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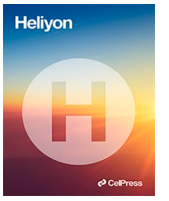

Older adults' intention to use voice assistants: Usability and emotional needs

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ABSTRACT

Population aging is a global problem, and improving the well-being of older adults is an urgent issue. Voice assistants (VAs) offer hands-free voice control and friendly human-computer interaction, making them a significant solution to address the aging problem. Most extant research on VAs is fragmented, and there are relatively few studies conducted from the perspective of emotional needs. This work proposes a comprehensive research model extending the technology acceptance model (TAM) by incorporating the influencing factors subordinate to two research directions: usability and emotional needs. Usability needs include three factors: perceived convenience, security/privacy, and Internet self-efficacy. Emotional needs include humanized interaction, perceived enjoyment, and perceived companionship. A structural equation model (SEM) was used to validate the model empirically with a sample of 425 older users of VAs. The analysis results are quite consistent with the research assumptions, and the findings illustrate that companionship is the most critical factor affecting older adults' intention to adopt VA use, which demonstrates the pivotal role of VAs in meeting the emotional needs of the elderly. The most unexpected observation was seen for the relationship between perceived ease of use and behavioral intention, which was non-significant. This result confirms that when a technology is perceived as very easy to use, perceived ease of use has little to no impact on individuals' intention to use that technology. The novelty of this study lies in the investigation of older adults' behavioral intentions toward using VAs, providing valuable insights for the design and development of VAs tailored for the elderly population. Beyond the academic realm, this research serves as direct inspiration for designers, developers, and policymakers in the fields of assistive technologies and geriatric care. It offers practical insights into creating VAs that effectively address the emotional needs of older adults and enhance their quality of life. Furthermore, elderly individuals are poised to experience significant benefits from the outcomes of this study , the insights garnered from this study empower the elderly to embrace technological advancements that align with their preferences and comfort levels. This study contributes to a more comprehensive understanding of VAs and their potential to enhance the well-being of older adults, while also paving the way for future investigations in this domain. As underscored by this study's emphasis on the significance of emotional needs in technology acceptance, it encourages the adoption of more user-centered design strategies in the development of future VAs.

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1. Introduction

Statistics released by the World Bank show that, by 2100, the population aged over 65 years will account for 22.49 % of the world's total population, reaching 2.52 billion [1]. The proportion of China's population aged over 65 years will increase to 13.5 %, reaching 190 million [2]. Owing to the increase in the proportion of the aging population, the well-being of the elderly population has become a notable focus of research. Due to the progressive and invasive nature of technology, older citizens will become more technology dependent [3], and voice assistants (VAs) are an important component among these technologies [4–6].

As an information and communication technology, VAs are known by a variety of names in various disciplines. Although there is no consensus on the definition of VAs, two broad categories can be distinguished: tangible conversational agents (ECAs) and intangible conversational agents (DCAs) [7]. The VAs in this study are DCAs, which interact with humans using unconstrained natural language input using speech recognition and synthesis [8]. The use of VAs has grown rapidly in recent years, with studies indicating that the number of personal VAs in use worldwide is expected to double from the 4.2 billion units owned in 2020 to 8.4 billion units by 2024 [9,10]. VAs have also become a core component of many intelligent products and systems [11–13], and family application has also increased [14,15]. VAs embedded in smartphones, smart wearable devices, and smart speakers, such as Apple Siri, Amazon Alexa, and Google Home, can provide information inquiry and entertainment functions in daily life [13]. The widespread use of VAs benefits individuals by providing a more convenient way to issue commands to products [16], replacing the requirement for physical input, VAs thus provide a more human-like, voice-based way to interact with devices [17]. Given the highly user-friendly nature of voice assistants, investigating how to enhance the utility of voice assistants for the elderly holds significant research value and relevance. Illustrated by a practical scenario, consider Ms. Li, an elderly lady residing independently in her home, who has experienced a gradual decline in physical capabilities due to aging. In her daily life, she relies on technological support, particularly for tasks like shopping, scheduling medical appointments, and managing household affairs. Nevertheless, she frequently encounters feelings of unfamiliarity and discomfort when confronted with complex technological devices and applications. Beyond the technical challenges, Ms. Li confronts another issue – the frequent absence of family members due to work commitments, leaving her in solitude. In this context, it becomes evident that elderly individuals like Ms. Li are increasingly reliant on technology, facing challenges in their daily lives, and experiencing emotional loneliness.This has led to a growing awareness and interest in the potential of VAs to support the health and independence of older adults [18]. Some studies have proposed that technical interventions can be used as a driver to promote recovery and enhance adaptive ability, to support the functional ability of older adults experiencing a decline in ability [19,20]. Research data indicate that setting reminders, searching for information, and checking the weather are the VA functions most frequently used by older adults [7,21]. In addition, voice-based systems can serve as health assistants for older adults by, for example, providing up-to-date information on dietary health [22], answering health-related questions [23], reducing loneliness [24], and encouraging participation in fitness exercises [25,26]. VAs are also being used in homecare, improving patient care by increasing efficiency, and presenting a new experience by offering a wide range of tools and capabilities [27]. Considering the ongoing demographic shift towards an aging population, an escalating number of elderly users, akin to the case of Ms. Li, will grapple with these challenges. Consequently, researching how older adults can better harness voice assistants to surmount the life difficulties and technological obstacles they encounter represents a profoundly meaningful and valuable research pursuit.

This study is dedicated to exploring the propensity of elderly individuals to adopt the novel technology of voice assistants. Despite the existence of numerous technological options, the decision to investigate voice assistants (VAs) is grounded in their distinctive potential, which can be expounded upon by examining three facets: user-friendly functionality, human-centered interaction, and emotional satisfaction. First, as executive control in the working memory declines with age, so too does functional status as measured by instrumental activities of daily living [28].VAs allow individuals to easily complete tasks without typing, reading, or using a handheld device, which is a level of convenience provided that is incomparable to any other technical system [12]. As an illustration, within the realms of self-monitoring, management, and home-based care, voice assistants offer essential daily support functionalities for the elderly. These functionalities encompass self-pain management and emergency call provisions [29], resulting in notable enhancements in both the quality of life and safety of elderly residents. Furthermore, situated within the sphere of chronic ailment oversight, voice-based digital aids, through timely prompts, facilitate patient compliance with pharmacotherapeutic regimens, encouraging them to undergo timely blood-related monitoring, thereby bestowing augmented disease management capabilities [30]. Second, from the perspective of human–computer interaction, older adults tend to perceive digital technology as complex to learn and use [31], possibly creating attitudinal barriers such as lower self-efficacy and anxiety about using computers [32], distrust toward adopting technology [33], and frustration [34]. Therefore, findings from Schlogl et al.'s [35] lab-based comparative study on using VAs such as Apple's Siri and a traditional graphical user interface (GUI) for writing emails suggest that older adults actually preferred Siri to the standard GUI. VAs thus appear to be beneficial to the elderly because interaction with the VA is more natural for the elderly than interaction with smartphones or computers [23], and the user interface is more simple [36,37]. Smith and Chaparro [37] have shown that voice input is the most effective and preferable input mode for the elderly. Third, many cases of social isolation and rejection are frequently found among the elderly population; these were commonly correlated with the weakening of the person's mental health, which can cause mental disorders such as depression [38–42]. Researchers investigating older adults in a nationwide life-span sample of adults in the United States found an increase in loneliness during the acute phase of the COVID-19 pandemic [43]. It has also been documented that promoting social engagement can motivate people to engage in more complex interactions, mobilize cognitive abilities, and help maintain good mental health [44]. Some studies have shown that the use of VAs among the elderly can reduce loneliness [24]. Specifically, under certain circumstances, VAs show great potential in relieving the psychological loneliness of the elderly [45]. Furthermore, voice assistants play a pivotal role in augmenting user experience, notably in the contexts of independent living and ensuring home safety, encompassing domains such as ambient assisted living and home automation. These

applications empower users to exert control over various facets of their domiciles through vocal directives and automation, encompassing tasks ranging from illumination adjustment and temperature regulation to security monitoring. Based on the analysis of these three aspects, VAs offer a diverse range of life support services for the elderly, encompassing various aspects of their daily lives, highlighting their enormous potential in promoting independent living for the elderly.

