A Systematic Survey of 15 Years of User Studies Published in the Intelligent Virtual Agents Conference

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ABSTRACT

The field of intelligent virtual agents (IVAs) has evolved immensely over the past 15 years, introducing new application opportunities in areas such as training, health care, and virtual assistants. In this survey paper, we provide a systematic review of the most influential user studies published in the IVA conference from 2001 to 2015 focusing on IVA development, human perception, and interactions. A total of 247 papers with 276 user studies have been classified and reviewed based on their contributions and impact. We identify the different areas of research and provide a summary of the papers with the highest impact. With the trends of past user studies and the current state of technology, we provide insights into future trends and research challenges.

CCS CONCEPTS

• **Human-centered computing → User studies**; • **Computing methodologies → Intelligent agents**;

KEYWORDS

Intelligent Virtual Agents, Systematic Survey, User Studies, Behavior, Physical Appearance, Identities, Applications

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1 INTRODUCTION

Advances in technologies such as motion tracking and display devices and breakthroughs in fields such as artificial intelligence, natural language processing, machine learning, and computer graphics have led to major improvements in the field of intelligent virtual agents (IVAs) and given rise to new application opportunities employing these agents. In particular, much research has focused on improving the human-like qualities of IVAs, such as their naturalness and believability as a human interlocutor in aspects such as behavior, appearance, and in consideration of various applications.

Due to the importance of human users' feedback in advancing the field of IVAs, and inspired by review papers in other domains [36, 53, 93], in this paper we provide a road map of these endeavours, focusing on user studies between 2001 to 2015 published in the IVA conference. While this conference started as a small workshop in Manchester in 1999, we decided to cover the period from the third IVA workshop in 2001, which became much larger, involved international researchers, and published an official volume of proceedings with high-quality papers. We sought to include as large a time span as possible to provide a broad view of IVA-related user study research and to ensure that the works chosen had sufficient time to leave an impact on the field; hence, the years 2016 and 2017 were excluded from this review. We used the topic categorization scheme in the IVA proceedings each year and the contribution of each paper to categorize the user studies and to understand the trends over the years. We provide an inclusive view of the history of IVA user studies and insights into future directions.

In the remainder of this paper, we first introduce our methodology in Section 2. In Section 3 we go over the main research topics. In Section 4 we provide a meta-analysis of the user studies. Section 5 discusses each topic and provides details on the most influential work in these areas. Section 6 discusses emerging research trends and directions. Section 7 concludes the paper.

2 METHOD

Our review process consisted of two parts. First, we reviewed all user studies published as full and short papers in the IVA conference proceedings from 2001 to 2015. Out of the 579 papers published in this time span, 247 described human subject studies. We focused on the following factors inspired by [36]:

- Research topics, keywords
- Participant's role (interactor, observer)
- Experiment space (physical environment, web-based)
- Experiment design (within-subjects, between-subjects, or mixed-factorial)
- Type of data collected (qualitative, quantitative, both)
- Study type (laboratory, web-based, pilot, field, heuristic, case study, clinical trial, focus group)
- Display type (TV/projection screen, immersive virtual reality, augmented reality, robotic representation)
- Demographics reported (number of participants, gender, age)
- Average citations per year

The second part of our review process consisted of choosing the papers with an Average Citation Count (ACC) higher than three citations per year (N = 72, collected from Google Citation Index on May 1st, 2018). We divided the papers among the co-authors based on expertise and provided summaries, contributions, and categorizations for each paper.

3 IVA RESEARCH TOPICS

We collected potential categories by coding keywords from the papers and determining which characteristics of IVAs each study considered, such as realism of physical appearance, personality, gesture, etc. From this, we identified three major topics that covered the different aspects of IVA research and evaluation: their human-like behavioral capabilities, the characteristics of their virtual representations, and their intended applications. These aspects provide a natural categorization for the reviewed papers. To categorize papers which described the combination of several topics, we carefully considered the main goals and the variables introduced and measured during the user studies.

Our categorization is as follows:

- **Non-verbal and Verbal Behavior** includes user studies focusing on the development of behavioral aspects associated with an agent, e.g., affective behavior, social behavior, and behavior exhibiting personality traits.
- **Physical Appearance and Identities** includes user studies on physical appearance, race, ethnicity, gender, and culture.
- **Applications** includes user studies of agents that were developed for a specific application such as training and education, social and assistant agents, etc.

