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ORIGINAL ARTICLE

Psychological predictors of consumer-level virtual reality technology adoption and usage

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Abstract
In recent years, virtual reality (VR) technology has been mainstreamed for at-home use, with various consumer-oriented devices released by media firms such as Meta, Google, Samsung, and HTC. The present research investigates the role of psychological traits—including immersive tendencies, absorption, sensation seeking, need for cognition, neophobia, and belief in science—as well as trait levels of individual innovativeness, self-perception of social well-being, and owner demographics, in predicting VR adoption rates and sustained use over time. Separate analyses were conducted for different classes of VR device (fixed, mobile, and standalone devices). In general, psychological factors generally emerged as more determinative of adoption than did demographics. Users' immersive tendencies predicted earlier adoption of VR technology while absorption was associated with later adoption, with both predictive of higher overall initial usage of different types of devices. Additionally, perceiving oneself as socially successful was associated with higher initial VR usage, while a tendency to see one's emotions as influenced by in-person rather than online contacts was negatively associated with usage. Finally, belief in science predicted greater consistency in usage over time while higher levels of absorption were associated with unstable usage patterns. These findings expand upon the limited work previously investigating the role of individual differences in adoption of VR and mark the promise of psychometrics for understanding the diffusion and continued usage of consumer-facing VR devices.

Keywords Virtual reality · Uses and gratifications · Adoption · Immersion · Absorption · Individual differences

1 Introduction

Once restricted to academic campuses, military bases, and other research laboratories, immersive virtual reality (VR) has in the last two decades spread to various private industry sectors, including manufacturing, employee onboarding, and health and rehabilitation. More recently, VR technology has been mainstreamed for at-home use, with various consumer-oriented devices released by media firms such as Meta, Google, Samsung, and HTC. However, while VR technology has proven itself "mature, stable, and, most importantly, usable" for particular industry functions (Berg and Vance 2016, p. 1), mainstream consumer-oriented VR is in its infancy, occupying the earliest of stages of the diffusion of innovations process articulated by Rogers (2003). Industry analysts have commented on the slow take-up of consumer VR relative to initial expectations (Roberts 2017; Bradshaw 2017). Others suggest that VR's mainstream appeal may have already peaked (Panetta 2017), with enthusiasm redirected instead toward the promise of augmented (AR) and mixed reality (MR) technologies (Statt 2018). Despite these observations, the actual availability of AR and MR hardware platforms oriented toward consumers remains extremely limited compared to the wide array of comparable options on the VR market.

To better understand the factors affecting and potentially constraining the adoption of mainstream VR technology for personal use, the present exploratory study takes the first steps toward building a theory of technological acceptance for consumer-grade VR and constructing a coherent psychological profile of its users. While much past research has focused on the psychological effects of immersive experiences, the present study is notable for being among the first

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to directly address individual differences in the psychological traits of owners of consumer-level VR, and the impact these may have on the adoption and day-to-day use of this technology. This study builds on past efforts to adapt models of technology adoption for VR (e.g., Mütterlein and Hess 2017) by examining and comparing the attributes of owners at different stages in the diffusion process. On a theoretical level, this development will allow scholars in the field to source relevant perspectives from the literature on individual differences, for the purpose of theory building and synthesis. On the level of methodology and research design, the psychometric predictors identified in this study may present as potential moderators or otherwise confounding variables in future VR research, which can now be appropriately measured and controlled for.

As an exploratory study, the goal of the present research was not to test a pre-selected hypothesis, but to take initial steps in exploring the possible connections between a variety of psychometric factors and VR adoption. Specifically, this study surveys 1265 individuals on various psychological factors, and their adoption of VR devices to establish associations between individual differences and rates of consumer-level VR adoption and usage. Through a data-driven cross-sectional analysis, this research explores the roles of various individual-level psychological factors—those which are potentially implicated by the unique affordances of VR as a medium, as well as those generally related to the propensity of the individual to adopt new technologies early in the diffusion process—in predicting adoption rate and patterns of initial and ongoing usage.

1.1 Factors influencing innovation adoption

Much of the foundational work on the diffusion of technological innovations heavily emphasized the characteristics of the innovation itself as determining the pattern of its adoption within a population (Rogers 2003; Robertson 1971; Rogers and Shoemaker 1971). For instance, Rogers (1961) originally proposed that inherent characteristics including relative advantage, compatibility, complexity, divisibility, and communicability were directly related to rates of adoption. In the context of digital media innovation, patterns of adoption may relate to both tangible and intangible affordances of technology. For instance, Venkatesh and Brown (2001) found the adoption of personal computers in the home to be influenced by expected utility as well as perceived hedonic and social outcomes, such as effects on status. Similarly, recent investigations into the adoption of early AR devices such as Microsoft HoloLens and Google Glass have found adoption decisions to be based on usefulness and ease of use, but also implications for self-image (Kalantari and Rauschnabel 2018) and their potential as statements of fashion (Rauschnabel et al. 2016). It is worth noting, however, that at the time of these studies, the devices in question were not available for sale to the general public, and so, the perceived exclusivity of ownership may have bolstered the desirability of these technologies as symbolic expressions of social status or tech-savviness (Arbore et al. 2014).

In addition to the inherent affordances of the technology, individual differences between users may also influence patterns of adoption and use. Within the consumer research literature, differences in income, product involvement, education, information-seeking behavior tendencies, and more have been considered as predictors of adoption for new products (Im et al. 2003). One user trait that is repeatedly emphasized in the context of technological adoption is that of *innate consumer innovativeness* (Im et al. 2003) or *personal innovativeness* (Huang and Liao 2015). This concept refers to an individual's overall disposition toward trying any new consumer technology and moderates the perceived salience of different categories of user experience (e.g., aesthetics, quality of service, usefulness, ease of use), suggesting that the appeal of any given technology, when first introduced, is not universal and will vary from person to person based on the psychological predispositions of the individual.

1.2 Individual differences and the adoption of consumer-level virtual reality

Previous research into the adoption and diffusion of VR has often concentrated on particular social domains, such as tourism (tom Dieck et al. 2018; Vishwakarma et al. 2020) or therapy and rehabilitation (Standen et al. 2015). Furthermore, the theoretical and practical importance of considering individual differences—including psychological factors such as personality, cognitive ability, and domain knowledge—in research on the use and effects of immersive technologies has previously been argued for by scholars (Chen et al. 2000; Chuah 2020). However, with the exception of general market research focusing on owner demographics (Clement 2021), there has been relatively little empirical investigation of the individual differences that may best predict mainstream adoption and usage of VR by the general public. A recent survey of German consumers by Herz and Rauschnabel (2019) highlights the broad range of user needs that may differentially influence perceptions of VR, including utilitarian and hedonic affordances, fashionability, comfort, and perceived mental and physical health risks. Mütterlein and Hess (2017) suggested that personality traits may be a potentially important contextual factor influencing the acceptance and use of VR at an individual level; however, they did not go so far as to identify specific dimensions of personality that might be relevant. Following this line of research, the present study seeks to explore the association between individual differences and rates of consumer-level

VR adoption and usage. The identification of psychological predictors for the adoption and usage of VR devices should yield new insight into the long-term promise of VR as a mainstream media technology, as well as the particular affordances of that technology that are most likely to drive—or hinder—widespread adoption. For instance, if individual differences in sensation seeking (Weisskirch and Murphy 2004) or personal innovativeness (Hurt et al. 1977) are found to predict acquisition and use, this may implicate novelty as a leading factor in the expansion of VR. Alternatively, if users' levels of immersive tendencies (Witmer and Singer 1998) or absorption (Tellegen and Atkinson 1974) positively predict adoption and usage patterns, this may indicate that the unique technological affordance of immersion has potential as a driver of long-term adoption.

1.3 Who is likely to use mainstream VR? A uses and gratifications approach

While exploratory in nature, the present study's investigation is guided by the uses and gratifications (U&G) theoretical framework (Katz et al. 1973). The U&G framework suggests that media use is the result of active, volitional selection of platforms and messages in light of their expected capacity to satisfy a user's needs and has been frequently applied as a motivational framework for explaining patterns of technology diffusion. For example, scholars working within this tradition have considered how technological affordances—as described in theoretical literature on diffusion of innovations—and individual needs may together predict seniors' use of social networking sites (Kim et al. 2019), the compulsion for "Twitter quitters" to abandon the platform (Coursaris et al. 2010), and the adoption and continued use of online games (Chang et al. 2006).

