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Quality of Experience in Relation to Personal Informatics Tools: The Analysis and Modelling of Quality of Experience for IoT

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Quality of Experience in Relation to Personal Informatics Tools:

The Analysis and Modelling of Quality of Experience for IoT

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Abstract

The exponential growth of services via personal informatics (PI) is making it increasingly important to cater to the quality expectations of end users. Quality of experience (QoE) becomes the guiding paradigm for managing quality provisioning and application design in PI. This study examines the relationship between human experience and quality perception in relation to the IoT, developing a conceptual model for QoE in PI. By integrating human perception and experience factors involving quality and heuristics into the assessment, our study proposes a user experience model that conceptualizes a QoE specific to PI and highlights its relationship with other factors. This model establishes a foundation for future IoT service categories through a heuristic quality assessment tool from a consumer-centered perspective. The results provide a ground truth basis for developing future PI services with QoE requirements, as well as for dimensioning the underlying network-provisioning infrastructures, particularly with regard to mobile access technologies. This study provides key insights into the role of expectations and experiences in technology adoption, while supporting a quality model.

Keywords: quality of experience; quality of service; user experience; personal informatics; Internet of things; quality measurement; human-centered design

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Quality of Experience for Personal Informatics Tools:

The Analysis and Modelling of Quality of Experience for IoT

Personal informatics (PI) systems are becoming increasingly popular, as their cost, design, and ease of use greatly improves. Consumers use PI systems to gather personal behavioral data, make better decisions, and make changes to their behavior (Rapp & Cena, 2016). PI is emerging as the next technology mega-trend, with repercussions across the business spectrum. Computing and information processing is going beyond the desktop model of computer interaction, and becoming integrated into the everyday objects we interact with and the activities we engage in (Epstein, 2015).

The rapid rate of growth and increasing demands of PI services is making it even more vital that service providers measure user satisfaction levels, since this will help them identify and address areas in need of improvement. Despite the increasing need for more precise and effective measurement of service quality, no agreement has been reached on how UX should be conceptualized or measured (Chun, Lee, & Kim, 2012). Improving user satisfaction with technologies has been a hot topic of research in telecommunications (Turel & Serenko, 2006). Despite numerous attempts to understand UX, studies have tended to measure UX superficial ways or focused on user satisfaction indices for entire industry sectors (e.g., American Customer Satisfaction Index; Fornell et al., 1996). Most previous studies have merely focused on quantifying technical performance while neglecting user values, such as quality of service (QoS). The telecommunications sector has relied on QoS as a measurement of overall performance. However, quantitative measurements of QoS have considered only technical network performance (Li & Rong, 2015). Few studies have explored the quality factors impacting UX

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and satisfaction or sought to develop strategies for quality improvement through user-centered approaches.

As smart technologies like PI become more complicated and compound, conventional QoS schemes and satisfaction approaches reveal their limitations: both neglect the perspective of end-users. The key is finding a way to correlate technical-level QoS with user QoE. While efforts have been made to map user behavior relative to technical network characteristics and QoS (Shaikh, Fiedler, & Collange, 2010), research on QoE and QoS has been isolated and fragmentary; their correlation remains unclear, particularly in emerging technologies (Ciszkowski et al., 2012). The example of some unsuccessful recent technologies suggests that, while technical QoS is excellent and proven, user QoE remains unexplored and unproven. For example, although PI services provide great value as well as convenience to users, numerous services have limited ability to promote engagement; people frequently stop these services without having meaningful outcomes and satisfaction. It is important to integrate QoS and QoE by developing a user-centered performance measurement for services. Both industry and academia acknowledge the need to develop reliable and usable methods of determining accurate measures of user satisfaction (Boakye, McGinnis, & Prybutok, 2014).

Beyond superficial behavior or meaningless satisfaction, it is important to understand how consumers cognitively perceive quality and what kinds of meaningful experience they derive from smart services. In light of this, the goal of this study is to develop a conceptual QoE model suitable for the emerging field of PI services. This study aims to develop a sustainable framework for evaluating PI by investigating how to quantify, observe, and analyze in order to characterize, assess, and manage services offered through a PI system. Three research questions guide this study:

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RQ1. What is the consumer experience of using PI, in terms of motivations and quality?

RQ2. What factors determine QoE, and how do these factors relate to each other in PI?

RQ3. How can QoE be measured from a consumer perspective, as opposed to a technology-centered approach?

Using the Expectation Confirmation Theory (ECT), this study proposes a model for the study of expectation confirmation in PI systems. Incorporating several quality factors central to PI, consumer expectations and user experiences were tested, conceptualized and operationalized to test the model. The model derived from these research questions opens avenues for systematic modeling and an analytical methodology for evaluating PI, surpassing the QoS evaluation advances made over the past two decades. This study contributes to the literature in three ways. First, its QoE model advances the UX literature by identifying key variables and the structural relationships between them. As IoT rapidly develops, traditional notions of QoS and UX must change to reflect the heterogeneous and complex nature of user preferences. Despite growing demand for effective QoE prediction and monitoring, there is a lack of QoE analyses of emerging technologies and new transmission networks. QoE is especially important for advanced networks, since the huge amount of traffic they experience exerts great pressure on resource-limited bandwidths. User-based designs for wireless systems based on a QoE index will enable a more effective use of available resources.

Second, the results should prove valuable to market research practitioners engaged in measuring PI user satisfaction, as they are increasingly responsible for developing of PI-specific factors and satisfaction indicators, and must make vital decisions based on them. As more personal and business applications migrate to the Internet of Things, quality becomes an important differentiator among providers. The relationship between the a priori expectations of

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consumers, their a posteriori experiences, and outcomes related to the planned future direction of PI systems has been a key issue since the launch of this technology. Understanding the gap between expectation and experience and its implications for PI adoption and use will be of great value, in both research and practice.

The QoE issue should attract a great deal more attention in the ICT sector, where UX is now considered more important than the traditional technology-centric QoS perspective (Kilkki, 2008). The new metric proposed in this study, and based on both subjective and objective analysis, provides useful insights, particularly when it comes to disentangling the causes of variable consumer satisfaction (and related issues) in wearable services.