Currently, VAs have gained special attention for being beneficial to older adults [46–49], while the use of the technology by older users is still in the exploratory stage [14]. Only a limited number of academic studies have delved into the factors influencing the utilization of voice technology by elderly users, with the majority of research primarily emphasizing usability-related aspects such as ease of use [36,37], user interface [36,37], as well as issues related to trust and frustration [33,34]. Through the preceding analysis, it becomes evident that, compared to younger users, another crucial dimension of elderly individuals' demands in using voice assistants is rooted in the emotional sphere. Multiple studies have indicated that voice assistants can alleviate psychological loneliness in the elderly [22,45], help them increase their sense of happiness [50–53], and contribute to maintaining their mental well-being [44]. Given the emotional value of VAs for the elderly, the context of VA acceptance can also be elucidated from the perspective of users' emotional needs. Therefore, incorporating the emotional acceptance of VAs by elderly users into the research scope is of paramount importance for a comprehensive understanding of their VA acceptance. Building upon this foundation, this study integrates the Technology Acceptance Model (TAM), usability theory, and user experience theory, amalgamating the concepts of technology acceptance, usability requirements, and emotional needs into a unified framework. This comprehensive model aims to bridge this existing research gap.

We have chosen the Technology Acceptance Model (TAM) as the foundational framework for our research and have introduced six additional constructs to expand and reconfigure the TAM. The determination of the theoretical framework and the selection of these six variables were primarily guided by three key factors: theoretical underpinnings [54–57], prior empirical research findings [58–60], and the specific emotional needs of elderly users [61–63]. The elaboration on the first two factors will be presented in the second section of this article. These six variables are categorized into two dimensions: usability needs and emotional needs. Drawing from usability theory, which is concerned with optimizing technology interfaces for enhanced user-friendliness, efficiency, and satisfaction, we have included perceived ease of use, security and privacy, and internet self-efficacy as variables that underpin the usability dimension. Moreover, we have taken into account the unique characteristics of elderly users and the challenges they encounter in their daily lives. We have placed particular emphasis on the potential of voice assistants to mitigate feelings of loneliness among the elderly. In this regard, we have introduced variables that address emotional needs, including perceived entertainment, human-centered interaction, and perceived companionship. The selection of these variables is aligned with the principles of user experience theory, which places a strong emphasis on the emotional and interactive aspects of user-technology interactions. The overarching objective of our research is to enhance our comprehension of the motivating factors that underlie the acceptance and usage of voice assistants by elderly users from a more comprehensive perspective. Ultimately, this study is poised to pave the way for tailoring voice assistant technology to better align with the real-life needs and emotional well-being of the elderly, thus enhancing their overall quality of life.

Table 1
Partial summary of existing research on virtual assistant acceptance/adoption.

Research study	Title of the Literature	Core theoretical model	Factors considered	Sample characteristics
[63]	The Investigation of Adoption of Voice-User Interface (VUI) in Smart Home Systems among Chinese Older Adults	TAM + STAM	Perceived usefulness, Perceived ease of use, Perceived Physical Conditions, Mobile Self Efficacy, Technology Anxiety, Self-Actualization Need	420 elderly individuals from China (aged 55 and above), data collected through an online questionnaire survey
[70]	Understanding the factors affecting online elderly user's participation in video UCC services	TAM	Perceived physical condition (physical age), Life course events (psycho-social age), Perceived user resources, Prior similar experience, Computer anxiety,	290 elderly individuals (aged 50 and above), data collected through an online questionnaire survey
[71]	Useful, Social and Enjoyable: Mobile Phone Adoption by Older People	TAM	Perceived usefulness, Perceived ease of use, Intrinsic motivations, Extrinsic motivations, Utilitarian motives	740 elderly individuals (aged 65 and above), data collected through an online questionnaire survey
[72]	Internet use intention and adoption among Chinese older adults: From the expanded technology acceptance model perspective	TAM	Perceived usefulness, Perceived ease of use, Subjective norm, Facilitating conditions	374 elderly individuals (aged 65–81), data collected through an online questionnaire survey
[78]	Wearable Technologies: Acceptance Model for Smartwatch Adoption Among Older Adults	TAM	Perceived usefulness, Perceived ease of use, Prior experience, Affective quality, Technology-related anxiety, Social support	76 elderly individuals (aged 50–74), data collected through an online questionnaire survey
[79]	Older Adults' Online Shopping Continuance Intentions: Applying the Technology Acceptance Model and the Theory of Planned Behavior	TAM + TPB	Perceived usefulness, Perceived ease of use, Perceived lack of shopping mobility, Perceived social isolation, Perceived behavioral control, Subjective norms,	366 U S. adults (born in or before 1965), data collected through an online questionnaire survey
[81]	Predictors of gerontechnology acceptance by older Hong Kong Chinese	TAM + UTAUT	Perceived usefulness, Perceived ease of use, Gerontechnology self-efficacy, Self anxiety, Facilitating conditions	1012 elderly individuals from Hong Kong (aged 55 and above), data collected through a face to face interview technique with a preset questionnaire

2. Theoretical background and hypotheses

This study aims to investigate the acceptance and usage intention of voice assistants (VAs) by elderly users from a more comprehensive perspective. To establish the theoretical framework and relevant variables for our research, we conducted an extensive literature review using keywords such as elderly individuals, technology acceptance, and TAM (Technology Acceptance Model). We searched multiple academic databases, including PubMed, IEEE Xplore, and Web of Science, to identify and obtain influential theoretical models and variables that are directly relevant to our research topic and have been widely acknowledged and validated in previously published studies.

2.1. Theoretical background related to TAM

Some research models and theories have been widely devoted to study user acceptance of new technologies, including the TAM, theory of reasoned action (TRA), and the unified theory of acceptance and use of technology. As the most important extension of TRA, TAM was proposed by Davis [56] to explain computer acceptance, and the model proposes that users' intention to use IT/services is determined by the usefulness and ease of use of the target technology/service. By incorporating social norms (TAM2) [64] and hedonism (TAM3) [65], several follow-up models have been proposed. Chen et al. [66] proposed the TAM for the elderly (STAM) for a comprehensive understanding of technology adoption among older adults, which further extends the TAM by incorporating factors such as self-efficacy, technology anxiety, and facilitating conditions. The UTAUT was formulated by Venkatesh et al. [67], and it added other determinants, including social influence, facilitating conditions, self-efficacy, and anxiety, to the TAM.

Through a literature review [68], we found that TAM is the most widely used model for studying technology acceptance among the elderly. For example, TAM was adopted to investigate the acceptance of ambient intelligence [69], as well as the intention to participate in video user-created content [70] and the acceptance of mobile phones [71], the Internet [72], and share touch hardware products [73]. Similarly, TAM was also used to investigate older adults' acceptance of mobile medicine [74], intelligent pension services [75,76], ICTs [77], wearable devices [78], online shopping [79], and tablet devices [80]. In Table 1, we provide a summary of the existing VA related adoption studies. The table indicates that the majority of studies have employed the TAM (Technology Acceptance Model) approach to explain the adoption intention of the elderly towards new technologies.

