The Psychological Structure of Interaction Naturalness and Its Effects

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Abstract

This paper investigates the psychological structure of interaction naturalness and its effects through three studies. Study 1 developed an initial scale containing 9 items through dictionary search, literature review, and expert interviews. Study 2 surveyed 353 intelligent connected vehicle users, and exploratory factor analysis revealed a two-factor structure ("Fluent Accessibility" and "Adaptive Responsiveness"). Subsequent analyses demonstrated that these two factors have significant unique predictive effects on key criteria such as satisfaction. Study 3 used a new sample (n = 349) to validate the stability of the two-factor model, and also found that these two dimensions of interaction naturalness experience have significant predictive effects on important variables such as recommendation intention and loyalty. Additionally, it was found that Fluent Accessibility is more influenced by functions such as basic driving assistance systems, while Adaptive Responsiveness is more influenced by interaction and intelligence-related functions. This paper further discusses how this scale can be used in future human-computer interaction research.

Full Text

The Psychological Structure and Influence of Interactive Naturalness

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Abstract

This paper investigates the psychological structure of interactive naturalness and its effects through three studies. Study 1 developed an initial 9-item scale through dictionary searches, literature review, and expert interviews. Study 2 surveyed 353 intelligent connected vehicle users, with exploratory factor analysis revealing a two-factor structure ("joyful fluency"and "universal awareness"). Subsequent analyses demonstrated that these two factors significantly and uniquely predicted key criteria such as satisfaction. Study 3 validated the stability of the two-factor model using a new sample (n = 349) and found that these two dimensions of interactive naturalness experience also significantly predicted important variables including recommendation intention and loyalty. Additionally, the results showed that joyful fluency was more influenced by basic driving assistance functions, while universal awareness was more influenced by interaction- and intelligence-related functions. This paper further discusses how the scale can be applied in future human-computer interaction research.

Keywords: Interactive naturalness, Intelligent connected vehicles, Psychological structure, Usability

1. Introduction

Human-computer interaction has evolved from command-line interfaces reliant on keyboard input, to graphical interfaces heavily utilizing the mouse, and further to current novel interaction modalities (such as gesture interaction, voice interaction, somatosensory interaction, and intelligent interaction). For these interaction methods that seemingly align more closely with human instincts, industry and HCI scholars often refer to them directly as natural human-computer interaction, with interfaces employing such methods typically called Natural User Interfaces (NUI).

But are so-called natural interactions truly natural? Norman (2010) answers this question negatively, arguing that so-called natural interactions are not necessarily natural. Taking gesture interaction, which is expected to become an important future interaction modality, as an example: although gesture interaction can provide more comprehensive and humanistic interaction compared to traditional keyboard and mouse, most gestures are neither innate nor easy to learn and remember (Grandhi et al., 2011). Like gestures, voice interaction or somatosensory interaction also requires specific physical activities to express interaction intentions (Hsiao, 2017). In this process, the difference between well-designed and poorly designed interaction interfaces is substantial, affecting sense of control (Verberne et al., 2012), sense of convenience (Kamide et al., 2012; Li & Yeh, 2010; Zhou, 2011), and even pleasure (Norman & Nielsen, 2010). Beyond experiential differences in use, these factors may also influence users' purchase intentions (Moons & De, 2015), loyalty, and recommendation willingness (Black et al., 2015; Grandhi et al., 2011; Rajendran & Jayakrishnan, 2018).

As can be seen in the above discussion, the "natural" in natural human-computer interaction refers to the adoption of certain "intuitive" and "instinctive" novel interaction methods (Grandhi et al., 2011). When distinguishing whether an interaction system is natural, the key lies in whether the system can shorten users' learning time, reduce mental workload, and increase more pleasant emotional experiences (Zhang & Zhang, 2018). To achieve such standards, the interaction process should conform to the laws of human information processing models during information exchange between humans and devices. Specifically, during "input," different interaction modalities should conform to basic perceptual organization principles, be based on users' existing knowledge representations, and reasonably guide users' attention allocation. During "output," the system should provide users with timely feedback and warnings, and the interaction interface should consider the dynamic changes in users' information processing throughout the entire interaction process, adjusting the system model to match users' mental models. In other words, when users input and output through natural interaction channels, they should not only focus on the interface fusion mechanism of the interaction modality itself but also improve the compatibility between the interface and memory decision-making, achieving and optimizing an interaction path that matches context-psychology-channel (Shi, 2018). Therefore, when evaluating "whether this interaction experience is natural," the focus should no longer be limited to specific products, interaction methods, and interface features, but should shift to human-centered experience —whether users feel natural when using products and interacting with interfaces (Jain et al., 2011; Wigdor & Wixon, 2011)—and whether the system conforms to the cognitive mechanisms of natural interaction mentioned above. This can be called perceived naturalness or natural experience. With the rapid development of new interaction technologies, new development standards and corresponding evaluation methods are becoming increasingly important (Norman, 2010), and perceived naturalness or natural experience should become an important evaluation content of natural human-computer interaction.