Technological affordances and the perceived satisfaction of user needs as predictors of new media usage have been further developed by Sundar and Limperos (2013) in their "Uses and Grats 2.0" framework. While Katz et al.'s (1973) original formulation of U&G places relative primacy on the predictive power of user needs in explaining patterns of media selection, the U&G 2.0 theoretical framework argues that affordances unique to or specially enacted through new media technologies may give rise to gratifications that are distinct from those offered by more traditional media. Notably, Sundar and Limperos specifically address VR as a modality that may gratify an inherent need for a sense of "being there" in a more intense and authentic manner than other modalities. Similarly, they suggest that the gratification of needs for escape and immersion is enabled through interfaces such as video games that provide navigable simulated spaces for exploration—an observation that arguably applies even more directly to the high fidelity, naturally mapped simulations of virtual space produced by VR platforms.

Guided by the U&G perspective, the present study specifically examines individual differences in psychological factors that are directly relevant to the unique affordances of VR technology—such as the affordance of "being there" discussed by Sundar and Limperos—and which VR may potentially realize to a greater extent than existing media technologies. Notably, consumer-level VR is an innovative, multi-modality, immersive medium capable of affording—compared other media formats—relatively high levels of spatial and social presence while engaging rich, vivid stimuli. In turn, we have focused our attention on the psychological traits most likely to be predictive of whether—and to what extent—an individual's personal needs may be gratified through the adoption and use of such technology.

1.4 Psychological factors

1.4.1 Immersive tendencies

Immersive tendencies refer to the predisposition of an individual to become involved or immersed in a given activity, particularly in terms of their cognitive engagement with mediated experiences such as movies, video games, and immersive virtual environments (Witmer and Singer 1998; Qin et al. 2009). A number of previous studies have found positive correlations between a high degree of immersive tendencies and the subjective experience of presence in mediated environments (Laarni et al. 2004; Wallach et al. 2010; Kober and Neuper 2013). Moreover, the experience of presence that is evoked by VR may positively predict adoption of the technology (Hartl and Berger 2017). Thus, the extant literature anticipates a positive relationship between immersive tendencies and the likelihood of adoption of VR technology at the individual level. Furthermore, users who are motivated by VR's affordance of presence rather than mere novelty may be expected to show less of a drop-off in usage following the initial period of ownership.

1.4.2 Absorption

With respect to individual differences, *absorption* may be considered as one's propensity to become deeply absorbed in mental imagery and particularly in fantasy (Roche and McConkey 1990), or to devote "total attention" (i.e., "perceptual, enactive, imaginative, and ideational" resources) to a particular object of focus (Tellegen and Atkinson 1974, p. 268). Absorption is closely related in the empirical literature to an individual's susceptibility to hypnosis (Patterson et al. 2006; Macedonio et al. 2007). Individuals exhibiting higher levels of absorption could potentially find more intrinsic value or enjoyment in the immersive quality and sensory richness of VR content and in turn might be more likely to adopt VR devices and to continue using them over time. Notably, absorption has been previously associated with presence (Baños et al. 1999), which—as noted above—has been found to predict VR adoption (Hartl and Berger 2017).

1.4.3 Sensation seeking

Steuer (1992) theorized that presence is the result of the capacity of a media technology to portray environments in a representationally rich, *vivid* manner. Vividness can be accounted for in terms of both sensory breadth (the number of sensory dimensions simultaneously presented) and sensory depth (the resolution or intensity of each of these channels). The immersive properties of VR technologies permit highly vivid, sensorially rich experiences, which may be of particular value to individuals with high levels of *sensation seeking*. This term describes a preference for novel and intense stimuli (Weisskirch and Murphy 2004), which is often associated in non-mediated contexts with risk-taking behavior (Arnett 1994, 1996; Zuckerman and Kuhlman 2000). This relationship would be expected to be driven by both the immersive properties and the relative novelty of VR technology for most consumers; however, in the latter case, motivation for continued use would likely drop-off over time, as the experience of novelty waned.

1.4.4 Need for cognition

VR adoption and use may also be associated with users' *need for cognition* (NFC), or the extent to which they are motivated to engage in effortful cognitive activity (Cacioppo and Petty 1982). As noted above, VR technologies permit the presentation of multiple simultaneous modalities of rich sensory input; this abundance of information may require greater cognitive effort for a user to structure and process, thereby affording greater satisfaction to those with high levels of this need. Moreover, correlations have previously been identified between NFC and levels of absorption (Osberg 1987), as well as the extent to which one values stimulating experiences (Lins de Holanda Coelho et al. 2020).

1.4.5 Belief in science

Belief in science is the extent to which one believes in the proposition that science offers a unique and exclusive insight into the nature of reality and is framed by Farias et al. (2013) as an inherently dogmatic attitude toward the power of science. Although this concept has not been widely deployed in the adoption literature, it is conceivable that one's attitudes and orientation toward science might account for a sense of affinity with new technology in general, driven by the desire to associate oneself symbolically with the products of scientific advancement.

1.4.6 Neophobia

Neophobia is the fear of and avoidance of novel things. In the context of the adoption literature, neophobia has been studied extensively as a psychological construct relating to the adoption of novel foods and food technology (Giordano et al. 2018) and has been found to drive reluctance to try new food products (Pliner and Hobden 1992). Additionally, related fears of new technology have been widely tied to the non-adoption of computer technology, particularly among the elderly (Sinkovics et al. 2002; Nimrod 2018). Notably, neophobia has been observed to relate negatively to sensation seeking (Pliner and Hobden 1992). As such, while other concepts may account for the value some individuals place on novel or extraordinarily vivid encounters with new media technology, neophobia relates to the trepidation experienced by many when they are faced with a new or unfamiliar experience and may independently predict new technology adoption and usage.

1.4.7 Social well-being

Hartl and Berger (2017) found that escapism—the desire to escape unpleasant realities or to distract one's attention from problems—moderates the extent to which the experience of presence impacts the perceived utility of VR. The problems that individuals hope to escape from via media use may, in some cases, be particularly tied to *social well-being*: Previous research has found media use—particularly in younger populations—to be negatively correlated with the development and maintenance of close personal relationships (Pea et al. 2012). Although there is an expanding range of virtual social experiences available to VR users, the historically solitary games and simulations offered by VR platforms have lead some scholars to associate the technology with antisocial behavior (Cescau 2016). To the extent that VR use is perceived as an isolated experience, individuals with relatively lower levels of social well-being may be expected to perceive lower social costs of isolation and higher hedonic benefits of escape and thus, may be more likely to adopt and continue using VR platforms.

2 Methods

To understand the factors underlying adoption and usage patterns of consumer-level VR thus far, an online survey of individuals ($N = 1{,}265$) was conducted in two waves: Respondents who reported owning at least one consumer VR device ($n = 1{,}002$) were recruited through a

Table 1 List of VR devices by device class

Class	Brand	Model	Wave 1	Wave 2
Fixed devices	Oculus	Rift	*	*
	Oculus	Rift S		*
	HTC	Vive	*	*
	HTC	Vive Pro		*
	HTC	Vive Cosmos		*
	Valve	Index		*
	Lenovo	Explorer		*
	Sony	Playstation VR	*	*
	Pimax	Vision 8K		*
	Pimax	5K		*
	Pimax	4K		*
	HP	Reverb		*
	HP	Windows Mixed Reality Headset		*
	Acer	Windows Mixed Reality Headset		*
	Asus	Windows Mixed Reality Headset		*
Mobile devices	Oculus	Go		*
	Samsung	Gear VR	*	*
	Google	Daydream	*	*
	Google	Cardboard	*	*
Standalone devices	Oculus	Quest		*
	Lenovo	Mirage Solo		*

representative panel assembled by Qualtrics. These panels are widely used in survey research. While Callegaro et al. (2014) note that online panels can vary in quality, they also suggest these impacts are less important when studying relationships between variables rather than estimating the raw prevalence of variables within a population. Additionally, Belliveau et al. (2022) find data from Qualtrics panels, specifically, matched well to the general population when studying gaming, a topic related to VR. Respondents recruited through Qualtrics for the current study were directly compensated at a rate established privately between panel participants and the service provider. Data collection for the first wave ($n = 529$) took place in April and May 2018; however, a substantial number of new, consumer-grade VR devices were released subsequent to this period and so, a second wave of respondents ($n = 736$) was recruited between July and November 2020. This second wave of data collection included a sub-sample of non-owners ($n = 263$) to serve as a point of reference for the general population. All respondents were over 18 years of age.

