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LONG PAPER

Identifying critical success factors for wearable medical devices: a comprehensive exploration

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Abstract
For healthy living, the successful use of wearable medical devices such as smartwatches, smart clothes, smart glasses, sports/activity trackers, and various sensors placed on a body is getting more important as benefits of these devices become apparent. Yet, the existing knowledge about the critical success factors for wearable medical devices needs to evolve and develop further. The main objective of this research is to distill salient constructs to enhance the successful use of wearable medical devices. Specifically, the study aims to identify factors, associated items, and interactions of the relevant factors. A questionnaire has been developed and deployed. The data were collected from 1057 people specifically chosen to represent a wide range of the population. Comprehensive and meaningful inferences have been drawn. Principally, as a fusion of factor analysis and path analysis, a partial least squares structural equation modeling approach consisting of exploratory and confirmatory factor analyses has been applied. In order to assess internal generalization and to precisely identify additional constructs, quasi-statistics have been used. The analyses of data collected revealed 11 salient constructs with 39 items and 18 statistically significant relationships among these constructs. Consequently, composed of distilled constructs and their associations, a novel model with an explanatory power of 73.884% has been approved. Moreover, 13 additional factors were identified as a result of the applied quasi-statistics. This research is the first of its kind on account of its sample characteristics with applied comprehensive methodology and distilled results. This research contributes to the pertinent body of knowledge concerning the critical success factors for wearable medical devices with distilled results. These contributions notably advance the relevant understanding and will be beneficial for researchers and for developers in the field of wearable medical devices.

Keywords Wearable medical device · Acceptance · Critical success factor · Attitude · Healthy living

1 Introduction

1.1 Background and motivation

1.1.1 Wearable medical devices

To improve the quality of life for everyone in the community from newborns to older people, technology is there as a salient instrument. For an active and healthy living, technology is appreciatively there to be employed. In this context, the application of information technologies like wearables intensely renovates our current and future healthcare views and experiences [1, 2]. Wearable medical devices are the instruments, which especially provide medical monitoring and support, to those people who wear them especially to manage and improve their health. The most commonly used examples of these devices are smartwatches, smart clothes, smart glasses, sports/activity trackers, or various sensors placed on a body [3, 4].

By definition, wearable medical devices are autonomous and noninvasive, and they perform certain medical functions of monitoring or support for an extended duration. Moreover, these devices are supported by either the human body or clothing [5]. For a wearable medical device to attach to a body, the wrist is the most fortunate place [6] and accordingly, smartwatches are the foremost disseminated one among all wearable devices [7–9]. For inclusive

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integrated care, investment in information and communication technologies is a must both for today and for the future [10]. Besides, there are also assistive technologies to support health [11]. The primary persistence of assistive health technology is to sustain and advance people's functioning and well-being [12].

Wearables are becoming more ubiquitous and have many benefits for our life [13–15]. Effective and sustainable wearable devices are bringing about positive changes for not only individuals but also societies at large [16]. In this context, wearable medical devices come up with unlimited potentials and promising future for healthcare settings [17]. Moreover, they provide remarkable means for reducing the burden on systems and costs associated with health care owing to aging society [18]. Furthermore, wearable medical devices are one of the most practical approaches to take precautionary health monitoring and to treat patients with a fairly custom-made method at an early stage to improve early detection, early diagnosis, and early treatment [19].

Wearable medical devices with a variety of sensors are used for a wide range of healthcare purposes [20]. Thanks to wearable medical devices, pervasive monitoring, transmission, and storage of data become more practical [21]. Nowadays, it is clear that wearable medical devices are pragmatic and clinically useful concerning diagnosis, treatment, and care [22–24]. Moreover, it is definitely projected that there will be many other user-acceptable, high-performance, and low-cost wearable devices to be offered for recognition of a variety of physical activities [25, 26]. Additionally, there is a notable increase in medical devices to control bodily functions and to measure certain physiological parameters [27]. However, the technology maturity level for home health monitoring technologies is still moderately low [28], yet wearable technology usage is projected to rise constantly [29]. Naturally, a transdisciplinary approach will move us fast forward on this journey [30–32] to understand critical success factors.

The term "wearable medical devices" can be rather broad, and it might mean devices and/or applications used for: (1) supporting patients in monitoring a disease (e.g., diabetes support applications), (2) general monitoring of well-being (e.g., heart rate, sleep, exercise), and (3) supporting elderly/disabled people in independent living. In this research, wearable medical devices are devices such as smartwatches, smart clothes, smart glasses, sports/activity trackers, and various sensors placed on bodies for health-related purposes.

1.1.2 Potential of wearable medical devices for health

Healthy aging can be defined as the course of developing and sustaining the functional ability that empowers well-being in older ages, where functional ability encompasses the health-related attributes that qualify people to be and to do what they have reason to value. Besides, physical activity and nutrition are the foremost aspects prompting healthy aging [12]. In this context, the essence of healthy aging is the functional ability comprising the intrinsic capacities of people, relevant environmental characteristics, and interactions between people and these [33]. Healthy aging is the concentration of the World Health Organization's work on the subject of aging between 2015 and 2030 [34]. Unambiguously, healthy aging is a course that occurs across the life course rather than as a state at a particular point in time [35].

Moreover, active aging is the progression of enhancing prospects for health, participation, and security with the intention of improving quality of life as people age [36]. For active aging, investigating digital strategies embodies a thrilling zone of global research [37]. Precisely, active aging is the process of improving prospects for health, participation, and security with the aim of boosting the quality of life as we age [12]. In this context, physical activity is a leading aspect of both health and well-being [38]. In addition, regular physical activity is very imperative for healthy aging, and luckily technology devices such as wearables are practically there to encourage people for regular physical activity [39–43].

Aging in place is the term where people safely and comfortably pursue their independent and high-caliber life at their own home and community. This obviously diminishes the possible associated costs of external supports for health and well-being [44]. In this context, new technological and innovative devices will be beneficial for tracking significant parameters to perfectly deliver preventive and proactive actions for health. Therefore, caring for people in their own homes thanks to technology devices like wearables will possibly be effective and economically adventurous [44]. To manage mobility loss of people, physical activity including physical exercise requiring energy expenditure is a must [45]. By means of active aging and physical activity, we will possibly be able to avoid, slow, or converse deteriorations regarding people's physical and mental capabilities [45].

Moreover, there is a major initiative, called Be He@lthy, Be Mobile, led by the World Health Organization, supporting the expansion of mobile health technology within health systems to help fight noncommunicable diseases and support healthy aging. In this initiative, Mobile Health for Ageing is a program to assist people in maintaining functional ability and living independently and healthily through evidence-based self-management and self-care [46]. The World Health Organization recommends that health systems ought to be oriented around intrinsic capacity and functional ability, and in this context, we need to employ technologies (like wearable medical devices) in clinical, home, and community settings [47].

1.1.3 Objective and importance of this study

In today's world, wearable technologies are becoming more ubiquitous. Moreover, wearable medical devices are becoming promising instruments for healthy living and aging. For these reasons, it is very important to align these health-related technologies with people's needs and expectations. Specific strategies of aligning health systems to the needs of populations and improving measurement, monitoring, and research in the World Health Organization's global strategy and action plan on aging and health are truly noteworthy [47]. In fact, we need to fine-tune and improve our way of thinking, sense, and actions regarding both age and aging [48]. Additionally, individuals' acceptance, adoption, and intention of the use of wearable medical devices are anticipated to grow in the near future [49] and the market for wearable medical devices is one of the fastest rising ones of this era [50]. Parenthetically, unlike typical technologies like smartphones, the rise of the adoption of wearable medical devices has been moderately slow. Thus, there is an increasing need to understand the full picture [51, 52].

Furthermore, smart wearable systems designed for health, wearable medical devices, are intensely in the interest zone of not only researchers but also industry professionals [53]. The acceptance of innovative technologies like wearables by people is a vital issue not only for governments and healthcare providers but also for technology providers and other key actors regarding people's life [54]. There are a number of efforts to utilize formerly established models of technology acceptance for success, yet pertinent models, unfortunately, have major themes to be improved regarding the attitude and behavior in the health domain, and further work is needed in this context [55, 56]. The related literature suggests that the original constructs of the technology acceptance model ought to be refined with some alterations and additions to better understand and predict the acceptance and success of information technologies related to health such as wearables [57]. The end-user acceptability of wearable medical devices, as well as the success of any systems in the healthcare banks mainly on user-awareness and user-acceptance, is very important [58]. However, the existing understanding of this context is lacking and needs firm improvements [59–62]. The technology acceptance model is fairly valuable to understand the acceptance leading to success, yet it needs to be unified into a more inclusive one with contextual features specific for relevant circumstances [63].