However, how exactly should we evaluate the degree of perceived naturalness? In fact, most studies use traditional "usability" dimensions to measure the experience of natural interaction methods (Agarwal et al., 2013; Bailey et al., 2018; Bassano et al., 2020; Falcao et al., 2015; Kharoub et al., 2019; Vallejo et al., 2016; Villaroman et al., 2011), such as visibility emphasized in traditional graphical interaction (Chuah et al., 2016), usability (Brooke, 1996), ease of use (Kamide et al., 2012; Li & Yeh, 2010; Zhou, 2011), fluency (Hsiao, 2017), learnability (Brooke, 1996; Lewis, 1992; Norman & Nielsen, 2010; Roupe et al., 2014), pleasure (Urakami et al., 2020), and cross-context consistency (Biever et al., 2020; Liljamo et al., 2018) to "correspond" to perceived naturalness.

But are these traditional usability standards equivalent to naturalness? First, starting from the concept of usability itself, usability mainly measures the basic characteristic of whether users can make the product work, generally including three dimensions: effectiveness, satisfaction, and efficiency (Kortum & Bangor, 2013). If naturalness simply equals usability, then many traits beyond product usability cannot be measured. Furthermore, Norman (2010) believes that usability may only be a prerequisite for the naturalness experience—without usability, there is certainly no naturalness, but being sufficiently usable does not necessarily mean being natural. More fundamentally, is naturalness the sum of these characteristics? Existing research cannot answer this question.

Some studies have begun to preliminarily explore direct measurement of naturalness. For example, Almeida et al. (2019) used a single item to measure naturalness when evaluating the experience of an immersive reality electronic glove: "How natural do you think the interaction with the virtual reality environment is?" The results showed that gloves with more freedom of movement, higher usability, and greater immersion provided better naturalness experiences. Research measuring gesture sensors also concluded that fluency is a key factor affecting natural experience (Hsiao, 2017). Some researchers have used a user-centered approach to determine natural gestures for common computer operations and standardize a natural gesture vocabulary library (Bailey & Johnson, 2020), using a 6-point rating scale from "completely arbitrary" to "completely natural" when evaluating gesture naturalness. In voice interaction, some researchers have measured whether users can perceive the "humanity" of chatbots to determine whether the interaction is natural (Atiyah et al., 2019). The results showed that chatbots with higher humanity scores received higher naturalness experience ratings from users. Similarly, Urakami et al. (2020) used pleasure to measure voice naturalness.

Using "natural" or synonyms of "natural" to measure perceived naturalness is certainly a very direct approach. However, measuring with a single item is not a reliable method, even from a psychometric perspective. At the same time, different individuals may have difficulty reaching a unified understanding of naturalness experience in interaction, creating the possibility that the content measured in different studies is actually completely different. More importantly, these studies still fail to answer the most core question: For users, what is natural interaction, what components does it include, and does a stable structure exist? If such a structure exists, do different components produce different effects? To answer these questions, the structural composition and mechanism of action of the psychological construct of interactive naturalness must be explored systematically.

To fill this gap, this study attempts to construct and validate a conceptual framework for interactive naturalness experience through systematic psychometric methods. It mainly includes three steps: First, Study 1 will use qualitative research methods, combining dictionary searches, literature reviews, and expert interviews to establish a comprehensive and representative item set for interactive naturalness, clarifying the conceptual network that interactive naturalness may include. Second, based on the items obtained in Study 1, Study 2 will use quantitative research methods to examine the factor structure formed by these items and conduct validity verification in conjunction with intelligent connected vehicle experiences and key consumer behaviors. Intelligent connected vehicles were chosen as the first validation object because such new vehicles represent an important application scenario for natural interaction and represent the development direction of natural interaction (Brunswicker & Chesbrough, 2018; Kuang et al., 2019; Pütz et al., 2019; Xu, 2019; Zhou et al., 2020). Third, Study 3 will use a new sample and more criterion variables to further validate the above findings, ensuring that the developed measurement tool has reliability, validity, and generalizability.

2. Study 1: Item Development

2.1 Research Objective

To establish a comprehensive and representative item pool for interactive naturalness through qualitative research.

2.2 Methods

2.2.1 Dictionary Definition Search First, we explored the multiple construct possibilities of interactive naturalness from different word definitions. We searched for different roots of naturalness in commonly used English dictionaries, such as "nature, naturality, natural, naturally," using the Oxford Advanced Learner's Dictionary (4th edition), Merriam-Webster's Dictionary (3rd edition), and Wikipedia. In Chinese dictionaries (i.e., Modern Chinese Dictionary 7th edition), we searched for "自然, 自然的, 自然地."