4 OVERVIEW OF IVA USER STUDIES

Across 247 papers, 276 user studies were conducted. Table 1 summarizes the number of user studies each year with regards to the factors mentioned in Section 2. Due to a few case studies and some studies experimenting with multiple display types, study types, and experiment spaces, some of the totals are higher or lower than the total number of user studies. Figure 1 shows the increase in the number of user studies over time, with more researchers conducting studies as part of their evaluation procedure as time passed.

As shown in Figure 2, the development of the behavioral aspects of agents has been the dominant topic each year (86.1%), followed by applications (26.2%), e.g., suggesting that increased agent capabilities resulted in a growing trend to employ them for applications. Physical appearance and identities have been researched less frequently in user studies than other areas (13.8%).

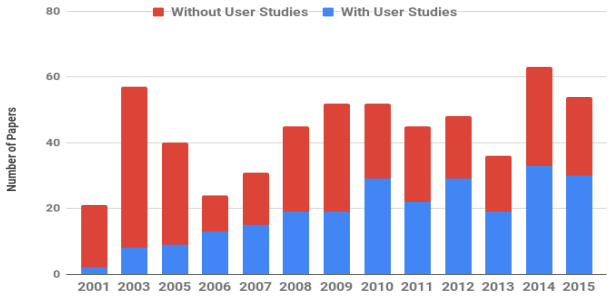

Figure 1: Trend in number of user studies from 2001 to 2015.

In 63.5% of the studies, the *participant's role* involved direct interaction with the agent through means such as verbal and non-verbal behavior or text, while in 36.5% participants observed an animation (77%) or a picture (23%) of the agent.

The majority of studies were conducted with one or more participants and agents/experimenters sharing the same *experiment space* (76%), while the rest happened through online means such as Mechanical Turk or custom web-based applications (24%).

Most of the studies used a within-subjects *experiment design* (56.2%), many used a between-subject design (37.6%), and only a few used a mixed-factorial design (6.2%).

Most studies collected data of the quantitative *data type* (78.1%) such as behavioral or perceptual/cognitive responses, while very few (6.9%) solely relied on qualitative data such as from a focus group; some (15%) used both types in their studies.

In terms of *study type*, most of the user studies were conducted in a lab environment (57.8%) or were web-based (19.5%), with only a few pilot (13%) and field studies (7.2%). Only 2.52% of the studies were focus groups, clinical trails, and case studies. We also found that information about pilot tests conducted before the main experiment was not commonly reported over this time period, appearing in only 8.9% of user study papers.

For the *display type*, the majority of these studies used screens such as TVs or computer/projection screens (92.5%), with a few experiments using other means such as immersive virtual reality (4.3%), augmented reality (1.1%), and robotic representations (2.1%), indicating that these forms of visual displays and embodiment are still not well explored through user studies in this venue.

Similar to Dey et al., we considered the number of participants, age, and gender (full demographics) to be important parts of the *demographic data* [36]. Reporting full demographics has been more common in some years like 2009, 2010, and 2012 but not others.

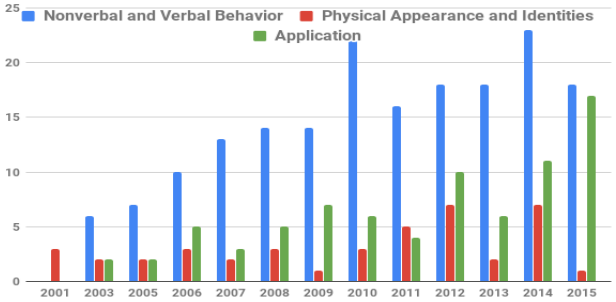

Figure 2: IVA research topic trends from 2001 to 2015.

Table 1: Summary of the 247 reviewed papers.