A list of devices commercially available to consumers at the time of each wave of data collection was provided (see Table 1); however, respondents could also self-report ownership of devices not included in this list. Attention check questions were included to allow respondents identified as not responding carefully to be removed from the sample prior to analysis. Respondents were initially asked all device-specific questions (e.g., time of acquisition, amount of usage) in a set order. Following this, all of the psychometric instruments were presented in a randomized order. In all cases where Likert-type questions were used, these questions were presented in a standardized fashion with seven points. A university institutional review board approved all questionnaire items and survey procedures.

2.1 Psychometric measures

2.1.1 Immersive tendencies

Immersive tendencies were measured through the Immersive Tendencies Questionnaire (Witmer and Singer 1998; Robillard et al. 2002; UQO Cyberpsychology Lab 2004). The scale consists of eighteen 7-point ordinal scale items, collectively gauging the respondent's predisposition to become deeply involved in and attentively focused on activities. Example items include "Do you ever become so involved in a movie that you are not aware of things happening around you?" and "How good are you at blocking out external distractions when you are involved in something?" ($M = 4.53$, $SD = 1.13$, Cronbach's $\alpha = .92$).

2.1.2 Absorption

Openness to absorption as a personality trait was measured through the Tellegen Absorption Scale (Tellegen and Atkinson 1974). The scale consists of 34 true–false items, including "I am able to wander off into my thoughts while doing a routine task and actually forget that I am doing the task, and then find a few minutes later that I have completed it" and "The crackle and flames of a wood fire stimulate my imagination." The total number of items indicating absorption was summed, per Tellegen and Atkinson's procedure, to generate a score for each respondent ($M = 19.84$, $SD = 8.58$, Cronbach's $\alpha = .92$).

2.1.3 Sensation seeking

Sensation seeking was measured through the Arnett Inventory of Sensation Seeking (Arnett 1994). The scale consists of 20 statements about preference for novel and/or intense experiences; for example, "I like the feeling of standing next to the edge on a high place and looking down" and "If it were possible to visit another planet or the moon for free, I would be one of the first to sign up." Respondents indicated the extent to which each statement describes themselves. The present study modified the inventory's original 4-point ordinal scale to a 7-point format to provide consistently scaled questions. Response options are weighted and tallied (accounting for reverse coded items) to produce a single score ($M = 4.12$, $SD = 0.81$, Cronbach's $\alpha = .78$).

2.1.4 Need for cognition

Respondents' relative need for cognition was measured through Cacioppo et al.'s (1984) condensed Need for Cognition Scale (NCS-18). The scale includes 18 items such as "I really enjoy a task that involves coming up with new solutions to problems" and "The notion of thinking abstractly is appealing to me." The present study modified the 5-point ordinal scale to a 7-point format, to provide respondents with consistently scaled ordinal questions ($M = 4.25$, $SD = 0.77$, Cronbach's $\alpha = .79$).

2.1.5 Belief in science

Belief in science was measured using the scale developed by Farias et al. (2013). The scale consists of ten 7-point ordinal Likert-type items, measuring the extent to which one has faith in science. Example items include "Science provides us with better understanding of the universe than does religion" and "Science is the most valuable part of human culture" ($M = 4.69$, $SD = 1.39$, Cronbach's $\alpha = .94$).

2.1.6 Neophobia

Neophobia was measured using the generalized neophobia scale developed by Pliner and Hobden (1992). The scale consists of eight 7-point Likert-type items, which assess the owner's fear of new and unknown experiences. Example items include "Whenever I'm away, I want to get home to my familiar surroundings" and "I avoid speaking to people I do not know when I go to a party" ($M = 4.08$, $SD = 1.39$, Cronbach's $\alpha = .90$).

2.1.7 Individual innovativeness

The questionnaire also included a measure of innovativeness—a personality trait commonly referenced in the literature on diffusion of innovations and technological adoption. Respondents' general orientation toward change and trying new innovations was captured with Hurt et al.'s (1977) individual innovativeness scale. The measure consists of 20 items, including "I am an inventive kind of person" and "I must see other people using new innovations before I will consider using them" ($M = 66.62$, $SD = 8.58$, Cronbach's $\alpha = .81$). For the purposes of the present study, the questionnaire modified the 5-point Disagree–Agree differential scale of the original to a 7-point format for consistency with other measures. Scores were then adjusted back to a 5-point scale prior to analysis, to match Hurt et al.'s suggested scale.

2.1.8 Social well-being

Along with the personality features noted above, respondents' self-perception of their own social well-being was captured through multiple scales previously employed when evaluating well-being with respect to media use (Pea et al. 2012). Separate 7-point ordinal scales were used to gauge *social success* (consisting of seven items such as "I feel like I have a lot of close friends" and "I feel like I'm important to my friends"; $M = 4.88$, $SD = 1.36$, Cronbach's $\alpha = .92$) and *normalcy feelings* (consisting of three items such as "Compared to people my age, I feel normal"; $M = 4.35$, $SD = 1.32$, Cronbach's $\alpha = .56$). Additionally, *source of positive feelings (online/offline)* and *source of negative feelings (online/offline)* each measured the extent to which feelings and behaviors are tied to in-person vs. exclusively online friends. Respondents indicated "online" friends or "in-person" friends for seven positively valenced items (e.g., "Who makes you feel more accepted?" and "I enjoy talking more to…"; $M = 0.46$, $SD = 0.66$, Cronbach's $\alpha = .95$) and three negatively valenced items (e.g., "I feel more judged by…" and "I feel more stressed by…"; $M = 0.18$, $SD = 0.73$, Cronbach's $\alpha = .61$).

2.2 Outcome measures

Given the ever-growing number of consumer-facing VR devices, for the purposes of this study, we propose distinguishing between devices that are *fixed, mobile,* and *standalone*: Fixed devices are those that are connected to a separate computer, which handles most of the computation necessary to sustain a virtual environment, and which may have additional external hardware such as lighthouse-style sensors. These devices typically provide the most computational resources to developers and are thus commonly associated with higher levels of visual and tracking fidelity—technological factors that have been broadly associated with the affordance of presence (Cummings and Bailenson 2016)—but also generally require the highest level of financial investment and technological literacy from users. Mobile platforms similarly rely on existing hardware owned by the user for computation; however, this is typically a smartphone, which can be mounted within or on the head-mounted display unit. This design removes the need for both a high-performance computer and a high-bandwidth (often wired) connection between the computer and the headset, affording the user a greater freedom of movement at a significantly lower financial cost than most fixed systems, while also sharply constraining the experience based on the limited computational resources available to developers and the lack of specialized sensor hardware. Paradoxically, while allowing users to move free of the confines of a cable, mobile VR devices are usually not capable of tracking translational movement about a space and thus, offer only three degrees of freedom (3DOF) compared to the six degrees of freedom (6DOF) typical of fixed platforms. More recently, standalone VR devices have become available that contain all of the required computer and sensor hardware in a single head-mounted package; optimization of this hardware for the single purpose of graphical processing generally allows for higher visual fidelity than would be possible on a mobile platform, while "inside–out" tracking systems based on multiple outward-facing cameras allow for 6DOF within a relatively compact package. While necessarily more expensive than mobile devices due to the added hardware, and while still technologically constrained relative to fixed devices, standalone devices offer an intriguing compromise between the competing demands of affordability, accessibility, and gratifications related to novelty, immersion, or sensory richness of media stimuli. Thus, in investigating how individual differences may predict VR adoption and usage, the present study partitioned analyses in light of the types of devices users reported owning.

2.2.1 Device adoption

For each VR device owned, the month and year of acquisition were reported. If an individual reported owning multiple devices, the earliest acquisition date was used for the analyses presented below. If an individual reported owning VR devices belonging to different device classes (i.e., fixed, mobile, and standalone), separate initial acquisition dates were noted for each category. Thus, a negative relationship with this variable indicates that a given factor predicts relatively earlier adoption.