2.2.2 Literature Review and Summary We searched Google Scholar and Web of Science for literature related to interactive naturalness from 1990–2021. The search keywords were [nature (OR) Human-computer interaction], [natural (OR) user interface], [natural interaction], [naturalness (OR) interactive scale]. The search yielded 287 documents, with 5 additional expert-recommended documents, forming a literature pool of 292 documents. After screening titles and abstracts, 105 documents were removed, and 187 full-text documents were read. Based on full-text review, 139 documents were removed. Literature exclusion criteria included: (1) patents and conference abstracts; (2) pure algorithm/technical improvement studies, animal studies, and other research unrelated to interactive naturalness in human-computer interaction; (3) incomplete data reporting. A total of 48 core documents were retained.

2.2.3 Expert Interviews Semi-structured in-depth interviews were conducted, with each interview lasting 30–60 minutes. Six experts in interaction design and engineering psychology and two senior product managers (5 males, 3 females) were invited. They had worked in user experience and human-computer interaction for many years and could fully express their views on natural interaction and interaction experience. The interviews mainly asked about interviewees' understanding and definitions of interactive naturalness, such as "Please describe your definition and concept of human-computer interaction naturalness, your understanding of interactive naturalness, and when did you first hear about it?" The items already formed from dictionary and literature reviews were carefully examined, and items that were difficult to understand, ambiguous, or similar in meaning were modified, merged, or deleted. Wording was also rated and optimized.

2.3 Results

Table 1. Interactive Naturalness Items from Qualitative Research

Item and Description	Interview Mention Frequency
Expectation Consistency: Naturally: From Oxford Advanced Learner' s Dictionary (4th edition), Modern Chinese Dictionary (7th edition). The usage method of this system is consistent with expectations.	62.5%
Human-like Interaction: Interaction with this system is as natural as interacting with people.	87.5%
Pleasant Experience: When I use this system, I feel pleasant.	75.0%
Contextual Appropriateness: The system can make appropriate responses according to the current situation.	50.0%
Operational Fluency: Users operate in their own way without interruption, experiencing the fluency of operation.	87.5%
Universal Accessibility: Anyone (including children) can use this system freely.	62.5%
Smooth Process: The overall process of using the in-vehicle system feels smooth and not abrupt.	75.0%
Ease of Learning: It is easy to learn various functions of the system without seeking help from others.	100%

Item and Description	Interview Mention Frequency
Logical Consistency: The usage method of the system conforms to normal logic.	87.5%

The results from three sources are as follows: First, dictionary definition searches collected 45 original items, including 6 from the Modern Chinese Dictionary and 39 from English dictionaries. Two engineering psychology experts deleted and merged duplicate meanings and definitions that did not fit the theme of interactive naturalness, retaining 16 items (deletion rate: 64.4%). Second, literature review and summary collected 62 original items. Similarly, 2 experts discussed and deleted items with unclear expressions or ambiguity, retaining 45 items. Third, the definitions of interactive naturalness mentioned by experts in interviews were all included in the items obtained from dictionary and literature searches. After expert review and wording optimization, the items were finally refined to 9 items (as shown in Table 1), with a deletion rate of 47.5%. The principle of merging was to discover and establish relationships between conceptual categories through constant comparison, linking similar descriptions together. Kendall' s coefficient of concordance for inter-rater reliability was greater than 0.90.

3. Study 2: Scale Construction and Validation

3.1 Research Objective

To construct the structure of the interactive naturalness scale and preliminarily validate its effectiveness in the first batch of online-recruited samples.

3.2 Participants

We conducted an online survey of intelligent connected vehicle owners (users who purchased L2 or above-level intelligent connected vehicles in 2016 or later). A total of 413 online questionnaires were distributed. Participants with duplicate IP addresses and those with excessively long response times were excluded (response time: M = 1506.84 s, SD = 991.90 s; participants beyond 3 standard deviations were removed, i.e., $>$ M + 3SD = 4483 s). The final sample consisted of 353 valid questionnaires, with an effective rate of 85.47%. Participants' ages ranged from 21 to 65 years (M = 32.75, SD = 5.47), 50.7% were male, most had bachelor' s or master' s degrees, and total driving mileage mainly concentrated between 20,000 and 100,000 kilometers.

3.3 Measures and Procedure

3.3.1 Measures

1. **Interactive Naturalness Scale**: The 9 items from Study 1 were used, all rated on a 5-point Likert scale (1: very poor to 5: very good). Higher scores indicated better performance on that item.

2. **Traditional Usability Scale**: A 7-point Likert scale (1: strongly disagree to 7: strongly agree) usability questionnaire was used as a criterion variable. Higher scores indicated better product performance. Three items measured the usability, usefulness, and ease of use of basic intelligent connected vehicle functions (Visser et al., 2012; Luo et al., 2018; Pak et al., 2012). These included the three most commonly used dimensions of usability: the degree to which "users can make the product work," the degree of "smooth and error-free product use," and the degree to which "users spend little time learning to use the product." Example: "The degree to which manipulating this vehicle' s steering wheel, brakes, and accelerator feels smooth and natural" ($\alpha = 0.82$).