Therefore, the main objective of this research is to distill the salient constructs to enhance the success of wearable medical devices, which are today's and tomorrow's promising technology solutions. In this context, the study aims to identify the factors, the interactions of the factors, and the accompanying items (i.e., the elements, features, and/or situations related to the factors) influencing the success of wearable medical devices for healthy living and aging.

1.2 Relevant prominent studies

1.2.1 Relevant studies focusing on wearable health devices

An empirical study of wearable technology acceptance in health care [64] with 462 contributors using a survey concluded that people's choice for having a healthcare wearable technology is determined by factors such as hedonic motivation, functional congruence, social influence, perceived privacy risk, perceived vulnerability, perceived expectancy, self-efficacy, effort expectancy, and perceived severity. Moreover, based on the data collected from 616 respondents, in a related research [65] on wearable healthcare devices, it was noted that consumer attitudes, personal innovativeness, and health interests are vital factors influencing the intention to adopt a wearable healthcare device. Moreover, with a sample size of 877, to understand usage intention, a study [66] on wearable devices as next-generation tools for health communication identified perceived control, interactivity of wearable healthcare devices, and innovative tendencies of users as main elements in consort with the main constructs of the original technology acceptance model. In another study [67] of an empirical investigation with 436 participants, scholars showed that the adoption intention of healthcare wearable technology is determined by technical attributes, health attributes, and consumer attributes concurrently.

Furthermore, in a study [49] focusing on wearable health products, to analyze what determines users' and physicians' acceptance, researchers integrated perceived risk and compatibility constructs into the original technology acceptance with a sample size of 730. In additional notable research [23], concentrating on healthcare wearable devices, including 333 responders, it was shown that people's choices to adopt healthcare wearable devices are determined by their risk–benefit analyses, and perceived privacy risk is important. Additionally, people's health, health information, and privacy concerns were shown to be significant regarding the adoption and diffusion of wearable devices for healthcare, in a research [68] with the data collected from 260 partakers. Yet another effort [69], focusing on the impact of exercise motives on adolescents' sustained use of wearable technology, investigated the influence of extrinsic and intrinsic exercise motives for the relevant context.

1.2.2 Relevant studies focusing on smartwatches and activity trackers

In a relevant research effort [70], with a total number of 363 participants, researchers identified the six psychological

determinants (affective quality, relative advantage, mobility, availability, and subcultural appeal) of smartwatch adoption and developed an extended technology acceptance model. In a relevant study [71], employing interviews, scholars identified that the look-and-feel is the most leading item for smart glasses and the availability of fitness apps is the most influential element for smartwatch adoption. Furthermore, based on the data collected from 375 people, in another pertinent study [72], scholars confirmed that perceived value is a net factor for adoption intention. Moreover, another relevant study [73], on activity trackers, conducted with 210 members, determined that attractiveness, monitoring, feedback, privacy protection, readability, and gamification are salient constructs for success. Additionally, through investigating the data collected from 143 people, researchers in another applicable study [29] identified that tech novelty, interface, and fitness application are critical factors for the adoption of wearable technology.

In regard to the prominent factors that support adoption and sustained use of health and fitness wearables, in a notable research effort [74] about health and fitness wearables with a total of 20 people participating in 5 focus groups, scholars concluded that the characteristics of the device, the context, and the user are significant. In addition, in a study [75] conducted with 146 samples about the smart wearables acceptance model for health monitoring through wearable technologies, related results showed that perceived usefulness, compatibility, facilitating conditions, and self-reported health status significantly add to intention to use. Furthermore, in another notable study [76] on wearable technology for tracking, interviews were conducted with 20 people and it was concluded that such devices must be useful, noninvasive, aesthetically pleasing, easy to use, comfortable, durable, reasonably priced, easy to care for, and capable of protecting the privacy of users to attain the success. Moreover, another work [77] noted that perceived usefulness, perceived enjoyment, social influence, trust, personal innovativeness, and perceived support of well-being are the main facets for the intention to use wearable self-tracking technologies, based on the collected data from 374 responders.

1.2.3 Other relevant studies

In a pertinent research effort [78], researchers developed and empirically tested a model for predicting the factors for home telehealth services acceptance behavior with a sample size of 400, and they identified six relevant predictors such as performance expectancy, effort expectancy, facilitating conditions, perceived security, computer anxiety, and doctor's opinion. They noted that perceived ease of use is the leading acceptance predictor, and perceived usefulness and perceived security are also major elements for success. Furthermore in a research [79] with a sample size of 426, it was shown that perceived advantage, image, and perceived ease of use factors have a weighty role on the intention to adopt the internet of things in healthcare technology products.

Moreover, as indirectly quite relevant and notable, there was a successful mobile phone intervention [80] for improving mental and physical well-being ensuring both usability and acceptability. Another noteworthy work in this context [81] was about a concept for personal and mobile wellness management. Researchers in the pertinent work of wellness management safeguarded the acceptance, ease of use, and usefulness for success. Besides, still another prominent and pertinent effort [82] of a home-based program with high levels of user acceptance and perceived usefulness firmly included educational and motivational components for success. Additionally, as extracted in some previous notable researches, usability [83] and previous exposure to technology [84] are essentially imperative aspects for acceptance and success.

1.2.4 Overview of the most relevant studies

While still open for firm improvements, there are some distinguished efforts which are quite relevant for the critical success factors for wearable medical devices. Consequently, an overview of the most relevant studies is given in Table 1 with details about factors identified and their foci.

To ground our research, we mostly benefited from the studies listed in Table 2. The review of the related literature is presented in Table 2.

2 Materials and methods

2.1 The instrument

A questionnaire has been developed and deployed to identify the factors, the interactions of the factors, and the accompanying items (i.e., elements, features, and/or situations) influencing the acceptance of wearable medical devices by people regarding the success of wearable medical devices,

The design and development of the questionnaire have been accomplished in three phases. In the first phase, the first version of the questionnaire with three sections including 89 questions (19 in Sect. 1, 69 in Sect. 2, and 1 in Sect. 3) was created. Next, in the second phase, in order to create a valid, improved, and refined version of the questionnaire, the first version was as reviewed by seven subject matter experts and professionals. The questionnaire has been improved and refined according to the comments. This second version of the questionnaire consisted of three sections including 66 questions (20 in Sect. 1, 45 in Sect. 2, and 1 in Sect. 3) in total. Furthermore, with comments from the reviews, the questionnaire has been shortened eliminating some items. In

Table 1 Overview of the most relevant studies

Factors identified	Focus	Ref.
Perceived control, interactivity, users' innovative tendencies, usefulness, ease of use	Wearable healthcare devices	[66]
Consumers' health concerns, consumers' health information concerns, consumers' privacy concerns	Wearable devices for health care	[68]
Hedonic motivation, functional congruence, social influence, perceived privacy risk, perceived vulnerability, perceived expectancy, self-efficacy, effort expectancy, perceived severity	Healthcare wearable technology	[64]
Perceived privacy risk, health information sensitivity, personal innovativeness, legislative protection, perceived prestige, perceived benefit, perceived informativeness, functional congruence	Healthcare wearable devices	[23]
Technical attributes, perceived convenience, perceived irreplaceability, perceived credibility, perceived usefulness, health attribute, consumer attributes, consumer innovativeness, conspicuous consumption, informational reference group influence, gender difference	Healthcare wearable technology	[67]
Perceived ease of use, perceived usefulness, behavioral intention, perceived risk, compatibility	High-tech wearable health technologies	[49]
Reliability, ease of use, interpretation, consumer demand	Wearable devices in health monitoring	[85]
Health value factor, compatibility, perceived usefulness, perceived ease of use, self-efficacy, technical support, training	Mobile healthcare systems	[86]
Perceived usefulness, compatibility, facilitating conditions, self-reported health status, aesthetics, external support, performance risk, reliability, accuracy	Health monitoring wearable technologies	[75]
Characteristics of the device, context, user characteristics	Health and fitness wearables	[74]
Perceived advantage, image, perceived ease of use, compatibility, trialability, perceived privacy risk, perceived vulnerability	Internet of things (IoT) products in healthcare	[79]
Habit, perceived usability, perceived enjoyment, confirmation, perceived usefulness, satisfaction	Smartwatches	[87]
Perceived usefulness, hedonic motivation, perceived comfort, perceived privacy, self-socio-motivation, hedonic motivation, battery-life concern, perceived accuracy, functional limitations	Smartwatches	[88]
Attributes, brand, price, stand-alone communication, display shape and size	Smartwatches	[7]
Perceived usefulness, visibility, fashnology	Smartwatches	[8]
Complementary goods, healthology	Smartwatches	[89]
Attitude, design aesthetics, perceived values, social value, performance value	Smartwatches	[90]
Compatibility, result demonstrability, perceived enjoyment	Smartwatches	[91]
Perceived enjoyment, perceived self-expressiveness, perceived usefulness, attitude, intention to use, ease of use	Smartwatches	[92]
Design, compatibility, healthology, additional features, complementary goods, enabling technologies	Smartwatches	[9]
Affective quality, relative advantage, mobility, availability, subcultural appeal, cost, perceived usefulness, perceived ease of use, user attitude, intention to use	Smartwatches	[70]
Notifications, GPS, GPS accuracy, fitness apps, waterproof ability, internet access, weight, hands-free feature, image, esthetics, information privacy	Smart glasses and smartwatches	[71]
Usefulness, ease of use, perceived health outcomes	Wearable fitness technologies	[59]
Interpersonal influence, personal innovativeness, self-efficacy, attitude, health interest, perceived expensiveness	Wearable fitness tracker	[65]
Privacy, value proposition, self-awareness, motivation, subjective norm, social support, sense of independence, equipment characteristics, display, battery, comfort, aesthetics	Wrist-worn activity trackers	[93]
Usability, accuracy, usefulness, encouragement, communicating personal benefits, creating tutorials, hints, trial-use	Activity trackers	[94]
Perceived usefulness, perceived enjoyment, social influence, trust, personal innovativeness, perceived support	Wearable self-tracking devices	[77]
Small, lightweight, neutral colored, useful, noninvasive, aesthetically pleasing, easy to use, comfortable, durable, reasonably priced, easy to care for, privacy, user experience	Wearables for tracking self and others	[76]
Performance expectancy, effort expectancy, facilitating conditions, perceived security, computer anxiety, doctor's opinion	Home telehealth services	[78]
Support, simplicity, age, marital status, education, health status, perceived behavioral control, perceived usefulness	Health-related ICT	[95]