Previous studies have shown that the TAM has a high explanatory power in the study of technology acceptance among the elderly. The TAM [56] was thus chosen for this study, and this choice can be supported by three reasons. First, given the ability to explain the acceptance behavior of different topics and different types of technologies, the explanatory power of TAM has been confirmed by many empirical studies [82–84]. Second, TAM's predictive power lies in identifying the relationship between two important aspects—the technical (e.g., perceived usefulness and ease of use) and the psychological (e.g., behavioral intention). Its inclusion of useful and valuable elements ensures its ability to serve the purpose of this study. Finally, the validity of extending TAM by including new constructs to increase its explanatory power has been confirmed by several studies [85–87]. It is thus permissible for scholars to restructure and modify the TAM according to the technology and background to be studied.

According to the TAM, the two most important factors in explaining acceptance and usage of an information system are perceived usefulness (PU) and perceived ease of use (PEOU) [88]. PU is the degree to which a person believes that using the particular technology would enhance his/her job performance. In the context of VAs, PU can be described as the extent or degree to which older adults find it convenient to use VAs for a variety of tasks [60] or can refer to the utilitarian benefits of using VAs [63]. PEOU is the extent to which a person believes that using a technology is free of effort [88]. The perceived difficulty of learning to use VAs is reflected in the PEOU in

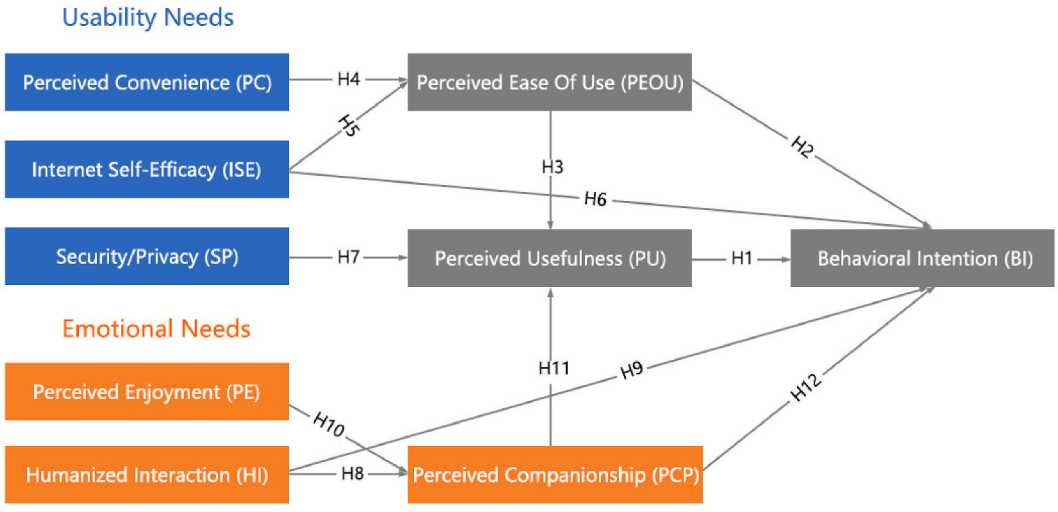

Fig. 1. Research model and hypothesized relationships among variables.

the context of VAs [63]; in consideration of offering a completely "hands-free" method of communication, we anticipate that the benefits and convenience of VAs will positively influence the user's intent to use it. In light of this model, PU and PEOU determine BI, and the relationship between PEOU and PU is significant. External variables mediated by PU and PEOU include convenience, ISE, and SP [88]. Therefore, based on the TAM, we propose the following hypotheses. Fig. 1 illustrates the study model and the hypothesized relationships among the variables.

H1. PU has a positive effect on BI.

H1 Description: PU reflects how older individuals perceive VAs' ability to significantly enhance their task efficiency. Higher PU levels indicate that older users view VAs as practical and beneficial in their daily lives, positively influencing their Behavioral Intentions (BI).

H2. PEOU has a positive effect on BI.

H2 Description: Perceived Ease of Use (PEOU) in TAM represents older adults' perception of minimal effort when using VAs. Due to VA's hands-free nature, older users find it straightforward and user-friendly, fostering a stronger inclination toward VA adoption, reflected in their BI.

H3. PEOU has a positive effect on PU.

H3 Description: PEOU's high rating indicates that older users consider VAs user-friendly and effortless to use. This favorable perception positively affects PU, suggesting that users find VAs easy to navigate and purposeful. PEOU thus positively influences PU, shaping older users' BI to adopt VAs.

The remaining six exogenous constructs are described in the following subsections.

2.2. Perceived convenience

Aging inevitably involves declines in sensory, perceptual, motor, and cognitive abilities [28], which make it difficult to interact with devices using a traditional GUI [60,89],. Brown [90] put forward the perspective that convenience is closely related to the following five key aspects: place, the product/service should be available to the consumer at a convenient location; time, the product/service should be available to the consumer at a convenient time; usage, the product/service should be easy for the user to use; purchase, suppliers should provide various financial channels for consumers to conveniently purchase the product/service; and execution, it should be convenient to decide to let others provide products/services for consumers, or to do it by oneself. Accordingly, VAs are convenient because they can provide services to consumers at a convenient place and time and are user-friendly. Using and operating VAs in daily life could be very simple for the elderly because of the human-like communication style [91–93]. In terms of time and place, as VAs are integrated in common smart home devices, such as cleaning robots, smart speakers, and TVs, it would be convenient for the elderly to interact with a VA anytime and anywhere. Given the hands-free functionality of the home VAs described above, which do not require interaction with a physical user interface, we hypothesized that the subsequent benefits and convenience provided by VAs would influence their continued use. Therefore, we make the following assumption.

H4. Perceived convenience has a positive effect on PEOU.

H4 Description: Given the potential challenges posed by age-related declines in sensory and cognitive capabilities among older individuals, it is hypothesized that virtual assistants (VAs), owing to their user-friendliness and temporal and spatial convenience, are poised to mitigate these challenges. This is anticipated to enhance the user experience with VAs, consequently fostering a greater willingness among users to sustain their usage. Therefore, it is hypothesized that perceived convenience positively influences the Continued Intention to Use (CIU) of VAs among older users.

2.3. Internet self-efficacy

UTAUT integrated self-efficacy into an extension of the original TAM, where it is seen as a predictor of PEOU [65]. ISE has been introduced to the model as a constituent factor and defined as the confidence in one's own ability to accomplish challenges using the Internet [94]. Studies have found that self-efficacy has a positive impact on the use of information technology [95,96]. According to social learning theory [97], confidence among older adults in their own capability to perform unfamiliar tasks, such as computer and Internet use, is critical to their success with such endeavors. Empirical studies in the field of Internet use indicate a more comprehensive role of self-efficacy and confirm links not only between ISE and PEOU but also with PU [98], BI [99], and Internet use [100]. Because the use of VAs depends on the network environment, we assume that the ISE of the elderly will have a positive impact on the use of VAs. We therefore tested ISE within the TAM network of constructs as an additional predictor of PEOU and BI. We thus proposed the following hypotheses.

H5. ISE positively influences PEOU.

H5 Description: This hypothesis is grounded in social learning theory, suggesting that older users who believe in their ability to successfully navigate various challenges and tasks on the internet may be more inclined to accept virtual assistants as tools to fulfill their internet-related needs. Therefore, we speculate that enhancing the internet self-efficacy of older individuals may positively influence their perceived ease of use of virtual assistants.

H6. ISE positively influences BI.