3. **Key Consumer Behavior Scale**: A 7-point Likert scale (1: strongly disagree to 7: strongly agree) questionnaire measuring key consumer behaviors was used as a criterion variable. The scale consisted of 9 items across two dimensions: use intention and satisfaction. Satisfaction was measured through three adjective rating scales assessing individual satisfaction with the intelligent connected vehicle driving experience (Pyrialakou et al., 2020), such as "minimally met my needs–maximally met my needs" ($\alpha = 0.96$). Use intention was measured using 6 items adapted from previous scales to assess individual willingness to drive intelligent connected vehicles (Moons & De, 2015), such as "I would feel uncomfortable if I didn' t use this car" ($\alpha = 0.90$).

3.3.2 Procedure After all participants signed informed consent forms, they first read an introduction about the survey, including the definition of intelligent connected vehicles: that such vehicles can flexibly adjust their actions according to the environment, even following relevant road rules. In most cases, they do not require driver control but still need human drivers to closely monitor and take over control at appropriate times. In-vehicle devices use wireless communication technology to effectively utilize all dynamic information of the vehicle to provide various functions and services (National Highway Traffic Safety Administration, 2016; SAE, 2016). The survey purpose was also explained: participants needed to express their attitudes toward intelligent connected vehicles. After confirming that participants understood intelligent connected vehicles and had purchased one, participants completed item comprehensibility evaluation, the interactive naturalness scale, other criterion-related validity measures, and demographic questions.

3.3.3 Statistical Analysis Data were processed using SPSS 25.0 and Jamovi 1.2.27.

3.3.4 Common Method Bias Test Exploratory factor analysis was used to test for possible common method bias (Podsakoff et al., 2003). All questionnaire items were integrated for exploratory factor analysis. The first extracted common factor explained 33.02% of the variance, which is less than 40%. Therefore, no serious common method bias existed in this study' s data.

3.4 Results

3.4.1 Item Comprehensibility Test All participants evaluated all items of the interactive naturalness scale, key consumer behavior scale, and traditional usability scale as "understandable" or "not understandable." The results showed that all participants understood the meaning and content of all items. Combined with expert opinions, the scales were deemed suitable for large-sample surveys.

3.4.2 Item Analysis According to item analysis procedures, participants were divided into high and low groups based on the 27th percentile. After t-tests on item means, the CR values of all 9 items formed in Study 1 were statistically significant at the 0.01 level, indicating that all items had good discriminative power and were retained.

3.4.3 Factor Analysis Results Exploratory factor analysis was conducted on the 9 items from Study 1 ($n = 353$). First, KMO and Bartlett' s sphericity tests were performed. The KMO value was 0.85, above the empirical standard of 0.80, indicating sufficient common factors among variables. Bartlett's sphericity test was significant ($^2 = 482$, df = 36, $p < 0.001$), indicating suitability for factor analysis.

Principal component analysis was used for factor extraction. When determining the number of factors, instead of the commonly used criterion of eigenvalues greater than 1 and scree plot inspection, parallel analysis was used to determine the number of factors to retain. The former is unstable as eigenvalues less than 1 are sensitive to the number of variables, and scree plots are difficult to interpret with smooth curves or multiple inflection points and lack objectivity (Ledesma & Valero, 2007). Parallel analysis is based on mathematical foundations, determining the absolute maximum number of factors to extract by comparing the intersection point of two eigenvalue curves from real data with those from random matrices (Franklin et al., 1995). Parallel analysis is relatively more stringent (Crawford et al., 2010; Hayton et al., 2004). Using parallel analysis and orthogonal rotation, two factors were obtained (loadings shown in Table 2). The two-factor model explained 32.1% of the total variance, with no items showing significant cross-loadings. Six items measuring learnability and fluency clustered together, while the other three items formed a factor measuring cross-context appropriateness. Therefore, these two factors were named "joyful fluency" and "universal awareness."

Table 2. Structure of Interactive Naturalness Items

Item	Factor 1: Joyful Fluency	Factor 2: Universal Awareness
1. Expectation Consistency	0.78	
2. Human-like Interaction	0.72	
3. Pleasant Experience	0.71	
4. Contextual Appropriateness		0.85
5. Operational Fluency	0.68	
6. Universal Accessibility	0.65	
7. Smooth Process	0.64	
8. Ease of Learning	0.62	
9. Logical Consistency		0.58
Percentage of Variance Explained	18.3%	13.8%
Cumulative Variance Explained	18.3%	32.1%

Note: Loadings less than 0.3 are not shown.