Table 1 (continued)

Factors identified	Focus	Ref.
Perceived efficaciousness, perceived usability, perceived collateral damages	Wearables or clothing attachments	[96]
Confidence with technology, motivation, routine, emotions	Sensors in wearable devices	[97]
Consumers' domain-specific innovativeness, product-possessing innovativeness, information-possessing innovativeness, relative advantage, social image, aesthetics, novelty	Wearable technology components	[98]
Perceived value, perceived benefit, perceived usefulness, enjoyment, social image, perceived risk	Wearable devices	[72]
Robustness, cost, privacy, aesthetics, comfort	Wearable technology	[2]

addition, some of the items have been improved and made clearer to get more dependable data. In this second phase, owing to such reviews and refinements, the content validity of the questionnaire has been achieved and ensured. In the third phase, a pilot study has been conducted to finalize the questionnaire for data collection. The second version of the questionnaire has been applied for data collection, and data were collected from 85 people for the pilot study. After analyzing data from the pilot study, the questionnaire has been improved and refined. In this context, as a result of analysis results and comments, no significant wording changes were applied, though 13 of the questions (7 from Sect. 1 and 6 from Sect. 2) were removed from the questionnaire. Consequently, the third and final version of the questionnaire has been created with three sections including 53 questions (13 in Sect. 1, 39 in Sect. 2, and 1 in Sect. 3) in total. Finally, this last version has been reviewed by three subject matter experts, and their final approvals were confirmed.

In this context, we developed our questionnaire such that people have clear understanding and directions while answering the relevant questions. Specifically, in order to make it clear about what kind of devices the respondents should have in mind while answering the questions, our questionnaire starts with the definition of wearable medical devices and an image supporting it on the cover page of the questionnaire. Precisely, the exact statement we included is: "Wearable Medical Device: Devices, which especially provide medical monitoring and support, those people wear to manage and improve their health. Examples of these devices are: Smartwatches, smart clothes, smart glasses, sports/activity trackers, or various sensors placed on bodies." Moreover, again on the cover page of the questionnaire, we included the purpose of the research to let the respondents know the content and context of our research while answering the questions. Clear directions have been included at the beginnings of each section to enable participants to complete the questionnaire easily and appropriately. The final version of the questionnaire is given in Online Appendix A of ESM. The items used in the questionnaire have been derived from the all-embracing literature review as presented in Table 2, where all the related References for the constructs in the final version of the questionnaire are given.

The instrument, i.e., the questionnaire developed, has been validated for content validity and reliability. Cronbach's alpha value of 0.913 was calculated with IBM SPSS. This is above the minimum requirements [130, 131]. Expert reviews within each of the three phases of questionnaire development assured the content validity of the instrument [130, 131]. In addition, the survey instrument has been examined and approved by the Middle East Technical University's Human Subjects Ethics Committee.

2.2 Dataset

Using the questionnaire developed in the context of this research, data have been collected from 1057 survey participants countrywide in Turkey, as given in Online Appendix B of ESM. Informed consent was ensured by all participants.

The demographic distribution of the data is presented in Table 3. The collected data set is all-inclusive ensuring both homogeneousness and heterogeneity to draw fairly dependable conclusions.

2.3 Data analysis

For data analysis, descriptive and inferential statistics have been used. Specifically, frequency statistics, exploratory factor analysis, confirmatory factor analysis, and partial least squares structural equation modeling have been utilized. Moreover, as a fusion of factor analysis and path analysis [132], the structural equation modeling (SEM) approach has been applied within data collection, model specification, identification, estimation, evaluation, and modification steps [133, 134].

More specifically, a partial least squares structural equation modeling approach [135–139], a nonparametric method requiring no distributional assumptions [140, 141] supporting both exploratory and confirmatory researches [142], was applied, including with seven steps: data collection, exploratory factor analysis 1, confirmatory factor analysis 1, model estimation and evaluation 1, exploratory factor analysis 2, confirmatory factor analysis 2, and model estimation and evaluation 2.

Table 2 Constructs and relevant items

ID	Constructs/items	References
PEU	Perceived ease of use	[64, 66, 70, 72, 75, 76, 78, 86, 87, 91, 92, 96, 99–107]
PEU1	My interaction with wearable medical devices must be clear and understandable, and must not require a lot of mental and physical effort	
PEU2	Wearable medical devices must be easy to use	
PEU3	It must be easy to find information and functions I need from wearable medical devices	
PUS	Perceived usefulness	[8, 59, 64, 66, 67, 70, 72, 75–78, 86–88, 91, 92, 94–96, 99, 101, 102, 104–109]
PUS1	Using wearable medical devices must be useful in managing and improving my health	
PUS2	Using wearable medical devices must enhance my effectiveness in managing my health	
PUS3	Using wearable medical devices must improve my performance in managing my health	
ABI	Attitude & behavioral intention	[65, 70, 85, 90–92, 101, 102, 104, 106, 107, 109–112]
ABI1	Using wearable medical devices is a good and wise idea	
ABI2	Using wearable medical devices will be valuable and beneficial	
ABI3	I have positive feelings toward wearable medical devices	
ABI4	I intend to use wearable medical devices in the future	
ABI5	I plan to use wearable medical devices in the future	
ABI6	Assuming I had access to wearable medical devices, I intend to use them	
PCS	Privacy, confidentiality, and security	[2, 23, 64, 68, 71–73, 75, 78, 79, 88, 93, 113–116]
PCS1	Users must have the authority to determine what information to share, with whom, and how	
PCS2	Information must be used for the intended purpose only, and user consent must be taken first for any disclosure	
PCS3	The protection to safeguard from unauthorized access to or modification, denial of service to unauthorized users, and provision of service to authorized users only must be ensured	
DPD	Dependability	[49, 67, 70, 75, 96, 109, 113]
DPD1	Wearable medical devices must ensure readiness for correct service to let users use them whenever they want to	
DPD2	Wearable medical devices must ensure continuity of correct service to let users have reliable information	
DPD3	Wearable medical devices must ensure absence of catastrophic consequences on the user(s) and the environment to let users feel safe	
DPD4	Wearable medical devices must ensure ability for maintenance and repair to let users conveniently continue using them	
CMP	Compatibility	[7, 49, 71, 75, 78, 79, 86, 93, 105, 111, 117]
CMP1	Using a wearable medical device must be consistent with my current preferences and habits	
CMP2	Wearable medical devices must be compatible with my existing electronic devices (smartphone, tablets, computer, etc.)	
CMP3	Using wearable medical devices must be compatible with all aspects of my life	

Table 2 (continued)