Finally, this study provides guidelines and guidance concerning the interface design for PI. Devices linked to the Internet of Things are unique in their focus on interface and interaction, which allow them to sense and actuate the human world. One challenge for the PI system, as computers become increasingly invisible and interface-free, is to make usable devices with no interface. By focusing on the QoE model, this study offers service designers practical tactics that include both a human-centered approach (to analyze user perceptions) and technology-oriented guidelines (to guide product development) in order to improve QoS in advance of full-fledged rollouts.

2. Theoretical Background

2.1. Expectation Confirmation Theory

ECT is a cognitive theory that seeks to explain post-purchase or post-adoption satisfaction as a function of expectations, perceived performance, and the disconfirmation of beliefs. According to ECT, users' continuance intention is mainly influenced by their satisfaction with prior technology use (Brown, Venkatesh, & Goyal, 2012).

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Satisfaction has been defined as a psychological effect related to and resulting from a cognitive appraisal of the expectation–performance discrepancy (Bhattacharjee, 2001; Jung, 2011; Shin, 2012). Satisfaction also refers to an affect that is accepted as a positive (satisfied), indifferent, or negative (dissatisfied) feeling. An affect (in the sense of an attitude) has been conceptualized and validated in technology acceptance research as a key factor in technology use (Lee et al., 2015). In addition, empirical studies show that a user’s continuance intention is positively affected by his or her levels of satisfaction (Liou et al., 2015).

Consumers accept and use new technologies, such as PI systems. Following a period of initial consumption, consumers form perceptions about the performance of each system, including whether or not it enables them to achieve their goals. Furthermore, they contrast the perceived performance of the PI with their own original expectations to determine the extent to which their expectations are confirmed. Because expectations and perceptions of performance can vary from customer to customer, a positive confirmation indicates that the actual performance of the PI system exceeds expectations. In this case, the consumer is satisfied. However, confirmation can be negative when the perceived performance of the PI system falls short of expectations; in this case, the consumer will be dissatisfied (Koo et al., 2011). In both cases, the consumer’s level of satisfaction or dissatisfaction will influence his or her intended behavior (Shin, 2012).

ECT is ideally suited to this investigation because it seeks to explain user behaviors as a function of expectations, perceived performance, and confirmation of beliefs. This study incorporates ECT as a tool to obtain the UX of PI. As a PI system offers various advanced features, it is important to understand user expectations, while also exploring how users actually perceive and experience features.

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2.2. *QoE*

Despite being robust and widely used, ECT has some limitations. ECT has been broadly applied to examine the intentions of technology users. Although “expectation” is enshrined in the name of the theory, the focus is actually post-consumption, rather than pre-consumption, expectation (Alamgir & Quaddus, 2011). In addition, while continuance usage intention has been validated as a dependent variable, the independent variables are quite varied. As a result, there is no general agreement about the definition, relationship, or measurement methods of the constructs involved in expectation and confirmation. This study attempts to provide a comprehensive review of expectation and confirmation, by adopting the concept of QoE.

The rise in convergence content on the Internet has renewed interest in quality evaluation. Unlike classic network-centered approaches, such as QoS, the new concept of “evaluation” focuses on the user’s perception of quality. Over the years, QoS, which is the overall performance of a telephony or telecom network measured in technological terms, by its error rate, bit rate, throughput, transmission delay, availability, and jitter, has been touted as a technological requirement for most telecom and multimedia services. While important, QoS has an exclusively inward orientation in its examination of network performance. Most service providers are thus shifting their focus from QoS to QoE, a largely outward-oriented, user-focused measure (Li & Rong, 2015).

QoE concerns the inclusive acceptability of an application or service, as perceived subjectively by the end-user (Shin, 2015). It is a subjective measure of a customer’s experiences with a service (Lauhari & Connelly, 2012), which focuses on the entire service experience; it is thus a more holistic evaluation than the more narrowly focused UX. QoE assesses user

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expectations, cognition, minds, perceptions, and satisfaction with a particular product, service, or application (Deng et al., 2010).

QoE can act as a useful complement to UX. Despite its popularity, the UX concept has been neither well defined nor understood (Shin, 2015). As technological services become increasingly complex, and as more service delivery occurs through advanced systems, the simple notion of UX as “usability” needs to be redefined. While QoE expands this horizon, most QoE approaches have been based on analyses of the media’s technical properties. It is important to estimate user satisfaction, and QoE depends on multiple factors in addition to technical properties and characteristics (Laghari & Connelly, 2012).

Quality of experience can be compared to QoS and UX. Although such comparisons cannot be exhaustive and may not be perfectly categorical, they are valuable. Table 1 shows the overall categories of medium, context, and user.

Table 1.

Comparing QoS, UX and QoE

	Source	QoS	UX	QoE
Medium	Content quality	Loading problems Compatibility	Enjoyment	Hedonicity
	System quality	Jitter, buffering, bandwidth, speed	Ease of use Usefulness	Convenience Utility
	Service quality	delay, packet loss	Satisfaction	Pleasure Fulfillment
Context		Physical environment Economic aspects Social situation	Engagement Participation	Affordability
User			Demographics Personality Previous experience	Coolness, Attractiveness Novelty Aesthetic value

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2.3. Personal informatics and user experiences

Personal informatics (PI) is a technology that helps people collect, monitor, and display information about their daily activities through intelligent devices, services, and systems (Rapp & Cena, 2016). They manage the flow of human activity data, engagement, and motivation. Personal data can be described from the human-data interaction perspective (Haddadi et al., 2013). Through PI, people record and monitor their own chosen target behavior, both through subjective information (for example, relating to a problem, situation, symptom, or disruption and the symptoms it produces, as well as to inner thoughts or feelings) and through objective information (e.g., the frequency or intensity of the behavior being observed). Self-monitoring technologies record occurrences of target behaviors, and provide feedback to help individuals increase their awareness and self-reflection (Choe et al., 2014). In order to properly present a user's working activity and self-monitoring information, the device must be paired with a user account, and data offered on a dashboard menu. By synchronizing user activity to the app, users can calculate calories, steps and distance over time, graph weight changes, trace food intake versus caloric burn, and assess their sleep quality and conditions.

While the proliferation of personal informatics makes collecting personal data easier, how best to help people engage with these systems over a long period of time remains an open question. This study explores which personal informatics factors lead to an engagement with UX and to sustained use.