3.4.4 Reliability Test Reliability analysis of the self-developed questionnaire showed that the consistency α coefficients for joyful fluency and universal awareness were 0.90 and 0.87, respectively. The split-half reliability of the total scale was 0.74, indicating good scale reliability.

3.4.5 Validity Test **Criterion-related validity.** The two factors were correlated with each other, showing a low correlation ($r = 0.19$, $p < 0.001$), indicating that the two factors are independent with weak association, suggesting different components that may have different influencing factors. The two factors and total scale score were then correlated with post-purchase and interaction experience factors. The results are shown in Table 3. All variables were significantly correlated with the two factors ($p < 0.01$), indicating good criterion-related validity of the interactive naturalness scale.

Table 3. Correlation Analysis: Criterion-related Validity of Interactive Naturalness Items

Variable	M (SD)	Factor 1: Joyful Fluency	Factor 2: Universal Awareness
1. Usability	4.34 (0.49)	0.44**	0.35**
2. Use Intention	5.64 (0.76)	0.39**	0.13*
3. Satisfaction	5.54 (0.66)	0.25**	0.25**

Note: p < 0.05. ** p < 0.01. *** p < 0.001.*

Discriminant validity. According to Wang et al. (2005), the Average Variance Extracted (AVE) value for each dimension should be greater than the squared correlation between that dimension and other dimensions. If the AVE value is greater than the squared correlation between two dimensions, it indicates good discriminant validity between the two dimensions. We used AVE to test the discriminant validity of the two variables. The AVE values for the two dimensions were 0.68 and 0.63, respectively, both above the critical value of 0.5 and both greater than the squared correlation between the two constructs (ϕ = 0.74, $\phi^2 = 0.55$), indicating good discriminant validity.

Predictive validity. To explore the predictive validity of the interactive naturalness scale and whether interactive naturalness is fundamentally different from traditional usability standards—whether interactive naturalness can explain additional variance beyond usability—hierarchical regression analysis was conducted. First, demographic variables and usability were entered as control variables. In the first block, demographic variables to be controlled were entered. In the second block, usability was entered. In the third block, the two interactive naturalness factors were entered.

Table 4. Hierarchical Regression Analysis Testing the Unique Effects of the Two-Factor Structure

Predictor	Overall Satisfaction	Use Intention
	Model 2	Model 3
Block 1: Demographics		
Family Income	0.29***	0.22***
Driving Mileage	0.14*	
Block 2: Usability	0.16**	
Block 3: Interactive Naturalness		
Joyful Fluency	0.29***	
Universal Awareness		0.28***
ΔR^2	0.16**	0.08**
F Change	28.33***	5.28**

Note: $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.*

The results (Table 4) show that after controlling for demographic variables and traditional usability indicators, interactive naturalness had a significant predictive effect on both satisfaction and use intention models. Specifically, joyful fluency predicted satisfaction well (confidence interval [0.02, 0.36]) and use intention well (confidence interval [0.07, 0.45]). A possible explanation is that when users are using the product and recalling its overall performance, smooth and pleasant experiences are more critical influencing factors.

4. Study 3: Cross-validation and Extension

4.1 Research Objective

To further validate the validity and discriminant validity of the interactive naturalness scale structure in a new sample. Two additional variables of key consumer behavior were added: loyalty and recommendation intention. Post-purchase recommendation is closely related to customer loyalty. When a product meets expectations (i.e., value, efficiency, economy, safety vs. potential problems, risks, or constraints), users are more likely to repurchase and recommend the product (Black et al., 2015; Grandhi et al., 2011; Rajendran & Jayakrishnan, 2018). Adding more variables for validity analysis and regression prediction in a new sample can not only verify the stable performance of the interactive naturalness scale across samples but also demonstrate the unique role of the interactive naturalness scale in a broader consumer behavior perspective.

4.2 Participants

We conducted an online survey of intelligent connected vehicle owners. A total of 428 online questionnaires were distributed, and 349 valid questionnaires were retained, with an effective rate of 81.5%. Independent samples t-tests showed no significant differences between Study 2 and Study 3 samples in gender, age, education level, total driving mileage, and other demographic variables.

4.3 Measures and Procedure

4.3.1 Measures

1. **Interactive Naturalness Scale**: Same as Study 1. Joyful fluency $\alpha = 0.91$ and universal awareness $\alpha = 0.90$.
2. **Traditional Usability Scale**: Same as Study 1, $\alpha = 0.83$.
3. **Key Consumer Behavior Scale**: In addition to the two factors used in Study 2 (use intention $\alpha = 0.92$, satisfaction $\alpha = 0.98$), we added:
    - **Loyalty** (7-point Likert scale, 1: strongly disagree to 7: strongly agree) measuring individuals' trust in and likelihood of continued purchase of the intelligent connected vehicle product or brand (Moons & De, 2015). It included 6 items such as "I often encourage others to buy this brand of car," $\alpha = 0.93$.
    - **Recommendation Intention** (11-point scale, 0: no chance of recommendation to 10: extremely likely to recommend) measuring the likelihood that a customer will recommend a company or service to others (Grisaffe, 2007). It used one item: "Based on your experience, how likely are you to recommend this car to friends or colleagues in the future?" as a criterion measure.
4. **Intelligent Connected Vehicle Functions**: Including media playback, navigation system, voice interaction, reversing radar, cruise control, auto-

matic parking, lane keeping, and automatic following. All were rated on a 7-point Likert scale (1: very dissatisfied to 7: very satisfied). Higher scores indicated better product performance on that function.