2.2.2 Device usage

Respondents who owned more than one device were asked to rank the devices they reported owning in terms of the total amount of time they had spent using each. Based on this ranking, respondents were then asked to report the amount of time they spent using each of their three most commonly used devices for various tasks (e.g., playing games, watching videos, engaging in non-game simulations, creating original content, and completing work). These measures were repeated for weekday and weekend usage of each device, during both the initial period of ownership and the month preceding data collection. Respondents in the second wave of data collection who reported acquiring a given device prior to January 2020 were also asked to report average weekday and weekend usage in that month.[1] Weekday and weekend reported usage were aggregated into an estimate of average weekly usage for each time period.

[1] This measurement was intended to provide a reference point for VR usage outside of the context of the COVID-19 pandemic, based on reports that indicated increased public interest in the technology during this period, particularly given the number of individuals affected by lockdown measures (Holman 2020).

2.2.3 Change in usage

Following the above procedure, either two or three aggregate usage measures were available for each device, reflecting usage at the time of device acquisition (i.e., initial usage), usage in January 2020 (i.e., pre-pandemic usage) for devices that were acquired prior to that time, and usage at the time of data collection (i.e., current usage). Each of these measures was summed within device classes. Difference scores were calculated on a pairwise basis for each device class between initial usage and current usage, as well as between initial usage and pre-pandemic usage. Paired-sample sign tests were performed contrasting these difference scores for each device class, as well as for the whole sample, and no significant differences were found ($p > .25$ in all cases). Thus, change in usage was calculated based on current and initial usage only for the purposes of analysis.

As respondents had owned their devices for varying lengths of time, there was insufficient information available to calculate the rate at which device usage changed over the course of ownership. In lieu of estimating the magnitude of this change, the ordinal direction (sign) of change was calculated for each respondent based on whether a respondent's current weekly usage was less than, the same as, or greater than their initial weekly usage. Thus, the measure of change had three possible levels: *negative change* (a decrease in usage over time), *no change*, and *positive change* (increase in usage over time). This procedure was then repeated separately for the reported current and initial usage of each device class.

2.3 Data cleaning

Cases were removed in which the respondent did not complete the questionnaire, completed the questionnaire in less than 5 min, did not pass an attention check, did not respond to any of the psychometric measures, reported owning a VR device that was not publicly available at the time of data collection, or reported excessive aggregate usage.[2] Additionally, five cases originally recruited as owners were determined to be responses from non-owners; these were subsequently aggregated with the data purposefully collected from non-owners as part of the second wave of data collection to yield a reference sub-sample of 268 cases. Following data cleaning, responses collected during the first and second waves were aggregated into a single dataset containing 1,005 valid cases, of which 737 were owners of at least one consumer VR device.

2.4 Analytic strategy

Owners of VR devices were contrasted against the control sample of non-owners with respect to each of the demographic and psychometric measures of interest. This was followed by a more extensive multivariate analysis to evaluate the potential of the candidate measures for predicting (a) the time of adoption, (b) the initial amount of usage, and (c) the direction of change in usage. Each of these outcome variables was aggregated for each class of device (as described above), as well as for VR devices in general. Due to the large number of device models available at the time of data collection (see Table 1), models were not fit on a model-by-model basis.

Based on the number and theoretical breadth of psychometric measures employed, an exploratory analysis was conducted to develop parsimonious models for each of the dependent variables of interest (adoption, initial usage, and direction of change in usage) based on the most promising predictive features out of a range of candidates. Linear models were fit to the ratio-level measures of adoption and initial usage, and multinomial logistic models were fit to the ordinal-level measures of direction of change in usage. To reduce the risk of overfitting, a stepwise deletion protocol was followed, beginning with a complete model including all candidate psychometric measures, as well as a block of demographic control variables (age, gender). At each step, the least significant candidate parameter—excluding the control block—was selected for deletion from the model. The model was then refitted using the reduced set of parameters, and the process repeated until all candidate parameters remaining in the reduced model met a significance threshold of $\alpha = .05$. In each case, the reduced model was confirmed to be an improvement on both the demographic-only control model and the complete model containing all candidate parameters, following Akaike's Information Criterion.

Some statisticians and methodologists have raised the concern that applying unpenalized stepwise parameter selection procedures to regression models carries the risk of biasing estimates of error toward 0 and inflating parameter estimates, leading to the spurious inclusion of variables that have negligible causal relation to the outcome of interest (Harrell 2001; Smith 2018). To address these concerns, a bootstrap resampling approach developed by Royston and Sauerbrei (2009) was used to assess the stability of the reduced models resulting from the parameter selection procedure described above. A total of 10,000 replications were performed for each of the reported models, with forced selection of the demographic control block. The stability of

[2] Data was not recorded for respondents who completed the questionnaire in less than 5 min or who failed the attention check, and so, these cases were not counted as part of the initial sample. For the purposes of data cleaning, excessive usage was defined as > 168 h, based on aggregated weekly usage across all devices and all use cases.

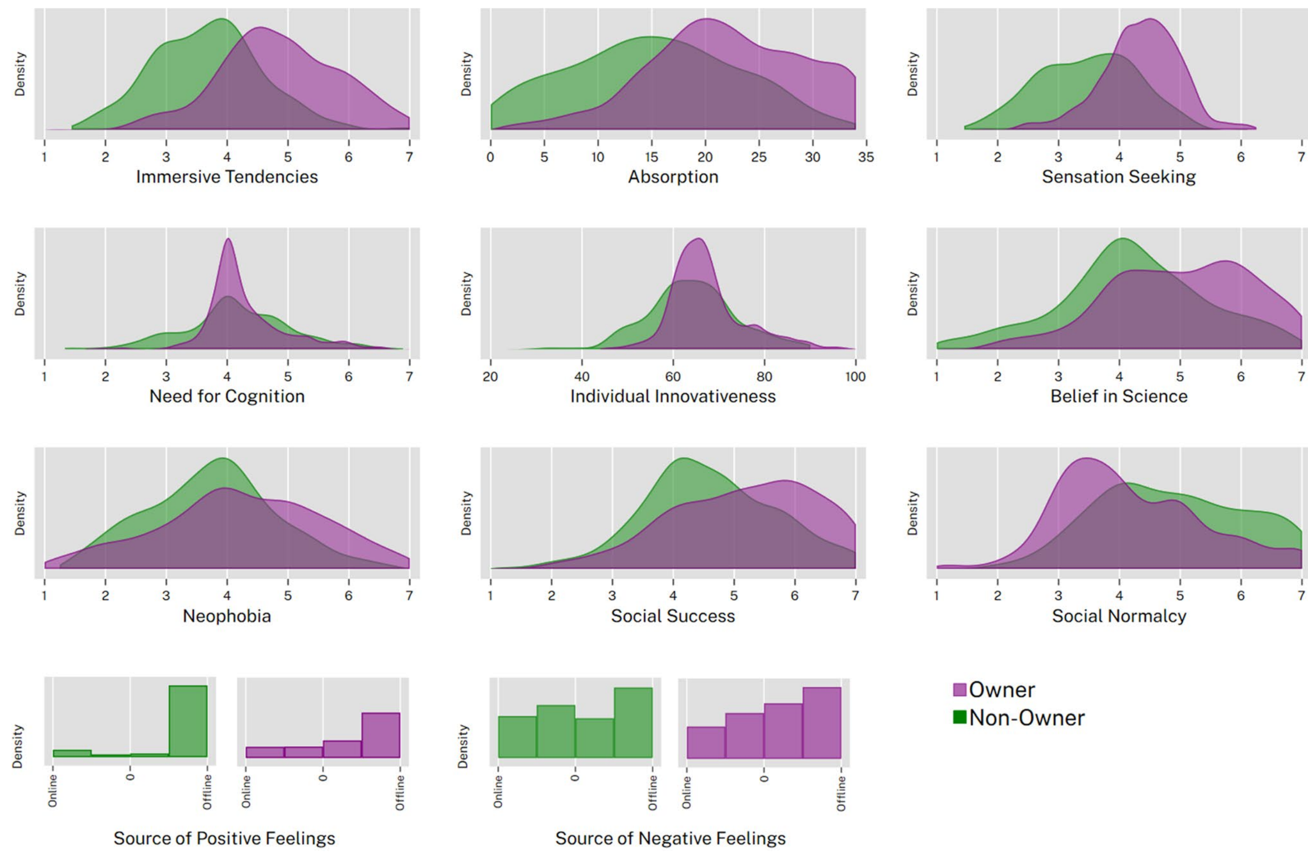

Fig. 1 Distributions of psychometric measures among owners and non-owners of VR devices

each of the candidate parameters is reported as the Bootstrap Inclusion Fraction (BIF).[3]

3 Results

3.1 Univariate analysis

3.1.1 Demographic measures

The mean age of respondents in the total sample ($N=1{,}005$) was 41.36 years ($SD=13.85$). The mean age among reported owners of VR hardware ($n=737$) was 36.97 years ($SD=11.86$), whereas the mean age of reported non-owners ($n=268$) was significantly higher ($M=53.43$, $SD=11.58$, $t(485.58)=19.79$, $p<.001$). Within the total sample, 48.65% of respondents ($n=487$) reported their gender as female, 50.75% ($n=508$) reported their gender as male, 0.60% ($n=6$) reported another gender, and 0.40% ($n=4$) did not report a gender. The ratio of female to male respondents was significantly lower among owners as compared to non-owners ($\chi^2(1)=24.30$, $p<.001$). See Table 2 for a complete reporting of gender and other demographic distributions across ownership categories.