3. Research Model and Hypotheses

3.1. Factors influencing QoE

Due to the numerous factors that can affect human interaction with PI, various services have different ways of deciding what constitutes a positive user experience. Thus, the first step in

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measuring the QoE of a PI service is to determine the sort of experience a customer hopes to experience through a particular service. This study conducted a preliminary qualitative inquiry, using a focus group, brainstorming sessions, and a literature review. Based on the preliminary study, a series of possible factors that influenced QoE were identified: satisfaction, involvement, affordance, coolness, enjoyment, and hedonicity; these results are largely consistent and consonant with previous studies, such as Zhu et al. (2015) and Gao and Bai (2014).

Following the approach of Per Boakye et al. (2014), this study divides the factors into two dimensions: attribute quality and subjective quality. The attribute quality refers to a technology's technical features, which can be normally measured using quantitative measures such as error rates, packet loss, throughput, the bit rate, error rate and delay, availability, and jitter. While similar to QoS, in this model case, attribute quality includes content, service, and system quality. Subjective quality is a measure of the consumer's subjective experiences with a PI service. While equivalent to QoE, subjective quality embraces the entire service experience, and is a holistic evaluation that goes beyond more narrowly focused usability. In this study's model, it includes traditional user factors such as usefulness, enjoyment, and satisfaction, as well as new heuristic factors like coolness and affordance. A high level of customer satisfaction leads to higher coolness and affordance, which provide strong cues for the PI system.

Content quality

In this study, content quality is defined as the relevance, reliability, and timeliness of the knowledge provided by PI services. The term "content quality" has been used interchangeably with "information quality," because numerous studies have shown that information quality helps to determine utility and ease of use (DeLone & McLean, 2003). Much research has focused on developing content quality as a discrete determinant of quality; content quality variables have

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been found to be useful predictors of ease of use and usefulness (Lin & Lu, 2000; Mazzoni et al., 2007).

As PI systems have become sufficiently complex to include a varied range of content, numerous studies have used perceived content quality in lieu of perceived information quality (Agboma & Liotta, 2010). For example, Cheong and Park (2005) applied perceived content quality to the mobile Internet acceptance model. Their factor analyses found content quality to be a valid predictor; they concluded that it was a significant factor in the adoption of that technology. Thus, user perceptions of PI utility seem determined by the quality of mobile content, as users heavily consume important content via their PI devices or systems. The following hypothesis can therefore be proposed:

H1: Content quality has a positive effect on the confirmation of PI.

System quality

System quality is the user's evaluation of how well the system performs when providing data/information and satisfying user needs (Shin, 2009). The PI is activated by operating systems that manage both hardware and software resources. These operating systems determine system quality, which is important in the context of the PI system. Consumers are reluctant to use PI when they experience frequent response delays, disconnection, lack of access, or poor security (Shin, 2014; Suki, 2012).

DeLone and McLean (2003) examined the relationship between system quality and user satisfaction, incorporating perceived usefulness as a measure of user satisfaction, and perceived ease of use, perceived usefulness, and information quality as determinants of user satisfaction. They found that system quality had an indirect impact on the extent to which the system was able to deliver benefits via mediational relationships, through usage intentions and user satisfaction

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constructs. Lin and Lu (2000) argue that information quality, response time, and system accessibility are effective predictors of ease of use and usefulness. Also, Hau, Kim, and Kim (2012) examined the effects of the perceived usefulness and perceived enjoyment of system quality in mobile services. Since response time and system accessibility, along with such factors as system reliability and security, can be understood as attributes that account for system quality, IS quality can be comprehensively determined by evaluating system and information quality. We thus propose the following hypothesis:

H2: System quality has a positive effect on the confirmation of PI.

Service quality

Service quality is the assessment of how well a delivered service conforms to user expectations. Hsu, Yen, and Chung (2015) argue that service quality, in conjunction with system and content quality, significantly affects ERP post-implementation success in the area of user satisfaction. Similarly, Kuo et al. (2009) have discussed the relationship between service quality, observed value, and user gratification in mobile services. The service quality of the PI is particularly important, as most applications are provided through a form of service.

Responsiveness, reliability, and assurance have been considered critical in PI services. Many recent studies have applied these elements to the mobile sector, as service quality has become increasingly important in mobile service (Aghdale & Faghani, 2012; Samen, Akroush, & Abu-Lail, 2013). We thus propose the following:

H3: Service quality has a positive effect on the confirmation of PI.

Confirmation and users' perceived value

It is widely accepted that users evaluate ICT services consider both their utilitarian and hedonic dimensions (Van der Heijden, 2004). While traditional ICT systems tend to be work-

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related and thus utilitarian, hedonic dimensions have become increasingly important in the design and adoption of smart technologies (Chun et al., 2012). Beyond utilitarian and hedonic values, users (in particular digitally oriented proactive users) might also enjoy heuristic values (Sundar, 2008). Adopting a heuristic approach to understanding user acceptance of digital technologies, Sundar (2008) proposes a series of heuristic factors such as affordance, realism, being there, coolness, novelty, and intrusiveness. Among them, this study has chosen coolness, affordance, and novelty as primary evaluative dimensions of PI services. These factors have been derived from the user acceptance model (Sundar, Tamul, & Wu, 2014; Kim, Shin, & Park, 2015) and subsequent studies (Shin, 2014; Sundar & Limperos, 2013). We thus propose the following hypotheses:

H4: Confirmation has a positive effect on the coolness of PI.

H5: Confirmation has a positive effect on the affordance of PI.

H6: Confirmation has a positive effect on the novelty of PI.

QoE: Satisfaction, coolness, affordance, novelty, and use behavior

As reported in studies such as Fornell et al. (1996), user satisfaction directly and indirectly influences user behaviors including purchasing behavior and intention to use. While user satisfaction has become a topic of great interest to HCI and marketing researchers alike, its relation to psychological factors has been widely debated, as user experience becomes more heterogeneous and new cognitive factors (such as coolness and affordance) emerge. An increasing emphasis is currently placed on the coolness aspects of technology because users feel “cool” when given newer, more innovative technological products, such as curved displays, smartwatches, and smartglasses (Kim et al., 2015). These cool devices invoke conscious acknowledgment of the “hipness” of the technology by triggering the coolness heuristic with its

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novelty and innovativeness, which ultimately produces positive user perceptions and experiences of the technology. In their study of the concept of “coolness,” Sundar et al., (2014) theorized that it was a socially constructed multidimensional user-based judgment consisting of four factors: attractiveness, originality, subcultural appeal, and utility.