		2001	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	
Number of User Studies		3	9	10	15	16	19	22	31	23	31	24	38	35	276	
Participant's Role	Interactor	3	5	5	9	9	15	13	20	12	22	12	24	25	174	274
	Observer	0	4	5	6	7	4	9	11	11	9	12	12	10	100	
Experiment Space	Physical	3	9	7	13	13	14	18	22	21	23	17	21	28	209	275
	Online	0	0	3	2	3	5	4	9	2	8	8	15	7	66	
Experiment Design	Within	0	5	5	7	9	13	15	18	18	11	13	22	18	154	
	Between	3	4	5	7	7	6	5	10	4	17	10	11	14	103	274
	Mixed	0	0	0	1	0	0	2	3	1	3	1	3	3	17	
Data Type	Quant. only	2	7	9	11	12	17	18	27	17	24	18	29	23	214	
	Qual. only	0	1	0	0	0	1	0	2	3	1	2	1	8	19	274
	Both	1	1	1	4	4	1	4	2	3	6	4	6	4	41	
Study Type	Lab	2	6	6	10	8	11	14	17	17	19	13	14	23	160	
	Web-based	1	0	3	2	3	4	3	8	2	6	7	8	7	54	
	Pilot	0	2	1	1	3	3	2	4	2	3	3	7	5	36	277
	Field	0	1	0	2	2	1	2	2	1	3	2	4	0	20	
	Other	0	0	0	0	0	0	1	0	1	0	0	5	0	7	
Display Type	Screen	1	8	9	15	15	17	21	31	21	29	24	35	34	260	
	VR	2	1	1	0	0	1	1	0	2	1	0	3	0	12	281
	AR	0	0	0	0	1	0	0	0	1	1	0	0	0	3	
	Robot	0	0	0	0	0	2	0	0	0	1	0	2	1	6	
Full Demographics (in %)		0	66.66	30	40	56.25	26.31	77.27	80.64	52.17	74.19	50	63.15	57.14	58.69	
ACC (average citations/year)		3.93	2.61	1.84	3.21	5.55	2.76	2.77	3.21	2.96	2.76	2.17	1.59	1.54	2.63	

5 DETAILED VIEW OF IVA TOPICS

For the 72 papers with ACC > 3 we looked into the sub-topics studied in each paper introduced in Section 3. Figure 3 shows the different topics and the number of papers in each group. In this section we provide statistics for the sub-topics of each group and present the researchers' contributions.

Since most papers researched several sub-topics at the same time, we categorized the papers based on the primary IVA topic considered. As necessary, we describe the other sub-topics used to supplement the capabilities of the described IVAs.

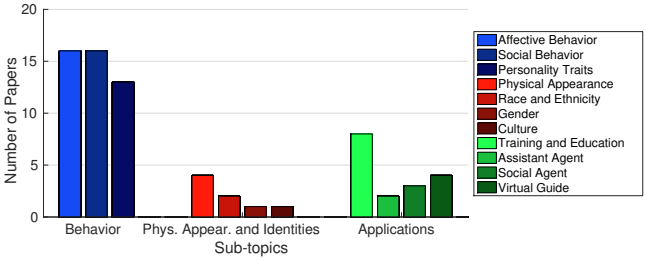

Figure 3: Researched topics of papers with ACC > 3.

5.1 Non-Verbal and Verbal Behavior

Both verbal and non-verbal behaviors are naturally involved in human-agent interactions, such as a social agent who nods and "uh-huh"s during conversation [76]. These behaviors could be used to show a mere behavioral ability of the agent, but more likely they have been perceived as portraying other features such as social or affective behavior indicating the evolution of the meaning of the word *behavior* [90]. Different verbal and non-verbal cues such as presence/absence of audio, pitch, prosody, backchannel (BC), turn-taking, body posture/gesture (upper-torso, arms, hands, legs, etc.), facial expression, gaze, etc. have been extensively researched.

Based on the high-level analysis (Section 4), this topic is also one of the main factors researchers have investigated to moderate an agent's realism. Surprisingly, however, our review found that verbal behavior has not been the main focus of investigation in the IVA papers (only 25.42%). While some verbal aspects, such as pitch or prosody, and the impact of empathic speech content have been developed and discussed as an aspect of IVA systems or a component of user studies, they were generally not the main contribution of the paper [7, 9, 13, 19, 21, 37, 47, 48, 66, 69, 70, 76, 77, 81, 85].

5.1.1 Social Behavior (16 papers). An agent's ability to behave according to a social context can highly impact how it is perceived by a human user. This ability is achieved through *social signal processing*. In an extensive survey, Vinciarelli et al. researched different aspects of this ability, i.e., modeling, analysis, and synthesis of social behavior [90]. In order for human-agent interaction to be natural and believable, researchers studied human-human interactions to develop similar social behaviors for IVAs, such as establishing rapport using appropriate BC signals which improves the positive feeling among interlocutors and their communication.

Studying rapport, researchers experimented with different aspects of BC signals such as contingency and frequency [41, 76], quantity, type, and timings [75], and testing with responsive and non-responsive agents [42], while some studied correlations between characteristics of the human interlocutors and levels of rapport experienced with different types of agents and humans [50].