3.1.2 Psychometric measures

Significant differences were identified between non-owners and owners of VR hardware across most psychometric variables measured.[4] On average, owners had significantly higher levels of immersive tendencies ($t(518.75)=16.37$, $p<.001$, $d=1.11$), absorption ($t(451.54)=10.30$, $p<.001$, $d=0.76$), sensation seeking ($t(406.19)=15.33$, $p<.001$, $d=1.20$), need for cognition ($t(382.27)=1.99$, $p=.047$, $d=0.16$), individual innovativeness ($t(402.89)=5.20$, $p<.001$, $d=0.41$),

[3] BIF ranges from 0 to 100 and can be used as a metric to assess the importance of a given parameter across bootstrap replications. A value of 50 indicates unstable or borderline estimates of significance, with parameters becoming more stable as the associated value of the BIF approaches 100.

[4] Levene's test was used to evaluate the assumption of homoscedasticity for comparisons between groups. As homoscedasticity could not be safely assumed for all comparisons ($\alpha=.05$), Welch's t test was used.

Table 2 Tabulation of demographic measures by device ownership

Variable	Value	Non-owner ($n = 268$)		Fixed ($n = 459$)		Mobile ($n = 360$)		Standalone ($n = 49$)		Total ($n = 1,005$)	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%
Gender	Female	163	61.05	181	39.61	173	48.19	13	27.08	487	48.65
	Male	100	37.45	275	60.18	186	51.81	34	70.83	508	50.75
	Other	4	1.50	1	0.22	0	0.00	1	2.08	6	0.60
	Not reported	1	0.37	2	0.44	1	0.28	1	2.04	4	0.40
Education	Did not complete	5	1.87	12	2.61	10	2.78	2	4.08	24	2.39
	High school	56	20.90	77	16.78	61	16.94	3	6.12	177	17.61
	Some college	75	27.99	110	23.97	93	25.83	12	24.49	265	26.37
	Bachelor's	83	30.97	147	32.03	121	33.61	15	30.61	326	32.44
	Master's	32	11.94	82	17.86	50	13.89	11	22.45	148	14.73
	Advanced graduate	15	5.60	31	6.75	25	6.94	5	10.20	62	6.17
	Not reported	2	0.75	0	0.00	0	0.00	1	2.04	3	0.30
Income	< $25,000	54	20.15	59	12.85	36	10.00	6	12.24	144	14.33
	$25,000–$34,999	21	7.84	46	10.02	35	9.72	3	6.12	99	9.85
	$35,000–$49,999	38	14.18	55	11.98	52	14.44	5	10.20	132	13.13
	$50,000–$74,999	53	19.78	101	22.00	94	26.11	11	22.45	224	22.29
	$75,000–$99,999	44	16.42	65	14.16	51	14.17	6	12.24	154	15.32
	$100,000–$149,999	35	13.06	84	18.30	60	16.67	11	22.45	159	15.82
	> $150,000	23	8.58	49	10.68	32	8.89	7	14.29	93	9.25

belief in science ($t(476.25) = 7.27$, $p < .001$, $d = 0.52$), neophobia ($t(574.45) = 4.27$, $p < .001$, $d = 0.28$), and social success ($t(516.37) = 5.22$, $p < .001$, $d = 0.36$) than non-owners. Owners also rated online friends and acquaintances as a more prominent source of positive feelings, compared to non-owners, who rated in-person friends and acquaintances more highly ($t(543.95) = 8.39$, $p < .001$, $d = 0.56$). Conversely, non-owners reported significantly higher levels of social normalcy ($t(464.21) = 6.76$, $p < .001$, $d = 0.49$). The distribution of psychometric measures among owners and non-owners is visualized in Fig. 1, below. Complete summary statistics of all psychometric measures by device ownership category are reported in Table 3.

3.2 Multivariate analysis

3.2.1 Measures predicting device adoption

A series of linear models were fit on measures of device adoption—operationalized as the interval between the public availability of a device class and the first reported acquisition of a device in that class—both for VR devices in general and for each device class (i.e., fixed, mobile, and standalone VR devices).

Gender was found to be a marginally significant predictor of device adoption, with male respondents adopting VR devices later than female respondents ($\beta = 0.113$, $p = .002$).[5] Age was also a factor, as older respondents reported adopting VR devices earlier ($\beta = -0.096$, $p = .009$). However, several psychometric factors were more determinative in the reduced model, with immersive tendencies predicting earlier adoption ($\beta = -0.204$, $p < .001$, BIF = 98.00), absorption ($\beta = 0.181$, $p < .001$, BIF = 99.54), and neophobia ($\beta = 0.095$, $p = .013$, BIF = 54.08) predicting later adoption, respectively. All model specifications for overall device adoption are reported in Table 4.

While neither gender nor age was a significant predictor for adoption of fixed VR devices, immersive tendencies did predict earlier adoption ($\beta = -0.213$, $p < .001$, BIF = 93.53), while absorption predicted later adoption ($\beta = 0.132$, $p = .006$, BIF = 81.13), similar to the pattern of adoption for VR devices overall. All model specifications for fixed device adoption are reported in Table 5.

A similar pattern was identified in the reduced model fit on adoption of mobile VR devices: Male respondents reported later adoption than female respondents ($\beta = 0.150$, $p = .004$), while older respondents reported earlier adoption ($\beta = -0.132$, $p = .011$). Immersive tendencies once again predicted earlier adoption dates ($\beta = -0.137$, $p = .019$, BIF = 66.09), while absorption predicted later adoption ($\beta = 0.199$, $p = .001$, BIF = 88.80). All model specifications for mobile device adoption are reported in Table 6.

The only significant predictor of adoption for standalone devices in the reduced model was a component of social well-being, as respondents who reported that in-person friends and acquaintances were a more prominent source of negative feelings compared to online contacts also reported later adoption of standalone VR devices ($\beta = 0.376$, $p = .010$, BIF = 79.81). All model specifications for standalone device adoption are reported in Table 7.

3.2.2 Measures predicting initial usage

An additional series of linear models were fitted on the reported level of average weekly usage in the first month of ownership for both VR devices in general and for each device class. The complete model for each class, containing all candidate predictors, was again reduced following the procedure described above.

Initial usage of VR devices was predicted at a statistically significant level by several psychometric factors: Immersive tendencies ($\beta = 0.170$, $p < .001$, BIF = 94.67) and absorption ($\beta = 0.112$, $p = .003$, BIF = 79.48) were associated with higher usage during the first month of ownership, while need for cognition was associated with lower usage ($\beta = -0.074$, $p = .040$, BIF = 52.38). Social factors also played a role, with social success predicting higher levels of initial usage ($\beta = 0.112$, $p = .005$, BIF = 73.08), and the tendency to perceive in-person friends as a more prominent source of emotional experiences (both positive and negative) than online friends predicting lower levels ($\beta = -0.140$, $p < .001$, BIF = 92.83; $\beta = -0.079$, $p = .026$, BIF = 65.45). All model specifications for overall initial usage of VR devices are reported in Table 8.