Along with coolness, affordance has also become an important factor in HCI. An affordance is a relationship between an object or an environment and an organism which, through a collection of stimuli, affords the opportunity for that organism to perform an action (Norman, 1990). Sundar and Limperos (2013) argue that affordances provide cues to media users, which then trigger mental shortcuts in relation to the characteristics of the content they consume. They have proposed affordance as a new gratification for new media; it can be considered a new UX for smart technologies. The “affordance” concept is particularly important in the PI services because its interface with users is non-linear and unstructured. Affordable interfaces and interactions facilitate certain user behaviors. We therefore propose the following hypotheses:

H7: Coolness has a positive effect on levels of user satisfaction with the PI.

H8: Affordability has a positive effect on levels of user satisfaction with the PI.

H9: Novelty has a positive effect on levels of user satisfaction with the PI.

Satisfaction and Intention

According to the ECT, the continuance intention of users is primarily determined by their satisfaction with prior technology use. Drawing on earlier research (Bhattacharjee, 2001; Jung, 2011; Shin, 2012), this study defines satisfaction as a psychological effect related to and resulting from a cognitive appraisal of the expectation-performance discrepancy. Satisfaction

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also refers to an affect that is captured as a positive (satisfied), indifferent, or negative (dissatisfied) feeling. An affect (as a type of attitude) has been conceptualized and validated in technology acceptance research as a key factor influencing technology use (Lee et al., 2015). In addition, empirical studies have shown that the continuance intention is positively affected by satisfaction (Liou et al., 2015). Applying the above arguments to PI services, a final hypothesis is proposed:

H10: Users' satisfaction with their initial PI service usage is positively associated with their intention to adopt and continue using the service.

In addition to these factors, user factors may also influence the adoption and usage process (Shin, 2012). The user factors in this study include age, gender, and prior experience, which are tested as moderating effects.

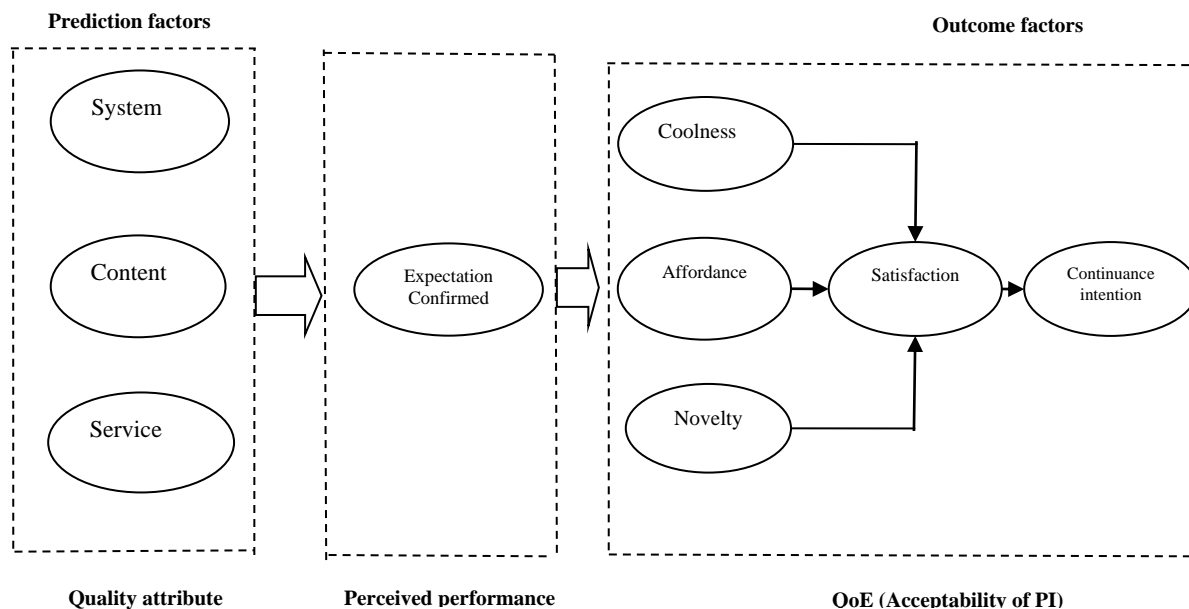


Figure 1. QoE Model for Personal Informatics

4. Study Design

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An in-depth assessment of QoE from the user's perspective requires that various methods be used to measure the QoE of PI. This study employs a combination of subjective and quantitative methods. As defined in ITU-T recommendation BT 500 (2014), QoE is the subjective user assessment of services. Thus, users' opinions and experiences are essential; the subjective method is an effective way of collecting such data. Moreover, as PI is a relatively new technology, qualitative data are helpful in understanding the overall picture of QoE in relation to personal informatics. Subjective quality assessments based on Epstein's Lived Informatics Model (2015) have been used in both experiments to evaluate the people's opinion as well as preliminary findings from the survey questionnaire. Subjective data were collected through ethnographic interviews with participants carefully recruited by a professional survey firm. The goal of ethnographic interviewing in the development of technologies is to understand users in their real environments, and to build personas and scenarios based on this understanding. Ethnographic interviews are designed to explain and specify the context of use and user requirements. Our initially selected participants were carefully tested and reselected. Fifteen subjects were dropped in the preliminary selection. A total of 89 subjects ultimately participated in the experiment. The participants were given a Wearable Band, a smart watch that displays data on health, walking distance, and activities (see Figure 2). The wristbands were specially redesigned to track the participants' activities. The devices allowed us to track users' physical activity, steps taken, and energy burned. The information from the wristband was integrated into an online community and phone application, allowing researchers to track the data and aggregate them on a daily basis, over a 10-day period. The experiment was focused on collecting data on tracking, acting, lapsing, and resuming, in accordance with Epstein's Lived Informatics Model. The experiment's log analyses were returned and analyzed. During the experiment, participants were required to use a

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QoS parameter scale composed of nine parameters. We used the ITU's mean opinion score (ITU, 2011)—an ordinal scale assessing quality on a 5-point scale from 1 (worst) to 5 (best).