4.3.2 Procedure Same as Study 2.

4.4 Results

4.4.1 Factor Analysis Confirmatory factor analysis was conducted on the interactive naturalness structure using the new sample. The results showed that the two-factor structure (^{2} = 35.3, df = 27, CFI = 0.98, TLI = 0.98, RMSEA = 0.03, SRMR = 0.04, AIC = 7151, BIC = 7253) had better fit indices than the single-factor structure (^{2} = 46.8, df = 28, CFI = 0.95, TLI = 0.94, RMSEA = 0.05, SRMR = 0.03, AIC = 7042, BIC = 7047; Δ ^{2} = 11.5, Δdf = 1, $p < 0.001$), consistent with Study 2 results, indicating that the obtained factor structure is reasonable and valid.

4.4.2 Reliability Test Reliability analysis of the self-developed questionnaire showed that the consistency α coefficients for joyful fluency and universal awareness were 0.91 and 0.90, respectively. Split-half reliabilities were all above 0.7, indicating good scale reliability.

4.4.3 Validity Test Criterion-related validity. The two factors and total scale score were correlated with post-purchase and interaction experience factors. The results are shown in Table 5. All variables were significantly correlated with the two factors ($p < 0.01$), indicating good criterion-related validity of the interactive naturalness scale.

Table 5. Correlation Analysis: Criterion-related Validity of Interactive Naturalness Items

Variable	M (SD)	Factor 1: Joyful Fluency	Factor 2: Universal Awareness
1. Usability	4.12 (0.60)	0.54**	0.40**
2. Use Intention	5.64 (0.76)	0.40**	0.29**
3. Recommendation Intention	5.51 (0.72)	0.23**	0.29**
4. Loyalty	5.26 (1.04)	0.44**	0.24**
5. Satisfaction	5.54 (0.66)	0.45**	0.44**

Note: p < 0.05. ** p < 0.01. *** p < 0.001.*

Predictive validity. Hierarchical regression analysis was continued in the new sample to explore the predictive validity of interactive naturalness and whether it differs from usability (Table 6). In the first block, demographic variables were entered. In the second block, usability and ease of use were entered. In the third block, the two naturalness factors were entered.

The results were consistent with Study 2. After adding the two interactive naturalness factors, the effect of usability in the model was significantly reduced. When predicting satisfaction, use intention, net promoter score, perceived loyalty, and perceived support, only the two interactive naturalness factors were included in the model. When explaining perceived controllability, both joyful fluency and usability were included in the model, while universal awareness was excluded.

The results (Table 6) show that after controlling for demographic variables and traditional usability indicators, interactive naturalness had a significant predictive effect on satisfaction and use intention models. Specifically, joyful fluency predicted satisfaction well (confidence interval [0.34, 0.67]) and use intention well (confidence interval [0.21, 0.55]), while universal awareness did not significantly predict these two variables, consistent with Study 2 results. On the other hand, both dimensions of interactive naturalness significantly predicted recommendation intention (confidence intervals [0.45, 1.22], [0.01, 0.49]) and loyalty (confidence intervals [0.47, 0.94], [0.23, 0.52]).

Table 6. Hierarchical Regression Analysis Testing the Unique Effects of the Two-Factor Structure

Predictor	Satisfaction	Use Intention	Recommendation Intention	Loyalty
	M1	M2	M3	M1
Block 1: Demographics				
Driving Mileage	.30***	.35***	0.19**	.32***
Block 2: Usability				
	0.16**			
Block 3: Interactive Naturalness				

Predictor	Satisfaction	Use Intention	Recommendation Intention	Loyalty
Joyful Fluency		0.29***		
Universal Awareness		0.28***		
ΔR^2	0.16**	0.08**	0.19***	0.03*
F Change	33.52***	24.07***	48.49***	12.74***

Note: p < 0.05. ** p < 0.01. *** p < 0.001.*

4.4.4 Relationship Between Vehicle Function Satisfaction and Interactive Naturalness Correlation analysis was conducted between the two factors and satisfaction with vehicle functions. The results (Table 7) showed that joyful fluency was more correlated with common basic functions (such as media playback and reversing radar), while universal awareness was more correlated with intelligent features (such as voice interaction and automatic parking). This further demonstrates that the two factors have unique roles in different functions.