When considering only initial usage of fixed devices, the device owner's age emerged as a significant predictor, with older respondents reporting lower usage ($\beta = -0.101$, $p = .029$). Consistent with the findings for VR devices in general, higher usage was associated with a greater tendency toward absorption ($\beta = 0.112$, $p = .017$, BIF = 60.04) and social success ($\beta = 0.116$, $p = .016$, BIF = 33.48), and negatively associated with a tendency to perceive in-person friends as more prominent sources of positive emotional experiences when compared with online friends ($\beta = -0.111$, $p = .022$, BIF = 42.62). This relationship was not statistically significant when considering negative experiences; however, it should be noted that all of the social parameters in the reduced model showed low stability in bootstrap testing (BIF < 50), and so the inclusion or exclusion of particular elements of respondents' social well-being should be

[5] All reported beta values are standardized as several predictors were measured on different scales, and the comparison between the contributions of predictor variables is of analytic interest to this study.

Table 3 Tabulation of aggregate psychometric measures by device ownership

Scale	Non-owner		Fixed		Mobile		Standalone	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Immersive tendencies	3.70	0.94	4.84	1.03	4.95	0.98	4.66	1.23
Absorption	15.32	8.50	21.70	7.88	21.52	8.04	22.71	8.01
Sensation seeking	3.49	0.82	4.37	0.65	4.40	0.66	4.24	0.74
Need for cognition	4.16	0.93	4.26	0.69	4.33	0.70	4.14	0.62
Belief in science	4.18	1.35	4.90	1.34	5.02	1.31	4.49	1.60
Neophobia	3.80	1.19	4.26	1.45	4.10	1.44	4.86	1.35
Individual innovativeness	63.85	10.69	67.58	8.82	67.77	8.36	65.48	7.57
SWB [social success]	4.53	1.26	5.08	1.37	5.09	1.28	4.61	1.52
SWB [normalcy feelings]	4.81	1.32	4.17	1.26	4.22	1.26	3.82	1.29
SWB [positive source][a]	0.72	0.58	0.31	0.66	0.44	0.62	0.09	0.74
SWB [negative source][a]	0.12	0.77	0.20	0.72	0.24	0.70	– 0.01	0.77

[a]Sources of positive and negative feelings were measured on a scale from online to in-person, with higher scores representing a tendency towards the latter

Table 4 Linear models for overall device adoption[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.112**	−0.094*	−0.096**	N/A
Gender [male]	0.094*	0.117**	0.113**	N/A
Immersive tendencies		−0.171***	−0.204***	98.00
Absorption		0.189***	0.181***	99.54
Sensation seeking		−0.025		11.90
Need for cognition		−0.018		10.78
Belief in science		−0.033		14.61
Neophobia		0.086	0.095*	54.08
Individual innovativeness		−0.002		6.98
SWB [social success]		−0.030		16.19
SWB [normalcy feelings]		−0.004		10.04
SWB [positive source]		−0.006		7.57
SWB [negative source]		−0.025		8.86
Model R^2	.022	.077	.072	
Adjusted R^2	.020	.060	.066	
AIC	5873.9	5853.9	5841.3	

[a]All model coefficients are standardized. *$p < .05$; **$p < .01$; ***$p < .001$

Table 5 Linear models for fixed device adoption[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.015	−0.009	−0.021	N/A
Gender [male]	0.041	0.072	0.066	N/A
Immersive tendencies		−0.195***	−0.213***	93.53
Absorption		0.154**	0.132**	81.13
Sensation seeking		−0.015		9.58
Need for cognition		−0.066		22.74
Belief in science		−0.001		4.61
Neophobia		0.045		14.92
Individual innovativeness		0.024		7.75
SWB [social success]		−0.095		36.18
SWB [normalcy feelings]		−0.006		9.83
SWB [positive source]		0.073		21.24
SWB [negative source]		−0.030		8.71
Model R^2	.002	.064	.049	
Adjusted R^2	−.002	.037	.040	
AIC	3601.0	3593.7	3583.2	

[a]All coefficients are standardized. *$p < .05$, **$p < .01$, ***$p < .001$

interpreted with caution. All model specifications for initial fixed device usage are reported in Table 9.

Neither age nor gender was a significant predictor of initial usage of mobile devices in the reduced model. Greater usage was associated with immersive tendencies ($\beta = 0.201$, $p < .001$, BIF = 83.47), consistent with the findings for VR devices in general, and the perception of in-person friends as more prominent sources of positive emotional experiences was likewise associated with lower levels of usage ($\beta = -0.162$, $p = .002$, BIF = 82.50). All model specifications for mobile device usage are reported in Table 10.

In contrast to the models fit for predicting adoption, usage of standalone devices in the first month of ownership was observed to be closely associated with psychometric factors ($R^2_{adj} = .411$). Absorption ($\beta = 0.302$, $p = .012$, BIF = 56.00), sensation seeking ($\beta = 0.352$, $p = .013$, BIF = 60.73), and neophobia ($\beta = 0.380$, $p = .004$, BIF = 52.83) were all strong predictors of higher levels of initial usage in the reduced

Table 6 Linear models for mobile device adoption[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.130*	−0.107	−0.132*	N/A
Gender [male]	0.129*	0.144**	0.150**	N/A
Immersive tendencies		−0.167*	−0.137*	66.09
Absorption		0.206***	0.199***	88.80
Sensation seeking		−0.012		4.89
Need for cognition		0.071		7.79
Belief in science		0.066		19.62
Neophobia		0.076		27.57
Individual innovativeness		−0.068		14.42
SWB [social success]		−0.037		11.94
SWB [normalcy feelings]		−0.002		4.64
SWB [positive source]		−0.015		7.10
SWB [negative source]		−0.007		5.47
Model R^2	.035	.084	.069	
Adjusted R^2	.030	.049	.058	
AIC	2874.2	2877.7	2865.6	

[a]All coefficients are standardized. *$p<.05$; **$p<.01$; ***$p<.001$

Table 7 Linear models for standalone device adoption[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	0.018	−0.015	0.035	N/A
Gender [male]	−0.219	−0.156	−0.133	N/A
Immersive tendencies		0.172		20.58
Absorption		-0.087		14.32
Sensation seeking		0.043		10.67
Need for cognition		−0.109		9.62
Belief in Science		0.246		17.83
Neophobia		−0.554*		60.90
Individual innovativeness		0.261		43.44
SWB [social success]		0.051		9.86
SWB [normalcy feelings]		0.205		13.68
SWB [positive source]		-0.343		40.10
SWB [negative source]		0.539**	0.376*	79.81
Model R^2	.049	.386	.183	
Adjusted R^2	.006	.152	.127	
AIC	315.3	316.3	310.0	

[a]All coefficients are standardized. *$p<.05$; **$p<.01$; ***$p<.001$

model. Conversely, and uniquely among all the models fit, need for cognition was associated with lower initial usage ($\beta=-0.273$, $p=.042$, BIF = 49.02). It should be noted, however, that despite the strength of the associations observed in the reduced model, the selection of predictors for standalone device usage was relatively unstable compared to other device classes. All model specifications for standalone device usage are reported in Table 11.

3.2.3 Measures predicting change in use

The direction of change in usage following the first month of ownership was predicted using a series of multinomial logistic regression models for VR devices in general and for fixed devices only, with *no change* serving as the base level. Parameter selection was performed in a similar fashion to the models described above, with the exception that candidate parameters were retained in the reduced model when the threshold for statistical significance was reached for coefficients associated with either of the possible non-base values

Table 8 Linear models for overall initial device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.094*	−0.050	−0.059	N/A
Gender [male]	0.051	−0.004	0.002	N/A
Immersive tendencies		0.147***	0.170***	94.67
Absorption		0.102**	0.112**	78.48
Sensation seeking		0.065		34.37
Need for cognition		−0.080	−0.074*	52.38
Belief in science		−0.026		7.16
Neophobia		0.039		16.90
Individual innovativeness		0.011		9.33
SWB [social success]		0.104*	0.112**	73.08
SWB [normalcy feelings]		0.005		7.49
SWB [positive source]		−0.134***	−0.140***	92.83
SWB [negative source]		−0.082*	−0.079*	65.45
Model R^2	.012	.131	0.127	
Adjusted R^2	.009	.115	0.117	
AIC	7484.8	7413.0	7406.2	

[a]All coefficients are standardized. *$p<.05$; **$p<.01$; ***$p<.001$

Table 9 Linear models for initial fixed device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.101*	−0.091	−0.101*	N/A
Gender [male]	−0.008	−0.050	−0.027	N/A
Immersive tendencies		0.067		33.08
Absorption		0.103*	0.112*	60.04
Sensation seeking		0.026		17.23
Need for cognition		−0.092		36.91
Belief in science		0.030		11.70
Neophobia		−0.052		9.29
Individual innovativeness		−0.009		10.17
SWB [social success]		0.067	0.116*	33.48
SWB [normalcy feelings]		0.023		8.74
SWB [positive source]		−0.092	−0.111*	42.62
SWB [negative source]		−0.082		50.02
Model R^2	.010	.065	.046	
Adjusted R^2	.006	.037	.036	
AIC	4537.9	4533.9	4526.8	

[a]All coefficients are standardized. *$p<.05$; **$p<.01$; ***$p<.001$

of the dependent variable (i.e., negative or positive change in usage). No candidate parameters were retained in the reduced models for either mobile or standalone devices, and so these sets of models have been omitted from reporting.