Figure 2. Personal informatics device used in this study

After the experiment, the participants responded to an online survey. The results derived using subjective methods provide basic and fundamental information drawn from the survey questionnaires. A structured survey questionnaire was designed, and the survey was administered to respondents who had used or experienced any kind of IoT service. A total of 490 valid responses were collected and analyzed using a partial least squares (PLS) tool.

4.1. Measurement development

Unlike other studies, which typically rely on previously validated measurements, this study developed its own measurements, starting with ethnographic user inquiries. Ethnographic methods produced a conceptual mapping with keywords. Such keywords in the conceptual map are matched to previously validated variables from earlier research. Keywords such as “expectation” and “confirmation” are compared to ECT value measurements adapted from Brown et al. (2012) and Shin (2012). Keywords like “happy” and “delight” are matched to satisfaction and usage measures derived from Gao and Bai (2014) and Roca et al. (2006).

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Coolness and affordances are expressed in various terms and wording. Those categories are broadly matched to the measures developed by Sundar et al., (2014) and Kim et al. (2015).

Keywords such as “service,” “system,” and “contents” are matched to the measurements developed by mainly information system research, such as Fornell et al. (1996), Parasuraman et al.’s SERVQUAL (1988), and Shin (2009). The scales used in this study consisted of 24 items, with three items per factor. A pilot test was conducted prior to analysis. Participants indicated their agreement with a set of statements using a 10-point scale.

A survey questionnaire was developed based on iterative processes: three rounds of comments from an expert panel and Delphi-method. The expert interviews were performed utilizing a structured communication technique based on a systematic, interactive forecasting method. The experts responded questionnaires in two or three rounds. A pretest was carried out to measure test–retest reliability and construct reliability indices before conducting the fieldwork. Thirty current users with an interest in PI and quantified self-services participated in the two pretests at two-week intervals.

4.2. Survey administration

The survey was processed after the qualitative experiment. To acquire good-quality data, it was administered by a marketing firm with a collaboration with the research team. As the topic was emerging PI service, it was helpful to use a specialized marketing firm to ensure data quality. To control for country-specific effects, general population of PI users in the world were surveyed. Surveying this sample population yielded statistical results that are generalizable to the entire user population, since all respondents had used wearable devices for at least four months, which is sufficient for establishing reliable perceptions and opinions of the service. In addition, this sample is representative of the entire Korean user population, based on a comparison of

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demographic data. A chi-square test for goodness of fit revealed that market shares did not differ significantly between our sample and the Korean market at the 1% level. The data give a chi-square test statistic of 17.79 with 3 degrees of freedom and a p-value of 0.00019.

Table 2.

Characteristics of respondents (N=411)

Gender	N	Prior experience	N	Education	N	Age	N
Female	205	Less than 3 months	60	High school or less	50	Under 20	40
Male	206	3–12 months	105	College	221	21–30	219
Korean	170	12–24 months	155	Graduate school or higher	89	31–40	102
Others	241	Over 2 year	91	Other	51	Over 41	50

5. Findings

As has been suggested in earlier research, it is worthwhile examining the relations using quantitative analyses. In the case of PI, QoS and QoE were compared in three steps. First, the QoS parameters (speed, packet loss, jitter, delay, bandwidth, and burst) of wearable devices were measured and recorded. QoS parameters were then normalized using a QoE evaluation scheme (see Table 3). Finally, these numbers were compared using a mean opinion score based on the self-reported data of users. These scores (on a Likert scale of 1–5) were computed for each QoS parameter.

Next, following the method used by Li and Rong (2015), a principal component analysis was conducted to compare QoS and QoE. Two principal components were obtained by carrying out a principal component analysis of the data from QoS and QoE. The principal QoS and QoE components were as follows:

$$QoS = 0.57Z_1 + 0.53Z_2 + 0.49Z_3 + 0.29Z_4 + 0.51Z_5 + 0.32Z_6$$

$$QoE = 0.58Z_1 + 0.23Z_2 + 0.46Z_3 + 0.21Z_4 + 0.54Z_5 + 0.14Z_6$$

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(Z_1 : delay, Z_2 : jitter, Z_3 : loss, Z_4 : error, Z_5 : speed, Z_6 : bandwidth)

The eigenvalues and contribution rates of the two principal components are shown below, along with their coefficients and significance.

Table 3.

Comparison of QoS and QoE

QoS Parameter	QoE evaluation					Factors	Quality
	1	2	3	4	5		
Packet delay	>210ms	190– 210ms	170– 190ms	150– 170ms	<150ms	Application (Functionality, accuracy)	Content quality
Packet jitter	>70ms	50– 70ms	30– 50ms	10– 30ms	0–10ms		
Packet loss	>1.4%	0.9– 1.5%	0.4– 1%	0.1– 0.5%	0–0.1%	Sensor (availability, robustness)	Service quality
Packet error Speed	1< >49%	2–1 59– 50%	3–2 69– 60%	4–3 79– 70%	5–4 100– 80%	Network (reliability, transmission, capacity)	System quality
Bandwidth	>49%	59– 50%	69– 60%	79– 70%	100– 80%		

Principal component	Eigenvalue	Contribution rate	Cumulative contribution rate	Coefficient	Significance p
QoS	3.071	61.31%	61.138%	0.434	0.000
QoE	1.949	38.74%	98.321%	0.413	0.000

The above comparison shows that the evaluation scores for QoS and QoE are proportional; their correlation shows a generally inverse proportion. The self-reported QoE score shows that functionality received the highest QoS score (4.89), followed by availability (4.72). Overall, the participants saw the application layer as the most important QoS, followed by the sensing and network layers. This result is consonant with the normalized QoS score, where service and content show higher coefficients than network quality. Our results suggest that users' evaluation of PI quality is aligned with the QoS of the PI.

5.2. Partial Least Squares analysis

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This study used PLS (SmartPLS version 2.0 M3) to analyze the data and assess the general significance of the model. PLS is a multivariate statistical technique, which is widely accepted and used in many different disciplines (Chin, 1998). It allowed this study to resample (bootstrap and jackknife) the collected data, given that different kinds of data (qualitative and quantitative) were collected at different times. Thus, PLS was a good fit for the data in the study because it does not have a classical parametric inferential framework.