H6 Description: Older users who have confidence in their capabilities in internet usage and utilizing virtual assistants may be more

inclined to engage in proactive intentional behaviors, such as actively seeking assistance from virtual assistants and using them more frequently to accomplish various online tasks. This hypothesis is based on the premise that users' self-efficacy beliefs may exert a positive influence on their behavioral intentions, thereby encouraging them to use virtual assistants more actively.

2.4. Security/privacy

Security/privacy is a major challenge affecting the use of VAs by the elderly, as has long been discussed in existing research. Lei et al. [101] outlined how Amazon Echo and other VAs have been exploited by hackers due to their security vulnerabilities. Several studies have indicated that individuals often avoid discussing sensitive topics or conducting financial transactions, such as making purchases or paying bills, with VAs due to privacy concerns [102]. Given that technology has become a core part of personal daily life, especially home applications, anxiety about privacy will continue to grow among users [12]. Owing to the poor technical foundation of the elderly, as well as their slow learning and adoption of new technologies/services, smart home SP issues are more likely to threaten them [103]. In the current research, SP indicates "the psychological state of the elderly who are concerned about the loss of personal data and invasion of privacy"; the relevant assumption is.

H7. SP negatively influences PU.

H7 Description: If older adults harbor doubts regarding the efficacy of VAs in adequately safeguarding their personal information, such mistrust may prompt them to exercise heightened caution when using VAs, and in some cases, opt to abstain from using them for tasks involving sensitive information. Consequently, this skepticism may have implications for their willingness to engage actively with VAs.

2.5. Humanized interaction

Humanized interaction refers to imbuing VAs with cognitive, emotional, and social human characteristics to render their interactions with consumers more "human". This humanized quality then drives consumers to engage in more interactions with the VA. The human voice and natural conversation of VAs can make them seem intelligent, friendly, and human-like and thus encourage more user interaction [11]. As voice-based interactions are simple and unchallenging [91–93], studies have shown that older adults generally have positive attitudes and perceptions when they are advised to use VAs [104] compared to traditional interactions with technology such as clicking or typing: the elderly tend to prefer voice-based user interfaces [105]. It is therefore crucial that we identify the role humanized VA interaction plays in driving the voice interaction experience for the elderly. Scholars have found [106] that a positive user experience is the driving force for maintaining continuous use of VAs, and this depends not only on how well VAs support users in completing tasks but also on the companionship users have established with the device. One study [107] investigated people reacting to a robot that was asking them not to shut it off, showing that people responded socially to robots demonstrating human-like behavior. Verbal interactions play an important role in social interactions, making people particularly prone to engage in conversation [108], and these features can increase positive emotions, reduce depression, stimulate interest in physical activity, and enhance social interactions [109]. Based on the above conclusions, we make the following assumptions.

H8. HI positively influences perceived companionship (PCP).

H8 Description: When older users perceive humanized interactions with virtual assistants, they are more likely to establish a sense of perceived companionship (PCP), viewing the virtual assistant as a companion with whom they interact. This positively influences their overall usage experience. Therefore, we hypothesize that the higher the level of humanization in VAs, the greater the impact on the perceived companionship among older adults.

H9. HI influences BI.

H9 Description: When older users perceive more humanized interactions with virtual assistants, they are inclined to use virtual assistants more frequently, engage in interactions, and perform various tasks with them. Thus, we hypothesize that a higher degree of humanized interaction in VAs is positively associated with the willingness of older adults to use VAs.

2.6. Perceived enjoyment

Perceived enjoyment (PE) is defined as "the extent to which the activity of using the computer is perceived to be enjoyable in its own right, apart from any performance consequences that may be anticipated" [110]. TAM2 and UTAUT show that enjoyment is an important factor influencing the use of technology in some cases [111]. Enjoyment, that is hedonistic motivation, has been one of the main factors responsible for the popularity of VAs, which, when placed in the social, collaborative, semi-private home environment, have lent themselves well to functions such as playing music, checking the weather, and information seeking. Playing music with a VA service is one of the most frequent user activities [112]. The ability of the VA device to classify and play songs according to the user's preferred genre, artist, language, or even emotion makes them more pleasant to use and enhances the VA's hedonistic value [113]. Thus, we propose the following hypothesis.

H10. PE positively influences PCP.

H10 Description: Perceived Enjoyment (PE) plays a crucial role in the utilization of VAs. When users derive pleasure from their interactions with VAs, they are more inclined to form a sense of closeness, considering VAs as companions rather than mere tools. Hence, we postulate that perceived enjoyment positively impacts Perceived Companionship (PCP), as an enjoyable usage experience

heightens the extent to which users perceive VAs as intimate companions.

2.7. Perceived companionship

Due to the lack of social interaction with groups of friends, family, and former colleagues, social isolation and loneliness are among the most important factors in the decline of life quality for older adults, and these factors have a significant impact on their overall health. Specifically, during the COVID-19 pandemic, social distancing strategies led to increased rates of loneliness and social isolation. There is a clear need for strategies to mitigate the effects of social isolation and loneliness on the mental and physical health of older adults. Because VAs are "always on" and "always listening," they can play the role of companion for the elderly. Some previous studies have shown that people personify smart speaker-based VAs in particular ways, such as describing them using personal pronouns [114,115]. For instance, Turk [116] noted the ways that people describe a smart-speaker VAs in human-like terms, such as "friend" and "invisible woman". Pradhan et al. [117] observed Amazon reviews calling Alexa the user's "bff","new best friend," and "someone to talk to". Based on the fact that most elderly people live alone and are prone to loneliness, we believe that older people would be more willing to use VAs if they consider VAs as their companions in life; so, we propose the following assumptions.

H11. PCP positively influences PU.

H11 Description: We postulate that when older adults establish intimate companion relationships with Virtual Assistants (VAs), they are more inclined to perceive VAs as beneficial. This sense of intimate companionship may foster emotional dependency, leading older adults to trust and rely on VAs more, consequently heightening their perception of VAs' usefulness.

H12. PCP positively influences BI.

H12 Description: We hypothesize that if older adults regard VAs as companions, they may display a greater propensity for proactive engagement, more frequent utilization of VAs, and the execution of diverse tasks. Consequently, perceived companionship could engender stronger positive intentions among older adults to utilize VAs, thereby increasing both the frequency and breadth of their interactions with VAs.

3. Research methodology

3.1. Sample and data Collection

To test the proposed hypothesis and conceptual framework, a questionnaire survey was designed and carried out. Although the questionnaire may be somewhat limited, it is a valid research method for the purposes of this study, and online sampling has been widely used to inquire about user adoption of VAs in previous studies [60,63]. We gathered survey data from a cohort comprising participants aged 60 years and above, delineating 60 years as the operational definition of older adults. This criterion was derived from pertinent scholarly literature [118] and also took into account the prevailing statutory retirement age in China, which stands at 60 for males and 55 for females. By adopting this age threshold, our aim was to attain a comprehensive vantage point that would enable our study to effectively capture the prospective demands of the elderly population in China.

The questionnaire survey included online and offline components. The paper questionnaire survey was conducted on campus, and the participants were college teachers aged 60 years old and above, who are important target users of this study. The experimenters who participated in the offline questionnaire were strictly trained. Before the participants filled in the questionnaire, the experimenter

Table 2
Descriptive analysis of participants.