ID	Constructs/items	References
PRO	Promotion	[52, 64, 70, 77, 78, 86, 89, 91, 93, 94, 100–102, 104–107, 110, 111, 118–120]
PRO1	I take into account the medical doctor's recommendation and views from my family, friends, and those whom I value to decide on the use of wearable medical devices	
PRO2	The use of wearable medical devices must be supported by complementary goods and services	
PRO3	The benefits and values of using wearable medical devices must be clearly communicated to improve acceptance and adoption	
UCA	User characteristics	[7, 23, 64–68, 70, 74, 77, 78, 86, 95, 97, 98, 101, 102, 104–107, 109, 111, 118, 120, 121]
UCA2	The use of wearable medical devices must be a habit	
UCA3	If i have health problems, i will more probably use wearable medical devices	
UCA4	My authentic characteristics and expectations of wearable medical devices determine my attitude and behavior in this context	
DES	Design	[2, 7–9, 29, 66, 71, 73, 75, 76, 90, 91, 93, 98, 122–128]
DES1	The color and materials of wearable medical devices must be satisfying regarding aesthetics, convenience, and robustness	
DES3	Relevant and target users must be involved throughout the design phases of wearable medical devices	
DES4	Wearable medical devices must be lightweight and durable	
DES5	Comfort, interface convenience and simplicity must be considered during the design of wearable medical devices	
DCF	Device characteristics and features	[3, 7, 29, 67, 71–74, 77, 92, 93, 98, 115, 129]
DCF1	Battery and energy efficiency of wearable medical devices must be satisfactory for convenient use	
DCF2	Wearable medical devices must use sounds, visuals, and haptics for continuous feedback	
DCF4	Wearable medical devices must provide a variety of functionality and added value to manage and improve health	
DCF5	Wearable medical devices must offer detailed analytics and recommendations to users	
WOR	Worthiness	[2, 23, 52, 59, 65, 70, 72, 77, 87, 88, 90, 92, 100, 102]
WOR1	Using wearable medical devices must offer value for money and effort spent	
WOR2	The performance and quality value of wearable medical devices must be satisfactory	
WOR3	Purchasing and maintenance costs for wearable medical devices must be affordable for users	

In order to explore and review the causal and principal correlational relations in the collected dataset, exploratory factor analyses [143] were applied with IBM SPSS 23. In this context, firstly, the sample size adequacy was checked and ensured. As the data were collected from 1057 people, this research met the sample size requirement above the recommended minimum values [131, 144, 145]. Next, an anti-image correlation matrix was analyzed to check whether correlations among the individual items are strong enough to ensure that the correlation matrix is factorable [146]. This condition, requiring all related values to be greater than 0.5, was met. Furthermore, Kaiser–Meier–Olkin (KMO) and Bartlett's tests were applied and extracted communalities were addressed. For acceptable factor analysis, the KMO sampling adequacy value of 0.6 or above, and Bartlett's test significance value of 0.05 or less are required [131, 147]. For this research, the KMO value is 0.884, and Bartlett's test significance is 0.000, meeting the pertinent requirements.

Additionally, extracted communality values for the items should be greater than 0.40 [148], and this condition was also met in this research as these values ranged from 0.525 to 0.872 for the 39 items included in the final model. Additionally, the factor analysis extraction method and the rotation method were defined. For this research, the principal components method as the most frequently used one was

Table 3 Demographic distribution of the data

Dimension	*N*	%
Gender		
Female	536	50.7
Male	521	49.3
BMI category		
Underweight	42	4.0
Normal	658	62.3
Obesity	61	5.8
Overweight	296	28.0
Income[1]		
Low	539	51.0
Mid	380	36.0
High	138	13.1
Generation[2]		
Gen Z	202	19.1
Millennials	439	41.5
Gen X	207	19.6
Boomers	209	19.8
Know Category[3]		
No	157	14.9
Yes	900	85.1
Use category[5]		
No	546	51.7
Yes	511	48.3
Education		
Prim. Edu	61	5.8
High Sch	193	18.3
Bachelor	501	47.4
Master's	238	22.5
Doctorate	64	6.1
Device known[4]		
Smart clothes	195	18.4
Body sensor(s)	258	24.4
Smart glass	288	27.2
Activity tracker	557	52.7
Smartwatch	806	76.3
Device used[6]		
Smart clothes	6	1.2
Smart glass	7	1.4
Body sensor(s)	28	5.5
Activity tracker	198	38.7
Smartwatch	392	76.7

[1]High: TRY 10,001 or higher; Mid: TRY 4001–10,000; Low: TRY 0–4000

[2]Baby Boomers: Born 1944–1964; Born Gen X: 1965–1980; Millennials: Born 1981–1996; Gen Z: Born 1997–2015

[3]Wearable Medical Device Know Category of Participants (Whether they know any of them or not.)

[4]Wearable Medical Devices Known by the Participants (Which one(s) they know.)

[5]Wearable Medical Device Use Category of Participants (Whether they use any of them or not.)

[6]Wearable Medical Devices Used by the Participants (Which one(s) they use.)

used to reduce data to a set of factor scores, and as the best orthogonal rotation, varimax was set [131, 147, 149].

Furthermore, item main loadings (coefficients) were checked and the rotated component matrix was created where item main loadings (coefficients) whose absolute values below 0.4 were suppressed in the composition of factor structure to make it more interpretable [131]. The rotated component matrix with item loadings for the final model is given in Online Appendix C of ESM. Accordingly, the number of factors was determined, and the total variance explained was evaluated. The Kaiser criterion, the number of factors to be extracted ought to be equal to the number of the eigenvalues of the correlation matrix that are larger than one, was used to decide the optimal number of factors [147], and 11 was determined. Moreover, the total variance explained was calculated as 73.884 for the final model, which is greater than the recommended value of 50 [150]. The total variance explained value for 11 factors is given in Table 4.

Consequently, factors and items per factor were defined and analyzed. In principle, three items per factor are sufficient for identification of the construct [151, 152], and for this research, this recommendation was also fully met as there are at least three items per factor in our research.

Regarding confirmatory factor analyses, SmartPLS 3 [153] was utilized. In this context, first of all, the model was drawn with SmartPLS, and PLS (partial least squares) algorithm was run. Subsequently, factor loadings and composite reliabilities (CR) were checked. In this context, individual-item reliabilities were evaluated by means of investigation of factor loadings (or basic correlations) of measures with corresponding factors [154], where factor loadings must be greater than 0.6 [155]. In our research, the items' loadings on the factors met this recommendation and related values are given in Online Appendix C of ESM.

Moreover, the average variance extracted (AVE) values were checked. In this framework, both convergent validity and discriminant validity were checked and ensured. In general, composite reliability values larger than 0.6 are normally judged as satisfactory, and average variance extracted values should be greater than 0.5 [154–156]. These conditions were also met in our work and pertinent values for these are given in Online Appendix C of ESM. Besides, bootstrapping with 5000 bootstrap samples [140] was performed meant for estimating the significance (*t*-values) of the paths [157]. Additionally, for the relations, common method bias was checked based on the VIF values (given in Online Appendix C of ESM), and it was seen that there is no common method bias for the identified relations among constructs.

Possible and meaningful relations among distilled constructs for the success of wearable medical devices were tested in the initial model. Relevant results for the initial model are given in Online Appendix C of ESM. Pertinent test results showed that 14 of the hypotheses were supported,

Table 4 Total variance explained

Comp	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Var	Cum. %	Total	% of Var	Cum. %	Total	% of Var	Cum. %
ABI	9.609	24.639	24.639	9.609	24.639	24.639	4.484	11.497	11.497
DPD	4.548	11.662	36.301	4.548	11.662	36.301	2.995	7.681	19.178
DES	2.491	6.388	42.689	2.491	6.388	42.689	2.726	6.990	26.167
DCF	2.436	6.245	48.935	2.436	6.245	48.935	2.556	6.553	32.720
WOR	1.886	4.835	53.770	1.886	4.835	53.770	2.541	6.517	39.237
PUS	1.533	3.930	57.699	1.533	3.930	57.699	2.452	6.286	45.523
PCS	1.481	3.798	61.498	1.481	3.798	61.498	2.413	6.186	51.709
PEU	1.373	3.520	65.018	1.373	3.520	65.018	2.405	6.166	57.876
CMP	1.238	3.175	68.192	1.238	3.175	68.192	2.144	5.498	63.374
PRO	1.153	2.956	71.148	1.153	2.956	71.148	2.083	5.342	68.716
UCA	1.067	2.736	73.884	1.067	2.736	73.884	2.016	5.168	73.884

Table 5 Relations tested in the final model

Relation	*T* Statistics	*P* values	Test result
CMP → ABI	3.440	0.001	Supported
CMP → DCF	6.833	0.000	Supported
CMP → PEU	2.216	0.027	Supported
CMP → PUS	2.312	0.021	Supported
DES → DCF	7.565	0.000	Supported
DES → PEU	2.838	0.005	Supported
DPD → DCF	5.996	0.000	Supported
DPD → PEU	4.398	0.000	Supported
DPD → PUS	2.984	0.003	Supported
PCS → ABI	2.232	0.026	Supported
PEU → ABI	2.031	0.042	Supported
PEU → PUS	8.930	0.000	Supported
PRO → PEU	2.632	0.009	Supported
PRO → PUS	2.869	0.004	Supported
PUS → ABI	2.547	0.011	Supported
UCA → ABI	13.139	0.000	Supported
WOR → PEU	2.941	0.003	Supported
WOR → PUS	2.212	0.027	Supported

whereas 13 of them were not supported based on the analysis of the collected data. After analyzing the results of the initial model, the final model was created and 18 possible and meaningful relations among distilled constructs for the success of wearable medical devices were tested. The pertinent results, given in Table 5, showed that the proposed 18 hypotheses were supported and verified based on the analysis of the collected data.