Different computational models have been proposed for autonomous agent behavior such as a model trained based on human data for turn-taking and BC behavior [47], a computation model for multi-party non-verbal agent conversational behavior incorporating turn-taking strategies, group formation management, and conversational behavior [79], a virtual agent's natural gaze aversion behavior by analyzing human dyadic conversation videos to achieve various conversational functions, such as turn-taking [1], a gaze-enabled agent based on human flirting behavior and its effect on engagement and gaze behavior [8], and a computational architecture of a socially adaptive agent which adjusts its behavior according to the user's behavior [92].

Different studies focused on user interpretations of BC signals such as when presented as context-free multimodal signals [13], and single and combined ones using facial expressions followed by a user study aiming to create a BC library [43].

Looking at other aspects of social behavior exhibited by the agents or the human interlocutors, researchers have experimented with agents capable of forming social relations by remembering past users [23], agents able to change the flow of narrative based on user gaze behavior [37], studying users' first impression of an agent while varying the agent's non-verbal immediacy cues (e.g., smile, gaze, and proximity) [20], and user politeness towards an agent when evaluating the agent directly or through indirect means [45].

5.1.2 Affective Behavior (16 papers). Expressions of emotion can be achieved via an agent's facial expressions, gaze, gestures, and behaviors. Agent emotional displays can impact decision making during human-agent negotiation [33], user cooperation levels with agents [32, 35], agent believability [72, 81], and human-agent emotional contagion [87]. Agents have also been used as a medium to reflect the user's emotional state [77].

Several researchers focused on building computational models for emotional expression development, such as a decision tree algorithm to determine the morphological and dynamic characteristics of a virtual agent's smiles based on user-generated descriptions [74], the WASABI Affect Simulation Architecture to simulate primary and secondary emotions [7], and A Layered Model of Affect (ALMA) for providing authentic believable emotions and moods for the agent [38]. Other studies have looked at how users perceive the agent's emotions in cases like presence or absence of audio during agent's facial expressions [19] and congruence between an agent's facial expression and body posture [26].

Researchers explored the expression of emotions and perception of agents through adding wrinkles, blushing, sweating, and tears [34] and experimented with real time facial animations such as realistic wrinkles [28], pleasure-arousal-dominance models linking gaze behaviors to emotional states through head movement and body gestures during gaze shifts [62], and implementing complex facial expressions such as superposition and masking [73].

5.1.3 Personality Traits (13 papers). Each person expresses their personality through their behavior, which impacts their evaluations of agents and their behavior [2]. User perception of an agent's personality traits is influenced by language extraversion, gesture rate, and gesture performance [46, 70], including non-communicative gestures like self-touch and eyebrow raising [59, 69]. Additionally, researchers have explored how agent turn-taking [85] and the correlation between perceived agent competence, gesture, and appearance [9] affect personality perception.

Some researchers have explored computational models for generating personality-related behaviors of IVAs and their impact on human perception of the agent, including arm and hand gestures, non-verbal signals based on given attitude traits such as warmth and competence, and gaze behavior based on a given dominance/submission level [10, 22, 56, 57, 71]. Such models might be machine learning-based or literature-based [63].

5.2 Physical Appearance and Identities

In this section, we focus on papers that research more realistic physical appearances and the impact of an agent's embodiment on a user's perception, as well as papers investigating how agents are perceived when a certain identity such as race, ethnicity, culture, and gender has been assigned to it.

5.2.1 Physical Appearance (4 papers). Exploring these behavioral and perceptual effects, researchers have experimented with effects of varying user avatars (e.g. humanoid and cartoon-style) on sense of presence [39], proximity to agent when confronted with a photographically realistic agent with their face compared to the face of a stranger [4], effectiveness and acceptance of agent embodiment (e.g. text, speech, and gestural effects) [60], and investigating the impacts of anthropomorphism on memory retainability [12].

5.2.2 Identities (4 papers). Exploring cultural effects, researchers introduced a subset of cultural parameters such as gaze, proxemics, and turn-taking to create culturally appropriate agents [49]. The effects of culturally matched verbal and non-verbal behaviors to ethnicity was studied during a pilot experiment [48].

User perception of agents was also studied in scenarios looking at an agent's gender and gaze behavior [61] and the influence of a virtual human's skin tone on the user's empathy toward the virtual human in a medical interview scenario [82].