Variable	Description	Count	Percentage
Gender	Male	283	51.4
	Female	268	48.6
Age	60–64 years	349	63.4
	65–69 years	118	21.4
	70–75 years	42	7.6
	75 years and above	42	7.6
Education	Junior high school	253	45.9
	High School	113	20.5
	Junior college education	89	16.2
	College/university	79	14.3
	Postgraduate	17	3.1
Income	Less than 2000 CNY	217	39.4
	2000-3500 CNY	130	23.6
	3500-5000 CNY	105	19.1
	Above 5000 CNY	99	17.9
Time of using VAs	Less than 6 months	186	33.8
	6 months–1 year	106	19.2
	1~3 years	64	11.6
	More than 3 years	69	12.5
	Never used	126	22.9

introduced the application scope of VAs, so that the participants accurately understood the survey objects and the purpose of this study. Prior to initiating the formal questionnaire survey, this study employed a preliminary pilot study methodology to evaluate the feasibility and content validity of our survey instrument. The primary aim of the pilot study was to proactively identify and address potential issues related to the questionnaire through a limited-scale pretest. Several concerns were identified during the pilot study, primarily related to the clarity of certain questions, which could introduce ambiguity for respondents. Additionally, some questions required further simplification in language to accommodate the comprehension abilities of elderly respondents. Subsequently, we made enhancements to the questionnaire to ensure improved question comprehension and more precise responses from elderly participants, thereby augmenting the trustworthiness and precision of our research findings.

A total of 143 paper questionnaires were received, and 17 questionnaires with several blank answers were considered invalid and removed. For the online research components, an online crowdsourcing platform in mainland China (https://www.wjx.cn/, accessed November 11, 2022) was used to collect data and test the assumed models; this platform provides functions equivalent to Amazon's Mechanical Turk, and 425 participants were recruited. We requested that participants share the questionnaire with their acquaintances and close friends. By implementing this strategy, our survey data showed a snowball sampling effect. Our questionnaire was divided into two sections: the first half collected demographic information about the participants (e.g., gender, age, education, income) along with a key question related to the duration of VA use, which was intended as a screening question to eliminate response bias among those with no experience of using VAs at all. A total of 126 participants selected the question about the duration of using a VA as "never used a voice assistant"; so, these users were excluded; therefore, 425 valid samples were collected in this survey in combination with online research and field research. The demographic information from the first half of the questionnaire is presented in Table 2.

3.2. Measurements

To measure all research constructs in this study, we employed validated multi-item scales that have been utilized in similar studies [60,63,113]. These scales assessed various aspects, including perceived convenience, perceived usability, and perceived usefulness. Table 3 presents the comprehensive details of the questionnaire and the corresponding reference materials. A 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree) was utilized to evaluate all items in the questionnaire. Prior to implementation, meticulous efforts were made to formulate, extensively test, and modify all items related to the research constructs, such as question wording, response options, and scale anchors, to ensure the clarity of survey questions. The reliability and validity of all measurement items were examined through Cronbach's alpha test and confirmatory factor analysis (CFA).

Table 3
Questionnaire title and corresponding references.

Construct	Item	Description	References
Perceived Convenience	PC1	Accomplishing tasks with a voice assistant (VA) makes my life easier.	[13,63,113]
	PC2	It is convenient that VAs help the users proactively without human intervention.	
	PC3	Using the voice interface brings a lot of convenience to my life.	
Security/Privacy	SP1	I am worried about revealing my personal information when I use the VA.	[60,113]
	SP2	I am concerned that the VA collects too much information about me.	
	SP3	I find it objectionable when I do not know what will be recorded by the VAs.	
Internet Self-efficacy	ISE1	I think I am competent to use Internet to browse the World Wide Web.	[63]
	ISE2	I can figure out almost any internet application with less effort.	
	ISE3	I am proficient in using Internet devices.	
Humanized Interaction	HI1	In my opinion, interacting with VAs is similar to interacting with humans.	[113]
	HI2	I think the way I interact with the VA is similar to the way I interact with a human being.	
	HI3	I feel like I am dealing with a real person during my interactions with the VA.	
Perceived Enjoyment	PE1	Using the VAs would provide me with a lot of enjoyment.	[13,60,119]
	PE2	I find that using my VA makes me feel very happy.	
	PE3	I think it would be fun to interact with a VA.	
	PE4	The use of a VA makes me feel good.	
Perceived Companionship	PCP1	I have a good time with the VA.	[113]
	PCP2	I think the VA could be a friend of mine.	
	PCP3	When I have an interaction with my VA, I feel like someone is in the room.	
Perceived Usefulness	PU1	Using the VA would help in my daily life.	[13,60,63,119]
	PU2	Using a VA increases my productivity.	
	PU3	VAs provide me with very useful services and information.	
Perceived Ease of Use	PEOU1	Using the VA would be easy and simple.	[60,63,119]
	PEOU2	Being skillful with using a voice interface is easy for me.	
	PEOU3	Proficient use of voice interaction is completely within my ability.	
Behavioral Intention	BI1	I want to spend more time with my VA.	[60,113,119]
	BI2	I intend to use my VA frequently for a long period of time.	
	BI3	I would like to introduce VAs to others to use in their daily lives.	

4. Date analysis and results

4.1. Analytical strategy

We used structural equation modeling (SEM) to examine the proposed relationships, including the hypotheses and paths of the research model. SEM is a well-established method renowned for its ability to manage intricate structural equation models and intricate interrelationships among latent variables. Given the multifaceted nature of our research, involving multiple latent constructs and intricate variable relationships, CB-SEM was deemed a fitting methodological choice for scrutinizing our theoretical model. This approach permitted the simultaneous evaluation of model fit and the statistical significance of individual structural paths, offering a comprehensive lens through which to scrutinize research inquiries. SEM has been used as a statistical method to test and evaluate multivariate causal relationships for nearly a century; it is a combination of two statistical methods: CFA and path analysis. CFA has the objective of estimating latent psychological traits, such as attitude and satisfaction [120], and it originated in psychometrics. It is thus appropriate to use this method to study the factors that affect the elderly users of VAs. As such, CB-SEM was aptly poised to address the research questions at hand.SPSS 23.0 was used to conduct the initial descriptive and reliability analyses. CFA [121] was performed using AMOS 24.0 to perform path analysis and evaluate the measurement model. According to the literature [122], SEM provides a maximum-likelihood estimation of the entire system in a hypothesized model and enables the assessment of variables with the data. In our analysis, we adopted a two-step strategy [123] to test the hypothesized model. First, CFA was used to confirm the measurement model, and we then performed SEM analysis to measure the fit and path coefficients of the hypothesized model. Because the Chi-square test is very sensitive to sample size, Brown [124] proposed that to evaluate the overall fit of CFA solutions, a range of other fit indices should also be utilized, such as the comparative fix index (CFI), Bollen's incremental fit index (IFI), Tucker–Lewis index (TLI), standardized root means square residual (SRMR), and root mean square error of approximation (RMSEA), and these were adopted here to estimate model fit.

4.2. Results

SEM was used to estimate and test the causal relationships between each of the latent variables shown in Fig. 1. Table 4 shows the recommended reference values for these indices. The first three fit indices, CFI, IFI, and TFI, have high values (around 0.94), indicating good model fit [125]. The values for RMSEA and SRMR are less than 0.07, which proves that the degree of fit is good, and the value close to 0.10 indicates that the fitting degree is general [126]. In this study, these indices were selected because of their overall satisfactory performance in the simulations [125]; the specific values of each index are as follows: $\chi^2/df = 2.410$, CFI = 0.944, IFI = 0.945, TLI = 0.936, SRMR = 0.041, and RMSEA = 0.069. As shown in Table 5, Cronbach's alpha coefficient was calculated to assess the reliability of the scales used in the study. Each scale exceeded the value of 0.7, affirming that the scales are reliable indicators of their corresponding variables [127]. Next, to measure the internal consistency reliability, convergent validity, and discriminant validity of the constructs in our proposed model, we performed CFA on the nine constructs (see Table 5). The results revealed that the composite reliability (CR) of each construct ranged from 0.882 to 0.937, exceeding the 0.60 CR threshold value and supporting internal consistency reliability [128,129]. In addition, the factor loading of the individual items in the model were all significant (all $p < 0.001$), indicating preliminary evidence for the convergent validity of the measurement model. Meanwhile, the average variance extracted (AVE) of all constructs ranged from 0.714 to 0.805, exceeding the 0.50 AVE threshold value [128,129]; so, the convergent validity was acceptable. Discriminant validity is used to evaluate the extent to which a construct in the model is uniquely different from other constructs [130]. Discriminant validity was examined by comparing the square root of the AVE of each construct with the correlations between the latent variables. Comparing all correlations in Table 5 with the square root of AVE, the results indicate that the discriminant validity is valid, because the diagonal elements exceed the off-diagonal elements [129] (see Table 6).