After controlling for demographic factors, absorption and belief in science were the only significant predictors retained in the reduced model: Absorption was associated with an increased likelihood of both negative and positive change in use over time ($RRR=1.047$, $p=.011$, BIF = 49.32; $RRR=1.040$, $p=.015$, BIF = 49.32), while belief in science was associated with a decreased likelihood of negative change ($RRR=0.724$, $p=.005$, BIF = 92.75). All model specifications for change in overall VR device usage are reported in Table 12.

The above patterns were also consistent when the models were limited to owners of fixed VR devices: Absorption remained associated with an increased likelihood of both negative and positive change in use of these devices over time ($RRR=1.063$, $p=.002$, BIF = 70.99; $RRR=1.058$, $p=.011$, BIF = 70.99), and belief in science predicted a decreased likelihood of negative change ($RRR=0.751$,

Table 10 Linear models for initial mobile device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.029	0.012	0.010	N/A
Gender [male]	0.004	−0.019	−0.018	N/A
Immersive tendencies		0.165*	0.201***	83.47
Absorption		0.068		22.47
Sensation seeking		0.016		5.78
Need for cognition		−0.098		27.38
Belief in science		−0.100		30.92
Neophobia		0.025		8.66
Individual innovativeness		0.071		14.41
SWB [social success]		0.063		17.78
SWB [normalcy feelings]		−0.047		14.74
SWB [positive source]		−0.150**	−0.162**	82.50
SWB [negative source]		−0.080		37.29
Model R^2	.001	.109	.082	
Adjusted R^2	−.005	.076	.071	
AIC	3555.0	3535.8	3528.7	

[a]All coefficients are standardized. *$p<.05$; **$p<.01$; ***$p<.001$

$p=.041$, BIF = 81.84). All model specifications for change in fixed device usage are reported in Table 13.

4 Discussion

Past research on factors influencing the adoption of new media technologies has historically focused on attributes of the technologies themselves, as well as differences in users' openness to innovation. Building off of the initial uses and gratifications theory provided by Katz et al. (1973), the U&G 2.0 framework suggests that key affordances of new media technologies may uniquely relate to specific user needs, affecting individual levels of media exposure and usage in turn (Sundar and Limperos 2013). The present study examined how psychological factors relevant to the unique technological and experiential affordances of VR—particularly immersion, mental absorption, heightened sensation, and escapism—may explain rates of mainstream adoption and usage over time. Acknowledging that substantive differences exist between devices with respect to these affordances—especially in terms of computational resources, tracking capabilities, and freedom of movement—these outcomes were also separately evaluated for different classes of VR device.

4.1 Key findings

The results of this study point toward the salience of a number of predictors for three outcome measures of owner engagement with mainstream VR technology—time of acquisition, initial usage, and change in usage—across three classes of device—fixed, mobile, and standalone—as well as for VR devices in general. While demographic factors (age and gender) were found to play a role in the timing of the initial acquisition of VR hardware, psychological factors generally emerged as more determinative in testing and consistently yielded improvements in performance when compared against the demographic-only control models.

In line with the uses and gratification theoretical framework, the current study observed that likelihood to adopt and use consumer-level VR technologies varies in light of particular psychological dispositions. A wide range of potential psychometric predictors were measured and evaluated, based on the prior literature; from these, a select few, including absorption, belief in science, and social well-being measures, were consistently included in the reduced models predicting adoption and initial usage. This finding was supported through bootstrap testing, which illustrated the differences in model stability in terms of the inclusion of each candidate measure. As might be expected, those features that were consistently included across the reduced models for different device classes were also relatively more stable within each model.

Immersive tendencies were a consistent predictor of earlier adoption of VR technology device classes, while absorption was consistently associated with later adoption. Both of these features also predicted higher levels of initial usage overall, although when different device classes were considered, absorption was uniquely associated with the use of fixed and standalone devices, while immersive tendencies were associated only with mobile

Table 11 Linear models for initial standalone device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Age	−0.030	−0.032	0.066	
Gender [male]	0.104	−0.029	−0.008	
Immersive tendencies		0.230		35.78
Absorption		0.241	0.302*	56.00
Sensation seeking		0.326	0.352*	60.73
Need for cognition		−0.373*	−0.273*	49.02
Belief in science		−0.023		29.24
Neophobia		0.281	0.380**	52.83
Individual innovativeness		0.246		35.60
SWB [social success]		−0.108		25.39
SWB [normalcy feelings]		0.145		26.26
SWB [positive source]		−0.075		30.12
SWB [negative source]		−0.125		18.78
Model R^2	.012	.564	.487	
Adjusted R^2	.032	.397	.411	
AIC	484.1	466.8	460.7	

[a]All coefficients are standardized. *$p < .05$, **$p < .01$, ***$p < .001$

devices. This finding may indicate that even closely related psychological traits, such as the propensity for absorption as opposed to presence, may have differential relationships to the affordances of particular VR devices. Note, for instance, that in this case, the tendency toward absorption seems more closely linked with use of devices that offer a higher degree of sensory fidelity. Neophobia was also associated with later adoption overall, although the low stability (BIF = 54.08) relative to other included predictors, and lack of inclusion in class-specific reduced models suggests that a lower degree of confidence should be placed in the salience of this predictor.

Alongside these relationships with psychological traits, respondents' self-perception of their social situation was also indicated as playing a role in the initial usage patterns of VR devices. Generally, the perception of in-person contacts as a more prominent source of emotion relative to online friends consistently predicted lower levels of usage—as might be expected for a technology capable of facilitating online social interactions, as well as occluding face-to-face interaction. The self-perception of being socially successful was also associated with higher initial usage both in general and for fixed devices in particular, although the salience of social factors as they apply to particular classes of VR devices should not be assumed, given their inconsistent inclusion and lower stability in the class-specific reduced models.

Notably, while not being strongly associated with initial usage, belief in science emerged as one of the only salient factors predicting change in usage after the first month of device ownership, suggesting a relationship between this trait and more stable usage patterns, as those with a higher belief in science appeared potentially more resistant to declines in usage over time, particularly for fixed devices. This observation may be related to the higher level of technological literacy and perceived self-efficacy generally required to setup and maintain these devices, which also require the user to own either a relatively powerful computer or a dedicated gaming console. Conversely, absorption—which consistently predicted higher initial usage of fixed and standalone devices, as well as of VR devices overall—also appeared to be associated with instability in usage patterns over time (i.e., likelihood of change in overall usage and use of fixed devices in both positive and negative directions). It may be that owners who are more susceptible to absorption are also more particular in terms of the types of immersive experiences they demand from their VR hardware and thus, are more likely to either grow attached to content that meets those needs or to disengage from content that fails to satisfy them. This interpretation, while speculative, would be consistent with the theoretical orientation of absorption—in contrast with related concepts such as *presence*—toward non-mediated experiences such as hypnosis (Glisky et al. 1991) and autonomous sensory meridian response (Janik McErlean and Osborne-Ford 2020). Additionally, need for cognition was found to be negatively associated with initial device usage, though only in the case of standalone devices. Considering its borderline BIF, this finding should be interpreted with caution. However, taken at face value, this might be interpreted as standalone devices—which do not require any interfacing with other computing devices or sensors for setup or use—being attractive to individuals that are intrigued by VR yet who are otherwise deterred by the technical effort required for using fixed or mobile devices.