Using PLS to interpret results is related to measurement and structural model methods of investigation. The measurement model is evaluated on the basis of individual item loadings, construct reliability, convergent validity, and discriminant validity. Subsequently, the structural model is assessed to observe the causal relationships and their significance.

-Measurement model

This study used the two-step approach to PLS modeling suggested by Anderson and Gerbing (1988). To examine the underlying structure of the data, an exploratory factor analysis (EFA) was carried out. Principal component analysis (PCA) with Varimax rotation was used to discover the underlying factors. Using the criteria of eigenvalues greater than 1 along with an examination of the scree plot and a cumulative percentage of variance explained at 80.01%, the existence of four factors was supported (Table 4). We did not identify any common method bias in the dataset, since none of the four exogenous variables accounted for more than half of the variance in the endogenous variable.

Table 4.

Factor loadings from the rotated factor pattern matrix

	Attribute quality	ECT	Heuristics	Intention
COQ	0.89			

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SEQ	0.85			
SYQ	0.79			
CON		0.87		
SAT		0.85		
NOV			0.90	
COO			0.82	
AFF			0.86	
INT1				0.85
INT2				0.79
INT3				0.81
% Variance (total=79.94%)	29.71	24.71	14.89	14.28

We also assessed convergent validity and reliability. Convergent validity was assessed through composite reliability (CR), factor loadings, and extracting the average variance (AVE). All constructs had CR values of more than 0.86 (the recommended value is 0.7). The AVE measures the variance captured by indicators relative to measurement error, and should be greater than 0.5 to justify using the construct. The AVEs were in the range of 0.85 to 0.93. The discriminant validity of the measures was assessed by examining correlations between the measures of potentially overlapping constructs. As shown in Table 3, the squared correlations for each construct were less than the AVE from the indicators measuring that construct, indicating adequate discriminant validity. Overall, the measurement model demonstrated adequate convergent validity and discriminant validity.

Table 5.

Correlation and Q^2 value

	COQ	SEQ	SYQ	CON	SAT	COO	NOV	AFF	INT	Q^2 value
COQ	0.85									0.013
SEQ	.311*	0.87								0.046
SYQ	.410**	.39	0.87							0.135
CON	.339*	.310*	.426**	0.93						0.344
SAT	.459**	.399*	.415**	.305*	0.90					0.431
COO	.381*	.471**	.422**	.321*	.422*	0.84				0.004

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NOV	.399*	.401*	.120	.311*	.298	.401**	0.81			0.001
COO	.410**	.300	.313*	.384*	.301*	.430**	.401**			0.002
AFF	.416**	.423**	.311*	.394**	.332*	.581*	.129	0.91		0.091
INT	.311*	.331*	.391*	.311*	.48**	.402**	.301	.310*	0.88	0.181

*p < .05; **p < .01

Finally, if a model consists of latent variables with high levels of internal consistency, the predictive relevance of the model should be examined with a particular focus, to be consistent with the causal-predictive goal of PLS. The extent to which this prediction exercise is successful can be measured using the Q^2 statistic. This study selected the omission distance (D) = 7. $Q^2 > 0$ indicates predictive relevance (Table 5).

-Structural model

Based on the validation of our measurement model, the significance of all paths of the structural model was tested using a bootstrap resampling. The hypothesized causal paths were estimated, and all 12 hypotheses were found to be supported (see Table 6). Our results also supported the proposed model, confirming the series of key roles of technological quality, perceived value, and subsequent satisfaction. Customer expectations and the results for all latent variables were of 0.9 or higher, well above the recommended tolerance of 0.7. Results relating to the total effects of satisfaction on coolness, affordance, and novelty were significantly positive. These results highlighted the significant role of expectation/confirmation in determining user satisfaction. In regard to the impact of quality on confirmation, all path coefficients were significantly positive. The strong predictive ability of quality for confirmation was evident. Perceived heuristic factors (coolness, affordance, and novelty) were shown to have significant direct effects on satisfaction (H7, H8, and H9). The impact of quality on satisfaction was generally greater than that of perceived value, in line with the notion that—although value may

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be more important in consumers' initial purchase decisions—quality still plays a dominating role throughout the usage process. It also supports the finding that consumer satisfaction is more quality-driven than value-driven. Considering the high impact of quality, additional paths from quality to satisfaction were further tested. Adding three new paths, improved the overall fit of the model, with improvements in most of the goodness of fit indices. All three paths showed significant coefficients, shedding light on the heuristic role played by quality as well as various dimensions.

In terms of the explanatory power of the model, PLS draws on R^2 values for each endogenous variable (Chin, 1998). The R^2 value ranged from 0.399 to 0.539, and its mean was 0.382. Overall, it can be concluded that the latent variables were selected correctly, that the model is valid, and that the paths are reasonable given the positive Q^2 of all of the endogenous latent variables.

Table 6.

PLS standardized path coefficients

Hypothesis	Path coefficient (β)	P-values	t-statistics	Support
H1: COQ→CON	0.48	0.002	4.231***	Yes
H2: COQ→CON	0.39	0.038	4.023**	Yes
H3: SYQ→CON	0.29	0.021	2.748**	Yes
H4: CON→COO	0.26	0.078	2.873*	Yes
H5: CON→AFF	0.38	0.031	3.211**	Yes
H6: CON→NOV	0.42	0.029	3.374**	Yes
H7: COO→SAT	0.43	0.001	5.451**	Yes
H8: AFF→SAT	0.25	0.002	3.847**	Yes
H9: NOV→SAT	0.42	0.081	3.251*	Yes
H10: SAT→INT	0.38	0.014	3.326**	Yes

-S.E. is an estimate of the standard error of the covariance

-All β are circumflex ($\hat{\beta}$)

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$

The R^2 of expectation/confirmation explained about 42% of the variance, according to the three exogenous constructs in the model. The R^2 of satisfaction explained approximately 44%

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of the variance per the three exogenous constructs. High R^2 values suggest that the model can be used to predict relationships between the constructs.