To check the relationship between variables, we used SEM to conduct path analysis. The results of the path analysis showed that 10 out of the total 12 hypotheses were supported or partially supported; detailed results are shown in Fig. 2 and Table 7. Similar to previous research [95,96], ISE has a positive effect on PEOU ($\beta = 0.234$, $p < 0.001$), which conversely affects PU ($\beta = 0.672$, $p < 0.001$). Likewise, the relationships PC–PEOU ($\beta = 0.759$, $p < 0.001$), PEOU–PU ($\beta = 0.672$, $p < 0.001$), and PU–BI ($\beta = 0.079$, $p < 0.1$) were also found to be true. Looking at emotional needs, PE ($\beta = 0.623$, $p < 0.001$) and HI ($\beta = 0.324$, $p < 0.001$) have a significant impact on PCP, which in turn influenced PU ($\beta = 0.114$, $p < 0.1$) and BI ($\beta = 0.97$, $p < 0.001$). Similarly, the HI–BI relationship ($\beta = -0.136$, $p < 0.05$) was also found to be true. Therefore, our proposed framework reaffirms the importance of the relationships between usability and emotional needs and BI. SP had no impact on PU ($\beta = 0.066$, $p > 0.1$); similarly, PEOU also had no effect on BI ($\beta = -0.014$, $p > 0.1$).

Table 4
Fit indices.

Fit indices	χ^2/df	CFI	IFI	TLI	SRMR	RMSEA
Reference value	<3.000	>0.900	>0.900	>0.900	<0.080	<0.080
Inspection value	2.410	0.944	0.945	0.936	0.041	0.069

Table 5
Reliability and unidimensionality.

Construct	Variables	Unstd.	S.E.	Z	P	Standardized Loading	Cronbach's Alpha	C.R.	AVE
Perceived Convenience	PC1	1.000				0.875	0.890	0.895	0.740
	PC2	1.039	0.056	18.660	***	0.822			
	PC3	0.995	0.047	21.403	***	0.882			
Security/Privacy	SP1	1.000				0.864	0.890	0.896	0.745
	SP2	1.132	0.056	20.290	***	0.971			
	SP3	0.866	0.056	15.475	***	0.738			
Internet	ISE1	1.000				0.821	0.898	0.900	0.751
Self-Efficacy	ISE2	1.097	0.058	18.884	***	0.905			
	ISE3	1.006	0.056	17.976	***	0.871			
Humanized Interaction	HI1	1.000				0.766	0.880	0.882	0.714
	HI2	1.193	0.075	15.875	***	0.87			
	HI3	1.194	0.073	16.319	***	0.893			
Perceived Enjoyment	PE1	1.000				0.884	0.937	0.937	0.788
	PE2	0.955	0.041	23.326	***	0.901			
	PE3	0.991	0.047	20.943	***	0.858			
	PE4	1.050	0.044	23.685	***	0.907			
Perceived Companionship	PCP1	1.000				0.9	0.915	0.916	0.786
	PCP2	1.034	0.04	25.673	***	0.918			
	PCP3	0.972	0.047	20.725	***	0.839			
Perceived Usefulness	PU1	1.000				0.859	0.925	0.925	0.805
	PU2	1.094	0.051	21.396	***	0.905			
	PU3	1.083	0.049	22.218	***	0.926			
Perceived Ease of Use	PEOU1	1.000				0.812	0.895	0.898	0.747
	PEOU2	1.157	0.063	18.286	***	0.878			
	PEOU3	1.107	0.058	18.971	***	0.9			
Behavioral Intention	BI1	1.000				0.885	0.900	0.901	0.752
	BI2	0.992	0.045	22.264	***	0.886			
	BI3	0.891	0.046	19.468	***	0.83			

Table 6
Correlations and the average variances extracted.

	BI	PEOU	PU	PCP	PE	HI	ISE	SP	PC
Behavioral Intention (BI)	0.867								
Perceived Ease of Use(PEOU)	0.735	0.864							
Perceived Usefulness (PU)	0.626	0.711	0.897						
Perceived Companionship (PCP)	0.964	0.695	0.570	0.886					
Perceived Enjoyment (PE)	0.866	0.766	0.673	0.900	0.888				
Humanized Interaction (HI)	0.783	0.651	0.538	0.838	0.808	0.845			
Internet Self-Efficacy (ISE)	0.665	0.828	0.512	0.609	0.618	0.612	0.866		
Security/Privacy (SP)	0.100	0.083	0.131	0.080	0.060	0.094	0.071	0.863	
Perceived Convenience (PC)	0.760	0.929	0.798	0.724	0.833	0.701	0.738	0.092	0.860

The square root of the average variance extracted for each construct is denoted in bold and italic, while the inter-construct correlations are shown off-diagonally.

5. Discussion

5.1. Theoretical implications

In this study, which sought to understand the willingness of elderly people to use VAs, we extended the TAM by proposing the dual perspective of usability and emotional needs. Although some previous studies have investigated the key success factors influencing the use of VAs [60,63], this is the first in-depth analysis of the factors that affect the adoption of VAs by the elderly from the perspective of meeting user needs, thus filling gaps and overcoming the limitations of previous research. Because an important factor for promoting the use of VAs among the elderly is whether the product design meets user needs, the main achievement of this work is to propose this model, which has a strong theoretical basis, to explain the BI of the elderly regarding VA use based on the dimension of user needs.

Our research comprehensively discussed VA characteristics and the needs of the elderly by combining the influencing factors of usability and emotional needs. The findings indicated that, among the three determinants of BI (PEOU, PU, and PCP), the β value for PCP was 0.97, indicating that it was the strongest predictor of BI. This result is surprising and has not, to our knowledge, been confirmed in any previous studies. This opens up a new avenue for research in which the factor influencing older adults' use of VAs can be hypothesized as dependent on their emotional needs. A plausible explanation for this result can be linked to three aspects: first, older adults spend more time at home compared to younger adults [131], especially during the COVID-19 pandemic; so, the feelings of social isolation and loneliness are more serious, and the need for companionship is more urgent than ever. Li noted that voice

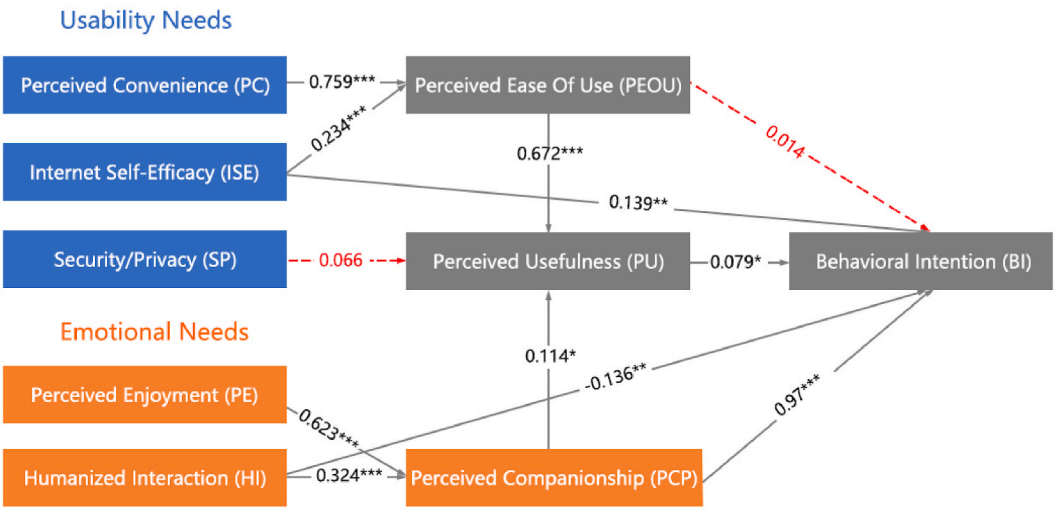

Fig. 2. Structural equation modeling results. *p < 0.1; **p < 0.05; ***p < 0.01.