5.3 Applications

As IVAs can consistently demonstrate desired behaviors, personalities, and appearances, they are often designed to support specific applications. Here, we highlight papers that primarily focused on application-driven IVAs, which we broadly categorize into virtual *assistants* (2 papers), *training and educational* agents (8 papers), *social companions* (3 papers), and *virtual guides* (4 papers).

Commercial "smart" virtual assistants, such as Amazon's *Alexa*, often support voice or text input but lack a human appearance. In this field researchers have experimented with using IVAs for explaining health documents [17] and assisting the elderly and cognitively impaired with scheduling and organizational tasks [91].

Additionally, IVAs have been widely used to support training and education, such as creating virtual patients for interview and diagnosis training [51], investigating the effects of a pedagogical agent's non-verbal behavior on the user's learning attitude and recall [6], a virtual therapy agent for users suffering from aphasia [88], employing agents in vocabulary learning [11, 68], negotiation training systems [18, 40], and number factorization tasks for students [27].

The social expressiveness of IVAs allows for compelling human-agent relationships. Researchers explored cases like including narratives that provided the motivations of the characters [80], agents that present autobiographical stories instead of third-person narratives [15], and a social companion agent for isolated older adults, who enjoyed storytelling and discussing various topics [89].

Finally, several researchers studied the impact of virtual guides on user experience, engagement, and learning. This includes a mobile-based context-aware virtual guide for touring purposes that was capable of portraying affection and personality [67], virtual museum guides (Ada and Grace) to increase interest of middle school students in the fields of science and technology [84] which were later improved in aspects including but not limited to speech models, audio acquisition, etc. [86], and a virtual museum guide (Tinker) with varying levels of relational behavior like reciprocal self-disclosure [14].

6 EMERGING TRENDS AND DIRECTIONS

Based on our review of human-subject studies at IVA conferences between 2001 and 2015, we identified three underrepresented research directions along with recent technological trends in IVA and

related domains: multimodal interfaces, human collaboration with one or more agents, as well as virtual and augmented reality.

Firstly, we observed most of the agents presented in the past 15 years of the IVA conference relied on auditory and visual modalities both for sensing input data and performing output behaviors during their interaction with human users. However, researchers in other related venues have studied the impact of using different modalities, like touch [16, 29, 44], haptic feedback [5, 64, 65], and agent physicality [25], each of which can have impacts on the users' behavior, perception of the agent, and social presence. IVAs that mimic real human abilities could be considered an extreme case of a multimodal interface; this emphasizes the value of future IVA research employing and studying the effects of different interactive modalities while introducing advanced signal processing methods for complex data and compelling input/output devices.

Secondly, only a few of the IVA publications focused on aspects of human-agent collaboration in user studies (9.8%). With researchers studying the challenges and requirements of creating supportive "team-player" agents [24, 58], we believe human-agent collaboration is a valuable avenue for future research. Also, IVA systems with multiple agents and user studies about perception or collaboration in multi-agent environments should be introduced and researched further [30, 31].

Finally, user perception of virtual agents and their impacts on learning, presence, and social presence, particularly in immersive VR and AR with head-mounted displays, have been studied by some researchers outside of the IVA conference [78, 83]. Using these mediums provides new opportunities for human-agent interaction. For instance, Kim et al. have shown that agent awareness of the physical and virtual environment in AR can have positive impacts on social presence and user behavior [52, 54, 55]. AR is anticipated to eventually become an even larger market than VR [3], and it can be an effective platform for IVAs. We think that exploring different aspects of agent behavior in AR can be useful not only for the design of more effective IVAs in our ordinary life but also for understanding human perception of and behavior with it. As only a few papers in past IVA conferences experimented with these mediums to portray IVAs in user studies, we think future research can strongly benefit from shifting more towards this direction.

7 CONCLUSION

In this paper, we classified and reviewed 247 papers with 276 user studies from IVA conferences between 2001 to 2015 based on their contributions and impact. Our results show that conducting user studies has become a more common practice in the field of IVAs, and the results provided an improved understanding of human interaction with agents: in particular, how it relates to an agent's verbal and non-verbal behavior, physical appearance, and identities.

We also documented an increasing trend towards application-oriented research with agents designed for specific scenarios or use cases. Additionally, we provided statistics on important features of the user studies, such as the medium used for the virtual content, the type of study design, the type of data collected, and related.

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