6. Discussion

Although UX research based on QoS models is designed to overcome the limitations of technology-oriented measurement, all of the models have weaknesses and problems. Most UX research is still superficial and mechanical, focusing on external user behaviors; it has been applied in an undifferentiated fashion by the industry. Few researchers have sought an in-depth understanding of quality of experience. Furthermore, there is no standardized measure for wearable computing services. Likewise, the quality literature tends to focus on non-user issues such as design features, technical functionalities, commercial advantages, and product capabilities, instead of asking how users really feel about and experience specific services. The UX index has been used for marketing and commercial purposes but has not been properly researched or analyzed. There are no studies of PI or related services in the research on UX and customer satisfaction. To address this gap, this study proposes a QoE model to explain users' heuristics: how individuals develop quality experience while using PI services. The results have increased our understanding of user perceptions of PI services and clarified the implications for the development of user-based PI services and applications. The results of the structural model tests also supported our proposed research model. Overall, our research has shown that the models demonstrate good predictive powers and explain the PI service quality index model.

The results of this study show that the QoE model can accurately describe the personal perceptions and QoE of informatics service users. Consistent with prior research on service satisfaction, the usage of PI services has been found to be determined by perceptions of value and quality, which lead to user satisfaction. High user satisfaction in turn affects coolness and

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affordance. Highly satisfied customers are highly likely to reuse or repurchase. Furthermore, our findings have confirmed the importance of perceived quality in relation to service, content, and system, while showing that these qualities contribute to the utilitarian and hedonic value of PI systems.

This study has taken a novel approach toward assessing QoS, by employing users' self-reported data, and measuring their perceived feelings about a service, rather than calculating technical performance. Interestingly, many aspects of QoS and QoE correspond or are equivalent (in coefficient and factor rank), implying that QoS is indeed based on the user dimension, and that quality is a user property that resides in user perception. While quality features (i.e., content, system, and service) may have their own properties, the way users perceive and experience them is more important. To improve QoS in certain technologies, the industry must not only improve technical features but also facilitate users' interactions with new technologies. In this study, the factors of coolness, affordance, and novelty (where new paths were established in the model) shaped user perceptions of the quality of PI. In other words, coolness and affordance play an intermediary role between users and technology, increasing usability and interface, and thus improving acceptance. Such factors are the key components of QoE, which this study defines as heuristic factors in personal informatics.

Based on our findings, we can propose a new way of conceptualizing QoE, by highlighting four ideas of quality. First, quality can be viewed from an interactive procedural perspective, rather than as a static factor. Most research on perceived quality has focused on discrete factors, such as content, service, and system, neglecting the way in which such factors are processed (e.g., how users perceive, accept, experience, and interact). The procedural view of quality highlights the dynamic nature of QoE. The combined qualitative and quantitative

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methods in this study reveal the dynamic way in which users' cognition influences and is influenced by quality.

In a second point, related to the first, quality can be seen as an in-between concept, which connects users and technologies playing heuristic roles. In previous research (e.g., Ciszkowski et al., 2012), there has been a tendency to see device quality as separate from perceived quality. That is, users' perception of quality is assessed separately from the technical quality embedded in devices. The identified roles of heuristic factors (coolness/affordance) in this study imply that quality can be a heuristic link between users and the technological domain. Quality should be seen as a concept that combines technical quality and users' perceived quality, given that these factors are correlated and interact with each other.

Thirdly, the importance of users' perceptions of quality shows that quality is closer to a user-dependent concept than a device-dependent feature. Our findings imply that, while technical features and functionalities can improve quality, how users assess, use, experience, and continue to use technology determines their ultimate satisfaction, which in turn creates QoE. During the process, users take control over technology and the device. Quality as a user-dependent concept naturally calls for a user-centered design principle.

Finally, considering the above points, quality can be a multifaceted concept rather than a single idea or link between factors; it can encompass many different interpretations of the device, context, and users. In reality, users judge and experience quality in various ways and diverse contexts. Instead of pursuing a universally applicable QoE model, one can regard the sense of contextuality that flexibly conjoins users with their devices and interactions as a relational or co-evolving concept. People's QoE is based on context, user demographic factors, user experience, and the quality of the content, service, and system.

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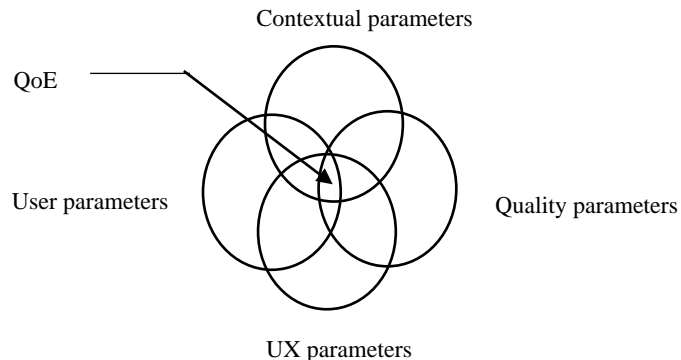


Figure 4. Compounding the Concept of QoE

7. Implications for Theory and Practice

-Theoretical implications

Our empirical findings confirm that the QoE model is a meaningful extension of the UX in the context of PI. The model allows the heuristics and quality of PI services to be effectively measured. Conventional UX and QoS approaches often fail to include all relevant factors, or measure them using older, less precise methods. These limitations have prevented traditional user requirement designs from producing powerful new-generation outcomes. A primary contribution of this study is that it provides a theoretical construct of the idea of quality in PI, establishing a relationship between technical quality and users' perceived assessment. Previous studies on user satisfaction and behaviors have often been indicated for their lack of in-depth analysis resulting from superficial approach. (Shin, 2105; Zhu et al., 2015); in addition, current satisfaction models have weak explanatory power due to their for their lack of context-specific understanding or user perspectives. Incorporating PI-specific factors and contextual considerations into a satisfaction model allows us to better explain how various factors influence user satisfaction, and how that satisfaction, in turn, affects behavioral factors.

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Although there have been many studies of UX and QoS, few have researched the measurement and scale of PI quality. Most UX research has examined the impact of perceived quality on customer service intentions. These studies have neglected to adequately define “quality” (Shin, 2015). This concept in the PI may refer to different experiences and user perceptions of them. It is necessary to approach quality from a user perspective. The rapid development of technologies has greatly improved the quality of services offered, as well as users’ expectations and thus their perception of quality. Given this technological evolution, it is useful to approach perceived quality in a more experience-based and user-oriented way. This study has divided the concept of quality into three dimensions, and showed that quality may reside in user perception as well as in a QoS technical performance.