Table 7
Results of hypothesis testing.

	Unstd. β	S.E.	Z	P-Values	Std.	Results
H1:PU→BI	0.079	0.047	1.673	0.094*	0.077	Partially supported
H2:PEOU→BI	−0.014	0.081	−0.177	0.859	−0.013	Not supported
H3:PEOU→PU	0.672	0.076	8.859	***	0.653	Supported
H4:PC→PEOU	0.759	0.062	12.277	***	0.752	Supported
H5:ISE→PEOU	0.234	0.046	5.06	***	0.262	Supported
H6:ISE→BI	0.139	0.055	2.532	0.011**	0.146	Supported
H7:SP→PU	0.066	0.044	1.496	0.135	0.066	Not supported
H8:HI→PCP	0.324	0.061	5.286	***	0.34	Supported
H9:HI→BI	−0.136	0.068	−1.984	0.047**	−0.141	Supported
H10:PE→PCP	0.623	0.066	9.504	***	0.617	Supported
H11:PCP→PU	0.114	0.066	1.723	0.085*	0.117	Partially supported
H12:PCP→BI	0.97	0.083	11.755	***	0.958	Supported

*p < 0.1; **p < 0.05; ***p < 0.01.

interaction can stimulate the sense of social presence in an individual's mind [132], which may be one of the important reasons for promoting the use of VAs among the elderly. Second, the VA user interface is simpler than the multi-modal interface of smartphones [133,134]. Looking at conversation style, Cerekovic et al. [135] proposed that people talk to VAs in the same way they talk to other humans, which is very useful for building rapport with AI assistants. Third, with the technical characteristics of being "always online" and "always listening," VAs can play the role of a companion to the elderly. To sum up, the key to the success of VAs lies in their ability to stimulate social presence for older users, and this emotional need for companionship is likely to motivate older people to continue using such devices.

It is important to acknowledge that our data was collected towards the end of 2022, during the COVID-19 pandemic. This particular context may have influenced our research findings, and it is imperative to recognize this limitation. Future investigations should strive to conduct further testing under more "normal" social circumstances. Additionally, as we did not collect information regarding the extent of social isolation experienced by our participants, it is important to acknowledge this as a limitation of our study. Future research endeavors should endeavor to collect more comprehensive data to better understand the impact of social isolation on the utilization of VAs among older adults and to further explore the relationship between emotional needs, usability, and VAs.

Two antecedents of PCP (PE and HI) generate different impacts, with the effect of PE being higher at 0.623. This result is consistent with the findings of previous scholars, whose results indicate that enjoyment is an important determinant of overall user intention [63, 136]. The development and popularity of technology promoted the integration of VAs with devices such as smartphones, computers, speakers, and smart homes. Depending on the device class used, it can be very useful and convenient to use VAs when performing certain tasks, while from another perspective, it can also serve as a source of entertainment. HI has significant influence on PCP and is the second predictor of PCP with a weight of 0.324, but interestingly, the effect is negative. We think this result may be a direct reflection of the current lack of humanized VA design. The relationship between the conversational nature of VAs and human attributes is inherent, and this can positively affect the user's experience with the VA, as users tend to personify the device [137]. Studies [138] have revealed that when VAs showed concern for and empathy with the user, it was seen as more human, because the user thought that the VA was a private conversation partner. When the VA provided advice-only support, it was perceived more as a tool and made the

user feel insecure. VAs have been popular for only 10 years, and the degree of their intelligence still needs to be strengthened, which also affects user experience and humanization. Conversational capabilities are critical to shaping the user experience with VAs, and much exploration and analysis need to be done to further expand the dialogue capabilities so as to enrich the user's voice interaction experience.

The analysis results also confirmed that PU positively influences older adults' BI to use VAs, and PEOU significantly affected PU, echoing previous work [63,139]. The more useful VAs are perceived to be, the more actively the elderly will use them. Such findings suggest that the attitude of elderly users toward VAs is positive, and they believe that technology can allow them to enjoy a better life with less effort. The results further revealed that, among the two determinants of PEOU (PC and ISE), the β value for PC is 0.759, which is a stronger predictor. It is evident that VAs can benefit the elderly. Unlike traditional interactions, which require input and output equipment [2], VAs enable older adults to control devices just by talking to them. For instance, compared with using remote controls to press buttons, integrating VAs into home automation systems allows older users to talk directly with smart TVs in a way that resembles having a conversation with someone in daily life. These voice-based dialogue interactions offer great convenience to elderly people with degenerating physiological functions and greatly improve the efficiency of human–computer interaction among older adults. ISE was positively correlated with PEOU (β value of 0.234) and BI (β value of 0.139), a result that is consistent with our previous hypothesis. The main reason for this is that the use of VAs depends on the network environment. Having extensive experience in using Internet devices provides users with the ability to learn VAs more easily and therefore promotes a more positive view of their ease of use as well. In terms of BI, some scholars' research [140] indicates that consumers with higher ISE are more likely to use e-services, and this implies that increasing older adults' ISE is critical to the success of spreading VA use.

The most unexpected research result lies in the correlation between PEOU and BI, which was non-significant. This is in stark contrast with previous research in which PEOU was an important determinant of user BI [60,115,139]. This finding stands up against recent criticisms of TAM studies that report insignificant effects of PEOU and BI [141,142]. These results suggest that when a technology is perceived as very easy to utilize, the variable PEOU has very little or no impact on individuals' intentions to use that technology [142]. A plausible explanation for this is that the VA's unique features of providing a total hands-free way of communication, as well as the voice-based dialogue system, which provides no difficulty for the elderly to use, together meant that the elderly people do not perceive that the ease of use of VAs is an important factor affecting their use. The contribution of this finding is that if there is eagerness to improve the VA usage intention of older adults, improving their understanding of the usefulness of VAs is essential.

The exploration of the SP structure also yielded interesting results. In terms of the relationship between SP and PU, both significant and non-significant relationships have been found in existing studies. In our study, the relationship between SP and PU was found to be non-significant, which is inconsistent with most extant studies [63,81]. However, our research result is line with the findings of Debajyoti Pal et al. [60]; they also found that the correlation between privacy risks and the attitude of using VAs is non-significant. A rational explanation for this result is that users are aware of the fact that if they intend to use more personal customized service provided by VAs, they have to divulge more detailed private information. Only by collecting more data can VAs work better and provide more utility and satisfaction to users [60]. Studies have also revealed that, in addition to the technical factors, numerous psychological antecedents also affect users' inclination to disclose personal information, which further affects the continuous use of VAs [143]. Considering the enormous potential of VAs to improve the quality of life for the elderly, our findings also indicate that, compared with the perceived risks, older adults are more concerned about the benefits of using VA services. However, the limitation of our sample consisting solely of VA users should be considered when generalizing these findings. Future research should aim to include a more diverse sample, including individuals with varying levels of privacy concerns, to further investigate the relationship between SP and PU in the context of VAs.