Table 7. Correlation Analysis Between Interactive Naturalness and Intelligent Connected Vehicle Function Satisfaction

Function	Factor 1: Joyful Fluency	Factor 2: Universal Awareness
Media Playback	0.39**	0.28**
Navigation System	0.35**	0.41**
Voice Interaction	0.28*	0.34**
Reversing Radar	0.40**	0.27**
Cruise Control	0.22**	0.38**
Automatic Parking	0.37**	0.13*
Lane Keeping	0.26**	0.43**
Automatic Following	0.42**	0.39**

Note: p < 0.05. ** p < 0.01.*

5. Discussion

This study constructed a conceptual framework of interactive naturalness experience and conducted systematic validation, developing an interactive naturalness scale and verifying its structural validity and criterion-related validity. To this end, three studies combining qualitative and quantitative methods were conducted. The results provide consistent evidence that a two-factor structure comprising joyful fluency and universal awareness best captures the essence of interactive naturalness experience. Correlation analysis shows that these two components have significant correlations with all other post-purchase and user experience variables ($p < 0.01$). Further hierarchical regression analysis demonstrates that interactive naturalness can better explain and predict post-purchase and experience variables.

The significance of this study is mainly reflected in three aspects:

First, based on systematic qualitative and quantitative research, the psychological structure of interactive naturalness was identified. The qualitative research based on dictionary searches, literature review, and expert interviews formed a comprehensive item set of interactive naturalness experience, filling the research gap that previous studies have not comprehensively and groundedly conducted qualitative analysis of the interactive naturalness construct from semantic and conceptual networks (Agarwal et al., 2013; Bailey et al., 2018; Bassano et al., 2020; Falcao et al., 2015; Kharoub et al., 2019; Vallejo et al., 2016; Villaroman et al., 2011). Our research shows that a two-factor approach is more suitable for capturing the essence of interactive naturalness structure. By examining possible outcome variables such as purchase intention, loyalty, and recommendation intention, we found that both components have significant relationships with these criteria, demonstrating good criterion-related validity of the scale. Additionally, evidence was found that the two-factor structure may help explain variance beyond usability and ease of use, showing good discriminant and predictive validity.

Second, the influence paths of other relevant variables on interactive naturalness within the context of intelligent connected vehicles were systematically validated. The two dimensions of interactive naturalness were significantly correlated with all post-purchase and user experience variables. The study also verified the differential correlations between the two factors and different vehicle functions. First, usability was significantly correlated with both dimensions of interactive naturalness. This quantitatively validates Norman' s (2010) view that natural products must be usable. Good naturalness experience requires ensuring that products can be used, focusing on whether products are easy to use, thereby achieving the goals of reducing users' cognitive load, shortening learning paths (Lewis, 1992; Norman & Nielsen, 2010), and optimizing user experience. Second, among post-purchase factors, loyalty showed the strongest correlation with both interactive naturalness factors. This finding indicates that good naturalness experience can strengthen users' likelihood of repeated consumption of the product or brand, thereby establishing loyalty—a finding consistent with the conceptual connotation of brand loyalty (Wernerfelt, 1991). It can be inferred that focusing on interactive naturalness experience in product development and design contributes to more positive consumer and post-purchase behaviors. Finally, joyful fluency was more correlated with basic vehicle functions, while universal awareness was more strongly correlated with intelligent interaction functions. This finding also corroborates the results obtained in predictive validity analysis. A possible explanation is that when users decide whether they like or will use a product, they focus more on whether functions are smooth and easy to use and whether they meet expectations, which to some extent reflects the satisfaction of instrumental motivations (Khalid et al., 2012). However, when users decide to be loyal to a brand or recommend the product to others, they not only value satisfaction of instrumental motivations but also need to satisfy emotional or symbolic motivations (Helander et al., 2013; McDonagh & Lebbon, 2000). The universal awareness dimension reflects the degree to which interactive products can understand users' intentions and provide humanized services. At the current stage, it may be more associated with concepts such as technological sense, intelligence, and humanized design (Hsiao, 2017), thereby satisfying consumers' motivations differently.