Despite an enormous amount of recent research, UX studies have not provided a clear or genuine concept of the “user dimension” and its relationship to other factors. The elements of UX and QoE remain undefined. This study has used a combined qualitative and quantitative approach to create a UX model of the consumers who actually use specific services, rather than modelling the responses of people who might never experience them. The data from our survey reflect profound user attitudes and meaningful behaviors, not just self-reported perceptions. Our findings imply that the key elements of QoE include coolness and affordance, which play facilitating roles. As QoE is subjective, coolness and affordance (generated by the subjectivity of users) is nicely consonant with it. Read et al. (2011) argue that coolness reflects the desire of users to have cool stuff and do cool things (via PI). Cool attributes make a service cool, leading users to use/reuse PI services. Cool experiences bring joy and satisfaction and help to fulfil people’s personal goals. This study has helped to define the cool experiences provided by PI.

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We would argue that coolness is a core UX element that has not been clearly represented except as an aspect of imagination. People's technology preferences have not been clearly represented because they are complicated and compounded with other factors, including how cool users consider the technology to be. Coolness is somewhat related to and overlaps with affordance. These two factors sometimes work together and/or mutually influence each other to affect user intention and behavior. Coolness is the mechanism that links users' perceptions and behaviors, while affordance is direct link between attitude and behavioral change. Together with affordance, coolness creates quality of experience through an inner psychological mechanism. Unlike QoS, QoE resides in users, not in technologies. How users feel about and perceive their technology usage is more important than what technological functions they can access. This finding is supported by the fact that QoE is greatly affected by users' demographic and contextual factors, while utility and hedonicity (both considered fundamental factors of UX) are not.

Despite this finding, we still have far to go to understand clearly what coolness is and how QoE is formed, sustained, and transformed. Given its complicated and compounding nature, future studies may further explore: (1) other QoE factors found in PI and other technologies; (2) how cool experiences can be measured; and (3) how affordance can be operationalized in accordance with user intention.

-Practical implications

Practical implications for the industry (in the form of strategies and new models for advanced smart services) can be drawn from these findings. The industry may come up with a developmental strategy based on the QoE model that balances feature-based and perception-based quality. This way can help to retain current customers and enhance the management of

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customer relationships. Every interaction a customer has with a company's products and services is a reflection on quality. The QoE findings suggest that the industry should move beyond monitoring QoS and expand its focus to QoE. It is not enough to measure indicators of network efficiency and performance. It is also necessary to find out whether the user enjoyed the content he or she accessed via reliable, efficient, and secure PI content delivery. Measuring QoE is no longer just about measurement methods or the level of device-level service quality; it is about seeking a holistic view of the entire UX spectrum.

The potential success of PI may be linked to the provision of diverse, useful applications and enjoyable services. Personal informatics is increasingly ubiquitous and accessible. Consumers want seamless interconnections among all kinds of devices and networks. As indicated in numerous studies, including this one, personal informatics devices represent digital connections to friends, family, and resources. This trend will strengthen and spread globally as personal informatics become increasingly available. Service providers should therefore increase its perceived availability among users.

As this study has focused on PI, it has potential implications for the design and implementation of future Internet services. Consistent with prior research in technology acceptance, the two constructs of perceived usefulness and hedonicity continue to play major roles in user perceptions and in follow-up behavior toward products and services. From a user perspective, this represents a useful and more enjoyable service, provided through a widespread and seamless network, which offers attractive smart service features to consumers.

As for quality, the results of this study can be used by the PI industry to better understand users and markets and to determine what quality factors to emphasize. Our findings also provide useful insights for the development of effective marketing strategies to meet customer demands

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and both retain and expand the user base. The finding that quality dimensions impact usage behavior through intention shows that carriers should focus on creating a consumer perception of quality. This can best be achieved by ensuring that the carrier's services meet user expectations—in other words, that their content is high quality, their service reliable, and their promises and commitments kept.

8. Limitations and Future Studies

Like most empirical research, this study is not without limitations. First and most importantly, the sample may not represent the whole population of PI users. Although a relatively large sample was collected, and the number can be considered large enough to generalize, questions can still be asked as to whether the sample was perfectly or objectively representative or offered an accurate picture of the entire population. Future studies should continue to use a systematic random sampling method to reduce bias.

Second, our findings reflect only limited aspects of user experiences with PI. Because personal informatics technology and its services are not yet a mainstream phenomenon, this research is exploratory and limited by the fact that its findings cannot be generalized to the overall experience of PI users. It is not clear whether or not PI represents a type of IoT. Furthermore, because current PI providers are continually updating the content and functions of their value-added services, it is difficult to follow the trail of consumer experiences. A longitudinal study could have monitored the evolution of customer behavior across changing services. Instead, the circumstances of this study led to limited generalizability. In addition, the research model is valid only for the Korean PI market, due to restrictions in data collection. Generalization of the application scope of the model would require a global data collection process for more thorough validation. Future studies could sample a larger and more diverse

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cross-section of the population, using stratified or quota sampling to ensure a certain distribution of demographic variables. A generalized application of the extended model would require a global data collection process for more thorough validation. The first step should involve testing the PI model in other countries, after which a globally accepted universal model could be developed.

There are numerous heuristic future research directions worth considering that could help to identify critical developments. PI users evaluate their own needs and confirm their interests, compatibility, availability, and other features when making decisions about their adoption and continued/sustained usage. The fit between personal needs and product features predicts how users will behave when adopting technological innovations. Future research could include user needs, innovative product characteristics, and media message content, as well as other, more specific dimensions, to conduct a more thorough investigation of the proposed model. A time series study measuring prior expectations and post-use evaluations of these constructs would increase the theoretical validity of this model. The extent to which this study reflects the actual phenomena found in current PI services must be considered with these limitations in mind. The proliferation of quality factors makes it important to develop a robust, unified, and quantifiable QoE metric. Future studies can work on the development of an efficient and effective QoE framework for monitoring and analyzing QoE and other influencing parameters of future smart services.

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