From the collective examination of the results for the initial and final models, it is seen that 13 of the proposed and tested relations (CMP → ABI, CMP → PEU, DES → PEU, DPD → PEU, DPD → PUS, PCS → ABI, PEU → PUS, PRO → PEU, PRO → PUS, PUS → ABI, UCA → ABI, WOR → PEU, WOR → PUS) were supported in both (the initial and the final) models. On the other hand, while PRO→ABI relation was supported in the initial model, it was not supported in the final model, based on the applied analysis of the collected dataset. Furthermore, even though PEU → ABI relation was not supported in the initial model, it was supported in the final model, based on the conducted analysis of the collected data. Besides, four new relations (CMP → DCF, CMP → PUS, DES → DCF, DPD → DCF), which were not proposed and tested in the initial model, were established and supported in the final model.

3 Results and discussion

3.1 Key findings

The analyses revealed 11 salient constructs with 39 items as the critical success factors to improve the acceptance of wearable medical devices. These constructs, in order from the highest to the lowest based on the variance explained by each factor, are "attitude and behavioral intention," "dependability," "design," "device characteristics and features," "worthiness," "perceived usefulness," "privacy, confidentiality, and security," "perceived ease of use," "compatibility," "promotion," and "user characteristics."

Furthermore, 18 statistically significant relationships among these constructs were identified. Figure 1 illustrates the final model reflecting the identified salient constructs and their significant relations that affect the success of wearable medical devices.

However, after the pilot study, the construct and items for "policy" have been removed [15]. This was because the survey participants were not policymakers; hence, they rated the items under the policy construct as either strongly disagree or disagree. In fact, we still think that policy might be a

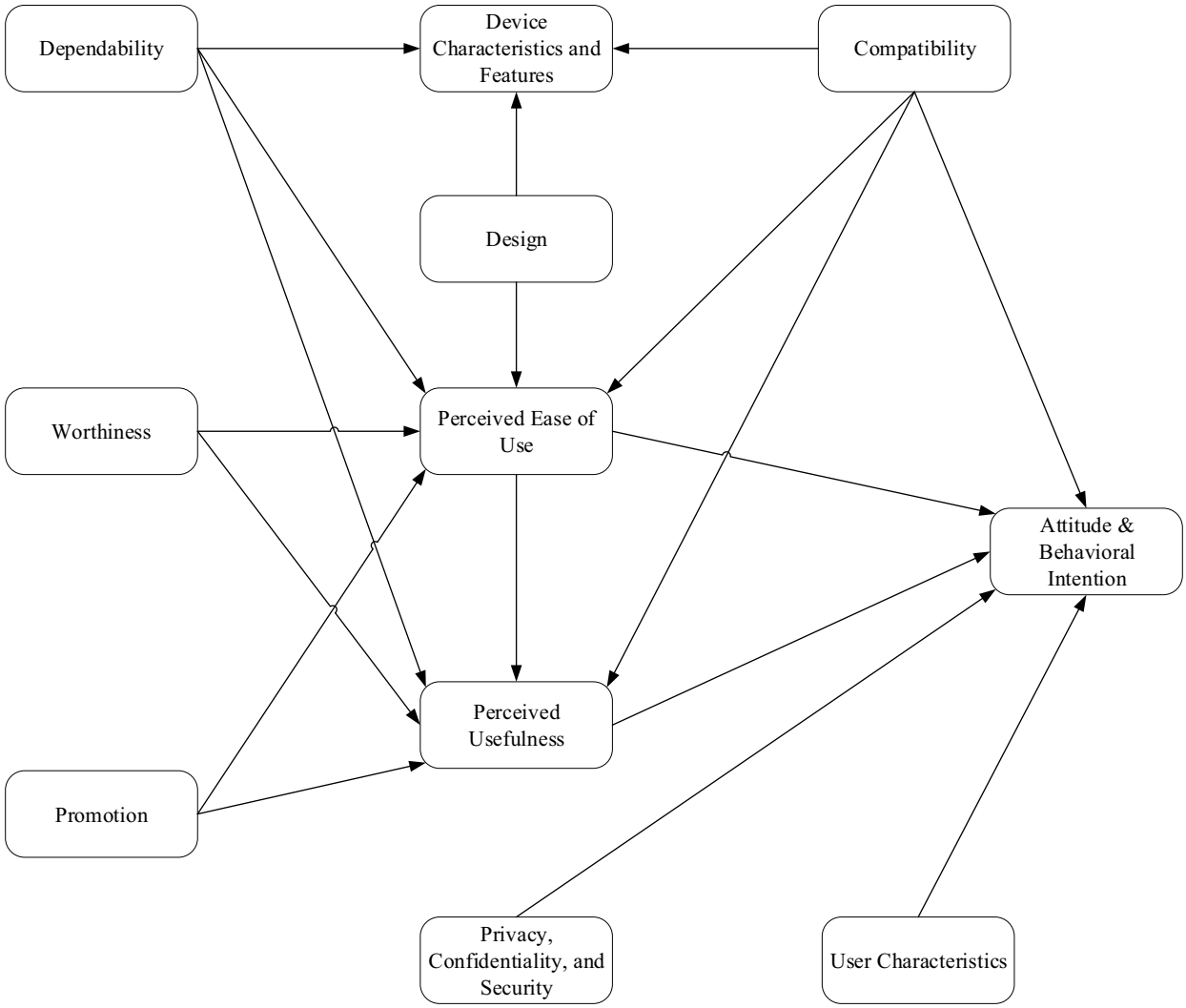

Fig. 1 Final model

salient factor for enhancing success, yet this question has to be asked to relevant people. Instead of asking this to users/potential users as done in this research, more dependable conclusions can be achieved if this was asked to policymakers or members of the regulatory bodies.

Besides, in order to see whether the factors we distilled differ for different user groups (i.e., participants who are already using at least one wearable medical device versus all sample), we applied the pertinent exploratory factor analysis to both of the groups (users versus all sample). We concluded that there is no significant difference in this context. The reason for this could be that majority of the participants knew or used at least one wearable medical device.

In addition, we applied partial least squares multi-group analysis [140] with the Smart PLS 3 in order to determine whether degrees of identified relations (paths) among constructs for user groups (i.e., participants who are already using at least one wearable medical device versus others) significantly differ. As a result, the relationship between user characteristics and attitude &behavioral intention UCA → ABI constructs significantly differed for nonusers ($M = 0.524$) and users ($M = 0.287$) groups ($p = 0.000$). In other words, participants who are not already using a wearable medical device (i.e., none of the smartwatches, smart clothes, smart glasses, sports/activity trackers or various sensors placed on body) more firmly think that the user characteristics factor is important in determining attitude & behavioral intention when compared to participants who are already using at least one wearable medical device. The reason for this could be that people using a wearable medical device may already be posing relevant user characteristics that they did not prefer to mention the importance of the user characteristics construct. Nevertheless, this path is significant for both groups, despite the degrees are different.

3.2 Explanations for distilled constructs

Attitude & behavioral intention, as a standard construct, can be explained with thoughts such that using wearable medical devices is a good & wise idea and will be valuable & beneficial. Moreover, in this context, people have positive feelings. Like so, people plan to use wearable medical devices in the future, and assuming they had access to wearable medical devices, they intend to use them.

Compatibility, as a modified and improved construct, means using a wearable medical device must be consistent with people's current preferences and habits. Specifically, wearable medical devices must be compatible with people's existing electronic devices (smartphones, tablets, computers, etc.) and all other aspects of their lives.

Device characteristics and features, as a modified and improved construct, consist of a number of certain elements. Primarily, battery and energy efficiency of wearable medical devices must be satisfactory for convenient use. Moreover, these devices must use sounds, visuals, and haptics for continuous feedback. Furthermore, these devices must offer detailed analytics and recommendations to users. Lastly, such devices must provide a variety of functionality and added value to manage and improve health.