Table 12 Multinomial logit models for direction of change in overall device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Negative change				
Age	1.000	0.999	0.997	N/A
Gender [male]	0.707	0.751	0.786	N/A
Immersive tendencies		1.056		14.81
Absorption		1.029	1.040*	49.32
Sensation seeking		1.153		23.72
Need for cognition		1.057		8.82
Belief in science		0.614***	0.724**	92.75
Neophobia		1.271*		39.46
Individual innovativeness		1.014		14.25
SWB [social success]		1.171		40.91
SWB [normalcy feelings]		1.036		6.67
SWB [positive source]		0.994		19.58
SWB [negative source]		1.078		14.34
Positive change				
Age	1.008	1.008	1.008	N/A
Gender [male]	0.811	0.814	0.859	N/A
Immersive tendencies		1.037		14.81
Absorption		1.037	1.047*	49.32
Sensation seeking		0.959		23.72
Need for cognition		1.180		8.82
Belief in science		0.718*	0.835	92.75
Neophobia		1.212		39.46
Individual innovativeness		1.006		14.25
SWB [social success]		1.282		40.91
SWB [normalcy feelings]		1.034		6.67
SWB [positive source]		0.829		19.58
SWB [negative source]		0.988		14.34
Pseudo-R^2	.003	.028	.017	
AIC	1223.0	1236.1	1213.7	

[a] All estimates are displayed as Relative Risk Ratios (RRR). *$p < .05$, **$p < .01$, ***$p < .001$

Table 13 Multinomial logit models for direction of change in fixed device usage[a]

Parameter	Control model	Complete model	Reduced model	BIF
Negative change				
Age	1.016	1.007	1.012	N/A
Gender [male]	0.623	0.807	0.675	N/A
Immersive tendencies		1.331		38.44
Absorption		1.063**	1.063**	70.99
Sensation seeking		0.760		39.28
Need for cognition		0.746		12.06
Belief in science		0.698*	0.751*	81.84
Neophobia		1.117		8.68
Individual innovativeness		1.039		20.45
SWB [social success]		1.009		9.63
SWB [normalcy feelings]		1.356		50.47
SWB [positive source]		1.043		12.02
SWB [negative source]		1.002		27.08
Positive change				
Age	1.023	1.014	1.022	N/A
Gender [Male]	0.702	0.923	0.698	N/A
Immersive tendencies		1.177		38.44
Absorption		1.070**	1.058*	70.99
Sensation seeking		0.540		39.28
Need for cognition		0.889		12.06
Belief in science		0.928	0.932	81.84
Neophobia		1.134		8.68
Individual innovativeness		1.038		20.45
SWB [social success]		1.023		9.63
SWB [normalcy feelings]		1.516*		50.47
SWB [positive source]		0.910		12.02
SWB [negative source]		0.791		27.08
Pseudo-R^2	.005	.053	.028	
AIC	779.8	786.9	770.4	

[a] All estimates are displayed as Relative Risk Ratios (RRR). *$p < .05$, **$p < .01$, ***$p < .001$

Several significant relationships were also observed between standalone device usage and psychometrics measures not included in reduced models for usage of other devices—namely sensation seeking and neophobia. However, given the small sample size and relative instability of this model (see Table 11), those relationships should be interpreted with caution.

4.2 Limitations and future directions

There are several limitations inherent in the methodology deployed for this study: Initial levels of usage for particular VR devices were measured using retrospective self-reporting, and the reliability of these measurements may therefore be affected by the ability of respondents to accurately remember their behavior several months after the fact. Future studies specifically focused on patterns of device usage over time may prefer to form a panel of owners at the time of adoption and collect data longitudinally.

Guided by the uses and gratifications theoretical framework, this study identified and evaluated psychological traits likely to predict gratifications experienced through the use of consumer-level VR technology. However, we did not directly measure users' specific gratifications; rather, gratification is presumed in the adoption and continued use of the technology. To confirm the causal mechanisms, future work should directly assess the gratifications that users experience with VR. This would permit insights into whether particular gratifications indeed differentially predict adoption and usage, as well as whether the failure of technology to provide expected gratifications during initial usage predicts change in usage.

As the uses and gratifications perspective is typically applied to the media selections of individual users, the current study focused on the dynamics of personal rather than institutional VR adoption and usage. Further research should separately consider mitigating factors beyond user traits that may influence the relative uptake and incorporation of VR technologies in professional business, education, and research settings. That said, at the level of personal consumer behaviors, this study examined VR as a relatively uniform technology, with some differentiation with respect to fixed, mobile, and standalone platforms. While VR as a whole may generally afford certain gratifications compared to more traditional media formats, future research should consider how gratifications—and, in turn, adoption and change in use—may be tied to the particular applications and content types (e.g., health, business, education, and entertainment) individual users engage with via these platforms.

At the time of the second wave of data collection, relatively few respondents reported owning a standalone VR headset ($n=49$), which limits the conclusions that can be drawn regarding patterns of device adoption and usage based on this sample. This is noteworthy, given the expanding significance of this device class within the VR device ecosystem at time of writing, as evidenced by the popularity of the Oculus Quest 2 headset (Chang 2021). As such, future studies will likely place greater emphasis on this device class than was possible at present.

The second wave of data collection took place during the COVID-19 pandemic, at a time when some respondents may have been facing heightened isolation as a result of public health measures or may have had greater free time due to being laid off or furloughed. To address these potentially confounding factors, respondents in the second wave were asked to report levels of usage both at the time of reporting and for an equivalent period in January 2020, prior to the spread of COVID-19 to the USA. As no statistically significant differences were identified between measures of pre-pandemic and current usage, the latter was used for the purposes of calculating change in usage within this sample. Nevertheless, future replication will be required to determine whether these patterns of use can be generalized to a post-pandemic context.

Additionally, multiple psychometric predictors were considered and included in the complete models fit as part of the selection protocol for this study, which was justified by the exploratory nature of the research and the desire to address a wide range of potentially relevant theoretical frameworks. While the potential for spurious parameter selection was partially addressed through the use of bootstrap resampling, the relationships identified should nonetheless be confirmed through replication using a more constrained model containing only those predictors that show a high potential for relevance based on the results of this study.

Finally, while the current study's classification of devices as fixed, mobile, and standalone provided some consideration of the diversity of VR technologies currently available, its intended focus was on human factors, examining how psychological traits may independently and uniquely predict VR consumer behavior compared to demographic variables. Building on the current findings, future work might consider how finer distinctions in device technology—including specific features such as FOV, latency, resolution, or input mechanisms—different types of content experiences—such as gaming, work, or virtual social spaces—and user traits jointly predict patterns of adoption and usage.

4.3 Conclusions

Despite these limitations, the present study nevertheless meaningfully contributes to the current state of understanding regarding the relationship between individual psychological traits and patterns of real-world adoption and usage of VR technology. Differences in these traits are shown to affect the motivation of individual users to seek out and spend time on immersive virtual experiences, with direct implications for the future of VR as a mainstream consumer-facing technology. Furthermore, it appears that different classes of VR hardware, with their attendant differences in technological capacity, interaction accessibility, and sensory fidelity, may appeal differentially based on the psychological profile of the user, reinforcing the link between technological affordances and individualized psychological needs.

Without a deeper understanding of the reasons why individuals choose to acquire and make use of VR devices, the effectiveness of interventions and other campaigns using this technology will be necessarily limited. Analysts have remarked on the slow uptake of VR technology by consumers—although it is worth noting that adoption has also been constrained, at times, by limited supply—indicating a possible enthusiasm gap between the range of possible applications touted by VR researchers and producers, on the one hand, and prospective users, on the other (Laurell et al. 2019; Jenkins 2019). By addressing the psychological dispositions of VR owners, this study provides some measure of groundwork for designers of immersive virtual experiences—in academia and in industry—to target their output more narrowly and effectively toward individuals who are more likely to engage with it. As exploratory, translational research, the present study helps to address the gap between the carefully controlled laboratory studies of immersive virtual experiences carried out in the disciplines of media psychology and human–computer interaction, and the more complex, in situ experiences of real-world users. The recognition of VR as an activity that is selected by users and motivated by their psychological needs is a precursor to greater ecological validity within the field, as well as a bridge from existing theories to more applied work.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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