Third, cross-sample analysis examined the additional contribution of interactive naturalness relative to other usability indicators. Hierarchical regression results from two different samples showed that the two dimensions of interactive naturalness could stably explain and predict key consumer behaviors, distinct from traditional usability, usefulness, and ease of use. This demonstrates that interactive naturalness has additional contribution beyond other usability indicators, further supporting the view that natural interaction experience is not equivalent to usability. Study 2 focused on how natural interaction affects users' satisfaction with the product during and after use. Specifically, when users use the product themselves, smooth and pleasant experiences make them more willing to use the product and give higher satisfaction ratings, consistent with previous research (Atiyah et al., 2019; Kamide et al., 2012; Li & Yeh, 2010). Furthermore, Study 3 considered not only individual post-purchase experience but also individuals' post-purchase interactions with other important people. When users want to recommend the product to others or even develop loyalty to the product, they need not only joyful fluency experience but also products with universal awareness that understand users' intentions and provide humanized services. The former satisfies users' basic functional needs (Khalid et al., 2012), belonging to basic product attributes; the latter pays more attention to users'emotional needs (Helander et al., 2013) and preferences for more intelligent products, belonging to advanced product attributes. This natural interaction experience enables users to experience stronger identity and value, which are also key factors in generating loyalty and recommendation intention (Moons & De, 2015). The intelligent, needs-understanding experience brought by new intelligent technologies is also crucial for generating user satisfaction and even willingness to recommend to others (Biever et al., 2020; Liljamo et al., 2018).

The limitations of this study are reflected in the following aspects. First, the measurement of interactive naturalness is not based on specific tasks but adopts a consumer behavior research approach, focusing more on overall product characteristics and how people cognitively understand naturalness. This approach also provides a certain methodology for improving specific functions and experiences in interactive naturalness. Future research can further refine the exploration of functions and experiences. However, the current tool can still provide comprehensive directional guidance during product development initial and final iteration stages. Future research can focus on natural design that adapts to human motor development and learning processes, using natural exploration methods to develop designs that adapt to motor skill development, providing developers with more detailed interaction modality design guidelines.

Second, there is a certain gap between questionnaire results and actual situations, as responses to items may not correspond to actual circumstances. In the future, behavioral experiments, real product testing, or simulator studies could be considered. Third, the scale was only validated on the single product of intelligent connected vehicles, which imposes certain limitations on generalization. However, specific product expressions were not used in the qualitative research phase; instead, a broad and comprehensive item pool was established. Future research will further validate the scale across intelligent products such as smartwatches, programmable robots, smart speakers, and VR glasses to improve the tool' s cross-product reliability and validity.

6. Conclusion

This study systematically employed psychometric methods to explore the psychological structure of interactive naturalness and its effects, and developed a tool for measuring the interactive naturalness of intelligent products. We found that interactive naturalness includes two dimensions: joyful fluency and universal awareness. Beyond traditional usability indicators, these two dimensions have significant additional predictive power for consumers' key experiences and consumption behaviors. These two structures are stable and distinguishable, and their measurement tool can be used in various natural human-computer interaction studies in the future, providing guidance for the design and evaluation of intelligent interaction products. Future research can explore the mechanisms and causes of these two dimensions across more types of intelligent products.

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Appendix 1: Interactive Naturalness Scale

How well do you think your car performs on the following factors? Please select the answer that best fits you from 5 choices. "Very poor" = 1, "Poor" = 2, "Average" = 3, "Good" = 4, "Very good" = 5.

1. The usage method of this system is consistent with expectations.
2. Interaction with this system is as natural as interacting with people.
3. When I use this system, I feel pleasant.
4. The system can make appropriate responses according to the current situation.
5. Users operate in their own way without interruption, experiencing the fluency of operation.
6. Anyone (including children) can use this system freely.
7. The overall process of using the in-vehicle system feels smooth and not abrupt.
8. It is easy to learn various functions of the system without seeking help from others.
9. The usage method of the system conforms to normal logic.

Appendix 2: Traditional Usability Scale

How well do you think your car performs on the following factors? Please select the answer that best fits you from 5 choices. "Very poor" = 1, "Poor" = 2, "Average" = 3, "Good" = 4, "Very good" = 5.

1. For driving this car, my overall evaluation is: (Used in both Study 2 and Study 3)
   - Very dissatisfied Very satisfied
   - Minimally met my needs Maximally met my needs
   - Far below my expectations Far exceeded my expectations
2. Based on your experience, how likely are you to recommend this car to friends or colleagues in the future? (Used only in Study 3)
   - No chance of recommendation Extremely likely to recommend

3. How well do you think your car performs on the following factors? Please select the answer that best fits you from 5 choices. “Very poor”= 1, “Poor” = 2, “Somewhat” = 3, “Uncertain” = 4, “Somewhat good” = 5, “Good” = 6, “Very good” = 7. (First six items used in Study 2; all items used in Study 3)

    1) I would feel uncomfortable if I didn' t use this car.
    2) Using this car has become my habit.
    3) I frequently use this car.
    4) I drive this car for everything I do.
    5) I often drive this car in various road conditions and weather.
    6) I often use this car to carry family and friends.
    7) I often introduce the advantages of this car to others.
    8) I often encourage others to buy this brand of car.
    9) I always advise people with the same needs as me to buy this car.
    10) I post positive information about this car on some Internet message boards.
    11) I plan to continue buying cars from this brand.
    12) I plan to use more products from this brand.

Note: Figure translations are in progress. See original paper for figures.