹ These broader implications should be read as exploratory hypotheses derived from a consumer-level sample rather than as confirmed market trajectories. While challenges remain, so do opportunities. The future of smart clothing is likely to depend on the ability of manufacturers to align technological innovation with consumer expectations while anticipating broader societal and environmental changes.

6. Conclusion

Smart clothing represents an exciting frontier at the intersection of fashion and technology as it combines psychology, self-expression, lifestyle elevation, and performance. However, despite its potential, there is limited adoption. Drawing on the empirical findings of this study, this limited adoption is particularly owing to pricing constraints, privacy issues, inability for brands to build trust, and consumer education gaps. These results confirm that technological innovation alone is insufficient to ensure market acceptance. By addressing these challenges and employing transparency, shared values, and usability improvements, the industry can accelerate adoption. Further, the research suggests that a balance between innovation, consumer expectations, and sustainability is cardinal. This balance directly reflects the key drivers and barriers identified across the quantitative and qualitative analyses. For smart clothing to gain better mainstream acceptance, manufacturers must focus on innovation as well as practical consumer needs. Furthermore, durability, comfort, and affordability should take precedence over excessive complexity of technology, a finding that strongly supports hypotheses H1 and H3. A phased introduction of wearable features can help to enhance consumer confidence and promote market expansion, particularly in early adoption phases. Notably, targeting young demographics, particularly those aged 25–35, would be highly effective. This group is the most receptive and ready to engage, especially through dynamic messaging that emphasizes the technological advancements and performance-enhancing benefits of smart sportswear, a result that partially supports hypothesis H2. These findings should nevertheless be interpreted with caution, as some age categories were represented by relatively small subsamples, particularly the 56-and-over group ($n = 9$), which limits the robustness of generational comparisons and the generalizability of age-specific conclusions. Further, future research should explore industry-specific applications, such as medical wearables and adaptive fashion, to further assess the long-term viability of smart clothing solutions, as well as longitudinal adoption patterns and lifecycle impacts.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: All authors

Formal analysis: All authors

Investigation: Jean-Philippe Harrisson-Boudreau

Methodology: Jocelyn Bellemare

Writing–original draft: All authors

Writing–review & editing: Jocelyn Bellemare

Ethics approval and consent to participate

This study was reviewed and approved by the institutional research ethics committee under reference number F20-PRI-SG-24708 (2025-7769). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional committee. Informed consent was obtained from all participants prior to their participation in the study.

Consent for publication

Not applicable.

Availability of data

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality and ethical restrictions.

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