Design, as a modified and improved construct, requires certain physiognomies. In this context, wearable medical devices must be lightweight and durable, and color & materials of wearable medical devices must be satisfying regarding aesthetics, convenience, and robustness. Moreover, comfort, interface convenience, and simplicity must be well thought out, and relevant and target users must be involved throughout the design.

Dependability, as an originally introduced construct, is there as a vital element constituting availability, reliability, safety, and maintainability attributes. Unambiguously, these devices must satisfactorily ensure: (1) readiness for correct service to let users use whenever they want to, (2) continuity of correct service to ensure reliable information, (3) absence of catastrophic consequences to letting users feel safe, and (4) ability for maintenance and repair to let users conveniently continue using.

Privacy, confidentiality, and security, as a quite standard construct, necessitate three main themes. First, users must have the authority to determine what information to share, with whom, and how. Second, information must be used for the intended purpose only, and user consent must be taken first for any disclosure. Third, the protection to safeguard from unauthorized access to or modification, denial of service to unauthorized users, and provision of service to authorized users only must be ensured.

Perceived ease of use, as a standard construct, requires that interaction with wearable medical devices must be clear and understandable and must not require a lot of mental and physical efforts. In this context, wearable medical devices must be easy to use, and it must be easy to find information and functions people need from wearable medical devices.

Promotion, as an originally introduced construct, involves that the use of wearable medical devices must be supported with some complementary goods and services, and the benefits and values of using must be clearly communicated. This construct also assumes that people bear in mind medical doctors' recommendations and views from their family, friends, and those whom they value to decide on use.

Perceived usefulness, as a standard construct, means that using wearable medical devices must be beneficial, enhance effectiveness, and improve performance in managing and improving health.

User characteristics, as a modified and improved construct, entail that people's authentic characteristics and expectations from wearable medical devices determine their attitude and behavior. This factor involves supporting the view of using wearable medical devices must be a routine. Moreover, with this factor, if people have health problems, they will more conceivably use wearable medical devices.

Worthiness, as an originally introduced construct, requires that using wearable medical devices must truly offer value for money and effort spent. Meanwhile, performance and quality must be satisfactory. Moreover, for this construct, purchasing and maintenance costs must be affordable.

3.3 Explanations for distilled relations

Compatibility positively influences attitude & behavioral intention: The more compatible wearable medical devices are with people's current preferences and habits, the possibility that people have positive feelings toward and intend to use wearable medical devices increases. Compatibility promotes attitude & behavioral intention as people have no major struggle or inconsistency, yet comfort and consistency owing to compatibility. That is why compatibility is the correct enabler for attitude & behavioral intention.

Compatibility positively influences device characteristics and features: Compatibility can normally be interpreted as a device characteristic and feature. Elements ensuring compatibility like providing compatible interfaces or protocols to work with other devices to ensure convenience is one example of device characteristics and features. Wearable medical devices must be developed and produced with expected compatibility characteristics and features. That is how and why the compatibility factor enhances device characteristics and features factor.

Compatibility positively influences perceived ease of use: As compatibility ensures consistency of using wearable medical devices with people's current preferences and habits (i.e., all aspects of their lives), it is fairly ordinary that people will find wearable medical devices easier to use thanks to

confirmed compatibility. People will not need a lot of mental and physical efforts as compatibility moderates the need for them owing to consistency and interoperability. Comfort and convenience boosted by compatibility will result to people perceiving improved ease of use.

Compatibility positively influences perceived usefulness: When compatibility is directly confirmed, using wearable medical devices will enhance effectiveness and improve performance to a greater extent. More usable devices will be there as a result of improved and enhanced functionality boosted by compatibility. Compatibility is to bring about more functionality and usefulness on account of extended capabilities through other devices, and this is going to particularly enhance perceived usefulness.

Design positively influences device characteristics and features: Design can normally be perceived as a device characteristic and feature. Wearable medical devices must be developed and produced with respect to sound design principles and elements which are the essence of the design construct. Design considerations are truly part of device characteristics and features. That is how and why design factor augments device characteristics and features factor.

Design positively influences perceived ease of use: Good design principles and practices are going to give a notable rise to further ease of use regarding wearable medical devices. Owing to comprehensive concerns regarding comfort, interface convenience, simplicity, and involving users throughout the design, interaction with such devices is to be clear and understandable and not to require a lot of mental and physical efforts. Good design makes it easier to find information and functions people need.

Dependability positively influences device characteristics and features: Comprehensive dependability as a fusion of availability, reliability, safety, and maintainability can typically be perceived as a subdivision of device characteristics and features construct. Obviously, dependability conspicuously adds to device characteristics and features factor in terms of certain elements based on availability, reliability, safety, and maintainability attributes of wearable medical devices. Once dependability is completely ensured with such attributes, the construct of device characteristics and features is remarkably promoted.

Dependability positively influences perceived ease of use: Dependable wearable medical devices do not require loads of mental and physical struggle while using. Readiness for correct service, continuity of correct service, absence of catastrophic consequences, and the ability for maintenance and repair on account of the main theme of dependability firmly develop perceived ease of use since all these characteristics of dependability construct deliver additional convenience end effortlessness.

Dependability positively influences perceived usefulness: Surely, availability, reliability, safety, and maintainability dimensions covered fully by the dependability of wearable medical devices let people use wearable medical devices whenever they want to, have reliable information, feel safe, and conveniently continue using, and this definitely increases usefulness as a result of enhanced effectiveness and improved performance in managing and improving health. Perceived usefulness requires enhanced effectiveness and improved performance in managing and improving health, and these are improved given that these devices are acceptably available, reliable, safe, and maintainable.

Privacy, confidentiality, and security factor positively influences attitude & behavioral intention: Normally and expectedly, people want to have the essential authority to determine what information to share, with whom, and how. Likewise, people want that information must be used for the intended purpose only, and user consent must be taken first for any disclosure. Above and beyond, people expect the protection to safeguard from unauthorized access to or modification, denial of service to unauthorized users, and provision of service to authorized users only. All these prospects are addressed by privacy, confidentiality, and security construct, and this construct improves positive feelings toward and intent to use wearable medical devices.

Perceived ease of use positively influences attitude & behavioral intention: As the interaction with wearable medical devices is clearer and effortlessly understandable, people are habitually going to have additional encouraging feelings toward and intend to use these devices. Additionally, if it is not legitimately easy for people to use wearable medical devices, this will influence their pertinent attitude and behavioral intention deleteriously. Provided that people find it easy to find information and functions they need from wearable medical devices, they typically have judgments such that using wearable medical devices is a good & wise idea and will be valuable & beneficial. Ease of use is going to improve the intention to use on the subject of using wearable medical devices.

Perceived ease of use positively influences perceived usefulness: When it is confirmed that wearable medical devices are easy to use, people's views regarding the devices' usefulness increase. As people moderately easily take advantage of information and functions they need from these devices, people's perception regarding enhanced effectiveness and improved performance in managing and improving health fairly expands. Actually, guaranteed ease of use will let people directly experience enhanced effectiveness and improved performance in managing and improving health.

Promotion positively influences perceived ease of use: Thanks to complementary goods and services, well-communicated benefits and values, and recommendations, people more potentially think wearable medical devices are easy to use. Such promotional practices honestly moderate people's perception of ease of use of wearable medical devices since

they are supported and vindicated in the related content and context by means of promotion construct attributes.

Promotion positively influences perceived usefulness: With the help of promotion construct involving provisions regarding benefits, briefings, and propositions, perceived usefulness notably enhances. As people become further aware of the benefits of wearable medical devices and reinforced by the people they value, their discernment on their interpretation that wearable medical devices are useful increasingly advances. Moreover, provisions regarding benefits, briefings, and propositions will let people experience enhanced effectiveness and improved performance in managing and improving health to a better extent.

Perceived usefulness positively influences attitude & behavioral intention: When people think using wearable medical devices is useful, the use of wearable medical devices notably enhances effectiveness and improves performance in managing and improving their health, their attitude & behavioral intention growths in a positive manner. Boosted effectiveness and enhanced performance in managing and improving health by means of perceived usefulness will end in views such that using wearable medical devices is a good idea and will be beneficial, and, in this context, people are going to have much more positive feelings toward and to a greater extent intend to use these devices.

User characteristics positively influence attitude & behavioral intention: Assuredly, people's certain and novel characteristics and expectations from wearable medical devices affect their attitude and behavioral intention regarding wearable medical devices. Unambiguously, if people have the view of using wearable medical devices must be a routine or if they have any prominent health problems, they more decisively think that using wearable medical devices is a good & wise idea and will be valuable & beneficial. In this context, appropriate user characteristics possibly will increase encouraging feelings toward and intend to use wearable medical devices in the future.