5.2. *Practical implications*

There are a number of practical implications stemming from the results of this article. First, the results indicate that companionship is the most critical factor affecting older adults' intention to adopt the use of VAs. Older users of VAs also have an interest in the technology and the products themselves, rather than considering the ease of use: they value the convenience and companionship afforded by VAs. It is thus necessary for VA designers and manufacturers to properly consider the features and designs that can meet user needs and improve the user experience, as this will increase the older adults' interests in these devices. This study also revealed that PE and HI have a significant effect on PCP. Older adults find it helpful to use their VAs to listen to music and jokes, watch TV programs, and be provided with medical reminders or even social chats to overcome loneliness. Designers and developers must therefore focus on improving the emotional and entertainment value of these VA products that can enrich the daily lives of the elderly. Our research also found that HI has negative significance on PCP, indicating that there are still many drawbacks in the current interaction of VAs. Specifically, through in-depth user interviews, we have discerned several pivotal issues. Firstly, a subset of elderly participants raised concerns regarding VAs' timeliness in responding during interactions, potentially engendering feelings of detachment or perceived indifference. Secondly, user feedback consistently indicates that VAs predominantly furnish formulaic responses, characterized by a dearth of emotional depth. This, in turn, engenders a perception among elderly users that VAs are inadequate in cultivating an intimate sense of companionship. Furthermore, from the vantage point of technological advancement, the performance of VAs in addressing complex emotional states and associated emotional needs warrants improvement. Despite their multifarious utility, VAs confront formidable challenges in the cultivation of profound emotional connections. This challenge is likely intertwined with the current state of natural language processing technology and the level of emotional intelligence exhibited by VAs. To ameliorate the companionship dimension of VAs, it is imperative to devote further research efforts and technological innovation

towards equipping VAs with an enhanced capacity for discerning and responding to users' intricate emotional exigencies. For example, a recent study [144] revealed that VAs' conversational style had significant interaction effects on social and behavioral intent outcomes; so, improvements must be made to enhance the HI value of these devices to further attract and guide the elderly to be willing to use and to communicate with VA products. With the development of science and technology, the smart senior care mode will surely benefit more elderly people, and VAs are important components of this. Our research reveals that convenience is a major factor affecting the use of VAs by the elderly. Our study reveals a robust positive correlation between the perceived convenience and the perceived ease of use, with the latter exerting a favorable impact on the perceived usefulness. Within the scope of our investigation, convenience pertains to the user-friendly and easily navigable attributes of VAs. Voice assistants adeptly utilize natural language or simple directives for articulating needs and eliciting prompt responses from VAs. Furthermore, the presence of a reduced learning curve implies that elderly users can rapidly acclimatize themselves to the utilization of VAs, obviating the necessity for intricate training procedures. In particular, smart appliances offer a variety of functions that require complex interactions. Owing to the integration of VAs, the PEOU and practicality for older users can be significantly improved, thereby greatly reducing the learning burden, which will contribute to their understanding of smart appliances and the establishment of a friendly human–computer relationship.

5.3. Distinctive findings in the paper

Our study has unveiled two distinctive discoveries that offer novel insights into the utilization patterns and inclinations of the elderly populace regarding voice assistants. Firstly, we have unearthed that, in the context of shaping the utilization behavior and willingness of elderly individuals towards voice assistants, the level of Perceived Companionship (PCP) emerges as the most influential predictive factor. This revelation holds a particularly unique aspect, as we had not hitherto envisaged that the satisfaction of emotional needs would wield such a pivotal influence on the utilization behavior and willingness of elderly individuals towards voice assistants. This outcome underscores, to a greater extent, the latent value of voice assistants in catering to the emotional needs of the elderly demographic. Secondly, we have discerned a phenomenon that deviates markedly from antecedent research. Specifically, there exists no statistically significant correlation between Perceived Ease of Use (PEOU) and Behavioral Intention (BI) among elderly individuals. This stark departure from earlier research implies that elderly individuals do not encounter substantial technological impediments in their use of voice assistants. These two unique findings collectively underscore the significance and import of our study. Our initial supposition posited that voice assistants could proffer convenience and augment the overall life contentment of elderly individuals. These findings not only substantiate our research hypothesis but also engender a more profound comprehension of the interplay between elderly individuals and voice assistants.

6. Conclusion and limitations

This work has many theoretical contributions for academic researchers. First, our research confirms the relationship between three usability needs of perceived convenience, ISE, and SP and PU as well as BI; it further confirms and supplements the research achievements of previous scholars [60,63]. To enhance users' technology acceptance, traditional approaches have focused on the usefulness and ease of use of the technology, considering the ease of learning, the ease of use, reduction of efforts, and increasing perceived convenience [145,146]. However, this study confirmed that, apart from technical factors, there are numerous emotional antecedents also affecting older adults' adoption of VAs. A high quality of companionship, more humanized human–computer interaction, and high levels of ISE were all related to greater use of VAs by the elderly. Our findings thus point to a new direction for designers and developers of VAs that emphasizes the value and significance of focusing on the emotional needs of users in enhancing technology acceptance. Some scholars have suggested that human-like VAs that can serve the roles of a friend, partner, or servant will be the future direction of VA development [11,147]. New designs must propose human-supportive VAs to facilitate users' social connection and well-being and to eliminate their sense of isolation and boredom [148]. VAs' potential to meet the needs of older adult users should be taken into account, because VAs could engage with the elderly more than a human being [149], especially in the post-epidemic era. We anticipate that our discovery will inspire future research to upgrade the usefulness and user experience of VAs to support the well-being of older adults and enhance their autonomy and quality of life.

Although the findings are encouraging and useful, providing several theoretical and practical implications, this study also has certain limitations, and the findings of this study warrant further research. The first limitation is the sample, as only older adults from China have been included in this study. The service of VAs may vary by country and culture, and different countries are also in different situations in terms of VA technology maturity and market. Therefore, to improve the generalizability of the current model, subsequent studies should consider older users from different countries and cultural backgrounds. Second, this research found that HI has a negative impact on PCP; so, the factors causing this result require further analysis. Researchers should thus further examine older users' concerns when interacting with a VA. For example, to examine the key human interaction features that influence the use of virtual reality by older adults, researchers can conduct further in-depth research through qualitative interviews. This will provide designers and developers with a set of action guidelines to improve interactivity and instill confidence in older users.

This study examined the psychological and emotional impact of VAs on elderly users and drew some preliminary conclusions. However, there is still much research to be explored in this area. For instance, related studies have indicated that VAs are challenging for adults with cognitive impairment to use, suggesting potential difficulties when these users encounter cognitive barriers. Furthermore, to our knowledge, there have been no scientific studies to determine the consequences when adults or older adults using VAs experience cognitive impairment. This is an area that requires further in-depth research. For example, it would be interesting to

investigate whether the interaction between older adults and VAs becomes frustrating as their cognitive abilities decline, potentially leading to negative perceptions of VAs, perceiving them as malevolent rather than friendly. These are compelling research topics that deserve further exploration in the future.

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Data Availability statement

Data will be made available on request.

Ethics declarations

All participants (or their proxies/legal guardians) provided informed consent to participate in the study.

CRediT authorship contribution statement

Mingzhou Liu: Conceptualization, Project administration, Supervision, Validation, Visualization. **Caixia Wang:** Data curation, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing, Conceptualization, Formal analysis, Funding acquisition, Resources, Software, Supervision. **Jing Hu:** Resources, Software, Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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