Worthiness positively influences perceived ease of use: As long as people contemplate that using relevant wearable medical devices accurately offer actual value for money and effort spent, their discernment on ease of use impartially cultivates. Owing to this fact, they find wearable medical devices satisfactory and affordable; they more conceivably perceive wearable medical devices easy to use in a better manner. The foremost justification for this interconnection might be that tangible value and clear worth make it easier to use as people are pleased and justified. Thanks to attributes of worthiness construct, satisfied and pleased people will perceive more ease of use regarding these devices.

Worthiness positively influences perceived usefulness: Satisfactory, reasonable, and affordable wearable medical devices, offering tangible and true value for money and effort spent in the relevant contexts, elevate perceived usefulness thanks to that using wearable medical devices is useful, and they enhance effectiveness and improve performance in managing and improving health. The foremost reasoning for this relationship might be that worthiness and usefulness are accurately interrelated based on their emphasis on real value and benefit. If people think that it is worth, their perception of usefulness markedly increases.

3.4 Additional findings

In order to draw additional conclusions regarding critical success factors for wearable medical devices, the qualitative data collected through Sect. 3 of the questionnaire were analyzed employing quasi-statistics. Section 3 of the questionnaire is optional for participants. The summary of the analysis of data collected in this part of the research is provided in Online Appendix C of ESM.

For qualitative data analysis, a table was composed to list and manage the qualitative data gathered by means of the questionnaire. After populating the table, the quasi-statistics were used to determine the possible additional success factors for wearable medical devices. In this context, in the analysis of the collected qualitative data, if there was something mentioned by participants related to already covered constructs (i.e., the 11 constructs distilled via the partial least squares structural equation modeling approach), relevant codes are assigned, and the analysis results for expressions mentioning related already covered constructs are given in Online Appendix C of ESM.

Promotion, worthiness, design, dependability, and perceived usefulness constructs for the success of wearable medical devices were found to be the top five constructs. For the promotion construct, the participants asked for more information and demonstration to enhance appropriate awareness. Intended for worthiness, the participants reiterated the importance of the affordable cost of the wearable device. For design, the participants highlighted the need for convenience and easy interaction. In the case of dependability, the participants underlined the reliability and correctness. Regarding perceived usefulness, people restated the absolute need for useful functionalities.

In the analysis of the collected qualitative data, new names and codes were assigned in case of any missing noteworthy issues. The results of the analysis of expressions mentioning new constructs are provided in Online Appendix C of ESM. In this regard, special functions, government support, data sharing feature, proactive alerts and notifications, after-sales support, balanced notifications, customization, development level of the country, environmental friendliness, explanations for side effects, involving doctors, robust to environmental conditions, and use of nanotechnology have been identified as new issues where *special functions, government support, data sharing feature,* and *proactive*

alerts and notifications were the most frequently mentioned constructs for the acceptance leading to the success of wearable medical devices.

Regarding *government support* to increase the success of wearable medical devices, participants in this research evidently mentioned that they expect the government or related authorities to supply them with wearable medical devices or to support their purchases of these wearable medical devices with incentives and promotions. In fact, this kind of support and incentives can truly be economically advantageous for the government in the middle or long run by decreasing related health costs as these devices are truly instrumental for managing and improving health.

Additionally, utilizing the new construct of *data sharing feature* to notably enhance the success of wearable medical devices, participants clearly underlined that they want to be able to share the relevant collected data via wearable medical devices with doctors or others as they wish. In fact, this item can be interrelated with the already covered compatibility and device characteristics & features constructs regarding the acceptance of wearable medical devices. However, while integrating this construct, privacy, confidentiality, and security constructs must also be fully addressed and contented.

Regarding the new construct of *proactive alerts and notifications* for enhancing the success of wearable medical devices, participants simply claimed that they expect their wearable medical devices to offer proactive and preventive alerts and notifications for managing and improving their health. This construct can also be treated as a subcategory of special functions construct, yet we preferred to define and treat it as a sole construct due to its importance as highlighted by the participants of this research.

The results of the quasi-statistics must be interpreted cautiously due to the small sample size when compared to the main data collected from 1057 participants. As the sample size is relatively low when compared to our main work, the results only reflect the views of our relatively small sample for the qualitative part of our work.

Moreover, the following three items are noteworthy as supplementary findings. First, wearable medical devices of smartwatch and sports/activity trackers are the most frequently known and used wearable medical devices by participants in this research. In point of fact, this conclusion is not that surprising since wearable medical devices like smartwatches and sports/activity trackers are the most mature and disseminated categories of wearable medical devices both in the industry and in the community. Second, wearable medical devices like smart clothes and smart glasses are the least known and used wearable medical devices by participants in this research. This is not surprising owing to the fact that these wearable medical devices are the least mature in the industry and also they are the least disseminated in the community. Third, we asked people what (i.e., functionality, nice look, or both) is the most important for them concerning wearable medical devices. The majority of the participants request and expect not only functionality but also a nice look relating to wearable medical devices. This needs to be taken into account predominantly by wearable medical devices product developers since people demand to have both functionality and a nice look to ensure the acceptance of a wearable medical device.

3.5 Implications

The implications of this research are twofold: (1) academic and (2) practical. First, the applied methodology and results of this research will be helpful as a guide for researchers in the field of technology acceptance and wearable medical devices. Practical implications would be for wearable medical devices product developers and product managers, who could benefit from the research findings.

Interested researchers and scholars in the pertinent study field may benefit from this research regarding study design, questionnaire development, applied methodology. Distilled results about the factors, accompanying items, and interactions of factors about enhancing the success of wearable medical devices may also be helpful when formulating their research questions. Findings of this research resolutely contribute to the acceptance of wearable medical devices literature, and other researchers may benefit to expand and refine the pertinent body of knowledge.

Specifically, other researchers might reuse, tailor, or adapt the constructs (i.e., compatibility; design; device characteristics and features; user characteristics) that are to some extent modified and improved in the scope of this research and the constructs (i.e., dependability; promotion; worthiness) originally introduced in the scope of this research in order to better understand and study critical success factors for wearable medical devices or other relevant technology products and services. Moreover, other researchers and scholars might reuse or tailor the questionnaire developed in their relevant studies.

Product developers and managers in the wearable medical devices business might benefit from the pertinent extracted outcomes with the intention of firmly attracting more customers and remarkably improving user satisfaction, customer loyalty, and user experience. By means of employing the distilled constructs and relevant items (elements, features, and/or situations) as a checklist, as given in Table 6, product developers and managers can appraise capabilities and maturities of their products and can identify main dimensions and points to improve in order to enhance their success.

Moreover, as discussed in Sect. 3.1, the distilled results of this study can be helpful for product developers to define certain terms. As for dependability, for example, they can

Table 6 Checklist for wearable medical devices product developers and managers

Factors and pertinent items	±
Dependability	
Ensures readiness for correct service to let users use them whenever they want to	
Ensures continuity of correct service to let users have reliable information	
Ensures absence of catastrophic consequences on users and the environment to let users feel safe	
Ensures ability for maintenance and repair to let users conveniently continue using	
Design	
The color and materials are satisfying regarding aesthetics, convenience, and robustness	
Relevant and target users are involved throughout the design	
Lightweight and durable	
Comfort, interface convenience and simplicity are considered during the design	
Device characteristics and features	
Battery and energy efficiency are satisfactory for convenient use	
Uses sounds, visuals, and haptics for continuous feedback	
Provides a variety of functionality and added value to manage and improve health	
Offers detailed analytics and recommendations to users	
Worthiness	
Offers value for money and effort spent	
Performance and quality value are satisfactory	
Purchasing and maintenance costs are affordable for users	
Perceived usefulness	
Enhances effectiveness in managing health	
Improves performance in managing health	
Privacy, confidentiality, and security	
Users have the authority to determine what information to share, with whom, and how	
Information is used for the intended purpose only, and user consent is taken first for any disclosure	
The protection to safeguard from unauthorized access to or modification, denial of service to unauthorized users, and provision of service to authorized users only are ensured	
Perceived ease of use	
Interaction is clear and understandable and does not require a lot of mental and physical effort	
Finding information and functions is easy	
Compatibility	
Consistent with users' current preferences and habits	
Compatible with users' existing electronic devices (smartphones, tablets, computers, etc.)	
Promotion	
Supported by complementary goods and services	
Benefits and values are clearly communicated	

more clearly identify what must be specifically addressed to ensure the dependability of wearable medical devices. That is, during design and development, for the case of dependability, they must confirm that their device satisfactorily ensures readiness for correct service to let users use whenever they wish; also ensure the continuity of correct service for reliable information; absence of catastrophic consequences to letting users feel safe, and the ability for maintenance and repair to let users conveniently continue using.

Furthermore, product managers or marketers are now able to appreciate the importance of worthiness for wearable medical devices. Explicitly, for worthiness, they need to ensure that using wearable medical devices must truly offer value for money and effort spent. Namely, performance and quality must be satisfactory, and purchasing and maintenance costs must be affordable for success. These are accurately valid for all of the distilled constructs (i.e., attitude and behavioral intention; dependability; design; device characteristics and features; worthiness; perceived usefulness; privacy, confidentiality, and security; perceived ease of use; compatibility; promotion; user characteristics) on account of the 39 distilled pertinent items. Specifically, interested parties now not only know the all-encompassing factors, but also become knowledgeable about specific issues to achieve success in related factors through relevant 39 items.

Additionally, as discussed in Sect. 3.2, by considering the distilled significant relationships among constructs, product developers and managers will be able to know how to exploit certain main constructs in relation to others. For instance, product developers are now capable of seeing how the compatibility of wearable medical devices influences perceived ease of use. Explicitly, comfort and convenience remarkably boosted by compatibility will let people perceive that ease of use is higher. Moreover, product developers and managers now know how the dependability of wearable medical devices influences the perceived usefulness of wearable medical devices. That is, perceived usefulness requires enhanced effectiveness and improved performance in managing and improving health, which can be improved if wearable medical devices are satisfactorily available, reliable, safe, and maintainable. These are valid for all of the 18 distilled statistically significantly meaningful relationships among constructs for enhancing the acceptance of wearable medical devices.

If the additional factors identified as a result of analysis of the collected qualitative data are taken into consideration, both researchers in the field and people in wearable medical devices business would know and appreciate further about the success factors of these devices. For instance, further research is needed on the role of government support for acceptance and success. Similarly, product developers might incorporate data sharing feature and proactive alerts & notifications capabilities to boost the acceptance and success of their products.

3.6 Limitations and potential for future research

Despite the fact that this research is an authentic and prominent one in exploring constructs to enhance the success of wearable medical devices, there are a number of limitations of this research and these can be addressed in future explorations.

At the outset, we need to draw attention to the fact that the concept of "wearable medical devices" is fairly broad-spectrum, and it may possibly cover diverse tools for diverse purposes. However, in this research, we set and limited the definition of wearable medical devices with smartwatches, smart clothes, smart glasses, sports/activity trackers, or various sensors placed on bodies for health-related purposes. This delimitation must firmly be taken into account while interpreting and implementing the results of this research.

Regarding data collection, the researchers intentionally limited the sample with a developing country, Turkey, and all participants are from Turkey. Nonetheless, it might be thought provoking to use the same instrument (questionnaire) developed and presented in this paper to collect data from other countries. This could form a basis for a cross-cultural study comparing and contrasting the results of this research.

Furthermore, in this research, wearable medical devices (smartwatches, smart clothes, smart glasses, sports/activity trackers, or various sensors placed on bodies) have been studied in a general sense. In that respect, it is also legitimate to study different categories of wearable medical devices one at a time. For each category, i.e., smartwatches, smart clothes, smart glasses, sports/activity trackers, or various sensors placed on bodies, different studies may be conducted, and their results may be compared and contrasted. Especially, regarding the least frequently known and used wearable medical devices (i.e., smart clothes and smart glass), a devoted study might be conducted to better understand the relevant success factors.

Moreover, relevant future studies might also be steered in a longitudinal manner with semi-structured interview portions drawing more comprehensive and loyal conclusions, and theoretical/practical implications enhancing the success of wearable medical devices. This is mostly recollecting data from the same people at different timeframes, and accumulating many further details with interviews might improve the reliability and validity of the conclusions. These practices can also be applied to different user groups (e.g., gender, education status, generations, health status, income levels) to better understand relevant group properties and dynamics regarding wearable medical devices.

Additional constructs identified as a result of the qualitative data analysis in the scope of this research can be transferred to a new or extended questionnaire, and their validity can be tested with larger samples. We evidently note that when compared to the sample size of our main analysis for the quantitative part, the sample size of our work's qualitative part is relatively lower. Hence, there is a net need to support or refute our pertinent drawings with larger samples.

Accordingly, what the results actually indicate is that as the central item of success factors for wearable medical devices, the pertinent attitude & behavioral intention construct can be achieved and improved employing the factors and relations. These results are beneficial for both researchers and product developers to improve the success of wearable medical devices. However, the results distilled in this research must be refined with contextual realities, if any, to ensure seamless fitting. Naturally, there might be certain political, economic, socio-cultural, and technological dynamics fairly applicable to different contexts and circumstances. Such dynamics must definitely be taken into account while interpreting and implementing the results.

4 Conclusions

Within this research, we tried to answer further research calls by some other salient studies [23, 55–63, 65, 67, 68, 70, 72, 75, 87], and to the best extent of our reviews and knowledge, this research is the first of its kind on account

of its sample characteristics with applied comprehensive methodology and distilled results. As a fairly transdisciplinary addition to other related and noteworthy studies, this research has the potential to enable researchers in the field to move quite rapidly forward. Since wearable medical devices are becoming more popular and ubiquitous not only for users but also for developers and researchers, the results of this research will be valuable for all pertinent stakeholders.

The results of this research concerning commonplace factors (i.e., attitude and behavioral intention; perceived ease of use; perceived usefulness) of technology acceptance are typically in parallel with the ones of the well-established technology acceptance studies [99–102]. Moreover, our results are moderately similar to the marks of [64, 76, 77] regarding the prominent effects of usefulness, design, ease of use factors. Furthermore, our results are similar to the results of [49], based on the fact that they also concluded that perceived risk and compatibility constructs along with the original technology acceptance model constructs are imperative for success. Besides, from the privacy and risks perspective, just like [23, 68, 72], we concluded that privacy, confidentiality, and security of wearable medical devices are vital for the acceptance and success. Nevertheless, truly in contrast to one relevant study [91], we found attitude as a strong mediator and ease of use as a significant construct for the acceptance and success of wearable medical devices. Furthermore, similar to the perceived value and benefit factors in noticeable studies [23, 70, 72, 87], we found moderately related factors such as worthiness and perceived usefulness as significant constructs for the acceptance of wearable medical devices. Above and beyond, in parallel with the results of other associated prominent researches [65, 70], we found factors such as behavioral intention & attitude and user characteristics as significant for the acceptance of wearable medical devices. Moreover, regarding convenience and usefulness, the results of this research are in agreement with the ones of still other related studies [59, 67, 87].

This research resolutely differentiates itself from the other relevant studies owing to the comparatively rich dataset, the applied comprehensive methodology, and newly introduced factors and relations for success. With this research, we not only purposefully added and improved some meaningful dots but also intelligently connected all pertinent dots to draw a comprehensive big picture regarding the success of wearable medical devices.

In brief, regarding the distilled salient constructs to enhance the success of wearable medical devices in the scope of our research, there are three main categories. The first category includes the constructs quite well-established and verified in the pertinent literature, researches, and applications. These include: attitude and behavioral intention; perceived ease of use; perceived usefulness; privacy, confidentiality, and security. The second category includes the success factors which are modified and improved to some extent in the scope of this research. These factors are: compatibility; design; device characteristics and features; user characteristics. The third category includes the constructs originally introduced in the scope of this research. These success factors include dependability; promotion; worthiness.

Our study mainly contributes to the relevant body of knowledge concerning the critical success factors for wearable medical devices with 11 salient constructs with 39 items and 18 significant relationships among the distilled success factors. The constructs are: attitude and behavioral intention; dependability; design; device characteristics and features; worthiness; perceived usefulness; privacy, confidentiality, and security; perceived ease of use; compatibility; promotion; user characteristics. Additionally, this research adds to the pertinent body of knowledge about results reflecting the additional 13 new constructs, which include: special functions, government support, data sharing feature, proactive alerts and notifications, after-sales support, balanced notifications, customization, development level of the country, environmental friendliness, explanations for side effects, involving doctors, robust to environmental conditions, and use of nanotechnology, distilled as a result of the analysis of the collected qualitative data.

In our opinion, these contributions notably advance the understanding regarding critical success factors for wearable medical devices which are today's and the future's salient technology products. We hope our findings are going to be useful for researchers in the field to develop and refine the body of knowledge, and for wearable medical devices product developers and managers to attract more people and improve user satisfaction, customer loyalty and user experience on the way to understand and enhance the success.

Author contributions MD was involved in conceptualization, methodology, validation, formal analysis, investigation, data curation, writing—original draft, and project administration, and S-OY analyzed conceptualization, methodology, writing—review & editing, and project administration.

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Availability of data and material See Online Appendix A and B.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest concerning this research.

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