Approachability: How People Interpret Automatic Door Movement as Gesture

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Automatic doors exemplify the challenges of designing emotionally welcoming interactive systems—a critical issue in the design of any system of incidental use. We attempt to broaden the automatic door's repertoire of signals by examining how people respond to a variety of "door gestures" designed to offer different levels of approachability. In a pilot study, participants (N=48) who walked past a physical gesturing door were asked to fill out a questionnaire about that experience. In our follow-up study, participants (N=51) viewed 12 video clips depicting a person walking toward and past an automatic door that moved with different speeds and trajectories. In both studies, our Likert-scale measures and open-ended responses indicate that participants viewing the door behavior prototypes show significant uniformity in the interpretation of the door's behavior, and that they attribute these motions as gestures with human-like characteristics such as cognition and intent. In all, this work suggests that gestural motions can convey a range of approachability even in non-anthropomorphic objects.

Keywords **-** Emotion, Gestures, Movement, Physical Interaction, Welcome

Relevance to Design Practice **-** This research will be useful to designers of interactive objects seeking to actively engage users or to communicate usage suggestions or product availability.

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Interactions group, which investigates the role of embodied action in communication and collaboration between people and designed objects. Major research objectives of the group are understanding the implicit role of physical cues in coordinating joint action, incorporating embodied presence and gestures to facilitate remote collaboration and ensemble play, and developing a broader array of actuation prototyping technologies for use by engineering and interaction design students. Dr. Ju teaches as an Assistant Professor in the Graduate Design program at California College of the Arts; she is also the founder of *Ambidextrous Magazine,* Stanford University's Journal of Design. Dr. Ju received her PhD in Mechanical Engineering from Stanford University in 2008; she also has a MS from the Media Laboratory at MIT, and an undergraduate degree from Stanford.

Leila Takayama is a human-robot interaction (HRI) research scientist at Willow Garage, a company that is researching and developing open-source, non-military personal robots. Coming from a human-computer interaction (HCI) background, she is now focusing upon understanding human encounters with robots in terms of how they perceive, understand, feel about, and interact with robots. Her research combines psychology and communication research methods to identifying ways to better design computational and robotic systems to effectively interact with people. She completed her PhD at Stanford (2008), where she was advised by Clifford Nass. During graduate school, she worked part-time at Palo Alto Research Center (PARC). Prior to Stanford, she completed her BAs in Cognitive Science and Psychology at UC Berkeley (2003).

Introduction

Approachability is a critical aspect of interaction design; designers need to convey when users are invited to interact with designed services. This objective is particularly critical when designing publicly used systems like doors, vending machines or kiosks that people use incidentally (Dix, 2002). The stakes for the user's experience are high; if such systems do not appropriately convey welcome to passersby and engage them in interaction, subsequent niceties and refinements of the system's design may be rendered irrelevant. Unlike many aesthetic qualities, such as visual form or personality, approachability is a dynamic characteristic, a property that might vary based on the time of day, the state of the system, or the identity of the person the system is addressing. This dynamicism is a unique and fundamental aspect of interactive products; because there is little in the way of design convention to guide the design of dynamic behaviors, designers of interactive systems often grapple with how to convey approachability.

Automatic doors exemplify the possibilities and pitfalls of designing approachable interactive systems. We have all experienced the welcome, convenience, and ease of having doors sweep open before us as we draw near a building. Automatic doors are common enough to be conventional, invisible—almost unremarkable—and yet still they suffer from interaction problems. Any sustained observation of a building employing automatic doors will reveal numerous breakdowns: people have difficulty distinguishing automatic doors from non-automatic doors; people inadvertently trigger the doors without meaning to; people walk toward the door too quickly, or not quickly enough; people frustrated in their attempts to trigger the door before or after regular hours. These problems show that extended use and familiarity alone are not sufficient to attain the critical sense of approachability; the conventions of design fail to respond to the broader dynamics surrounding the door to help people understand when the door is offering ingress, and when it is not.

What guidance, then, can we offer the designers of automatic doors? One possible answer lies in the theory of implicit interactions (Ju, 2008), which posits that the gestures and patterns of interaction that people use to subtly communicate queries, offers, responses, and feedback to one another can be applied analogously to the design of interactive devices to improve people's ability to "communicate" with interactive devices without necessarily resorting to having explicit speech. These gestures and interaction sequences could include aesthetic considerations, but are fundamentally oriented towards functional concerns about whether implicit behaviors and signals are noticed and properly interpreted by interactants.

The "offer" is one class of implicit interaction; offers perform the critical function of alerting potential interactants to the possibility of a joint action (Clark, 1996). A doorman can offer to open a door for a passersby, and thereby invite them into a building, by making eye contact with people, overtly placing his hand upon the door handle, motioning towards the door and even opening the door slightly; all of these actions let people know that they are able and welcome to enter through the door, and people respond predictably to this social engagement. The theory of implicit interactions suggests that we can design automatic doors analogously, employing equivalent sequences to enable engagement, overt preparation, deictic reference and demonstration, to convey a sense of welcome and to achieve a predictable response.

In this paper, we present a pair of studies that examine the use of door gestures to present different degrees of "approachability." In the first study, we use "Wizard of Oz" techniques to gesture physical doors at pedestrians; in the second, we use web-based video prototypes to show participants a range of door gestures. The goal of both studies is to show that door gestures will be interpreted in a predictable fashion by a range of study participants, even when the door gestures themselves are non-conventional. This work functions as a "proof of concept" for use of communicative analogues suggested by the theory of implicit interactions; designers looking for insights on how to convey approachability—or a range of other dynamic characteristics—can look to human-human interactions for conventions of communication when they lack communications of design to fall back on.

Related Work and Theory

In our studies, we are examining the way that an interactive object's actions influence a person's cognitive, affective and behavioral response. Although much research has been done on the influence of visual and tactual aspects of a product's design (e.g., Crilly, 2004, Krippendorf, 2008, Boess, 2008), and, more recently, on the role of aesthetics of interaction (e.g., Dalsgaard, 2008, Baljko, 2008), far fewer studies address the functional role that interaction plays on the user experience. Our study seeks to validate a theory about how to pattern the design of interactive products around human implicit interactions.

While implicit interactions may precede, prevent, or augment verbal or other explicit communication, they mediate interaction without requiring "linguistic" communication (Clark, 1996). Implicit interactions have two key qualities: they are *dynamic,* adapting their appearance, behaviors and responses to changing situations, and they are *demonstrative,* adopting embodiment and action for expression. These two properties make implicit interactions distinct from merely functional actions, which are not necessarily changing and not necessarily meant to be interpreted in any way, and explicit interactions, which are literal (employing words, symbols or graphic elements) rather than embodied. People use implicit interactions to communicate queries, offers, responses, and feedback to one another all the time. We extend an open hand to offer help; we gently pull back objects to signal that they are not for sharing; we avoid eye contact if we don't wish to speak to someone. The theory of implicit interactions argues that such interactions can be applied analogously to the design of interactive devices to improve people's ability to "communicate" intuitively with interactive devices (Ju, 2008b).

The theory of implicit interactions has its roots in human-centered design methodology; the design of implicit interactions requires practitioners to spend ample time observing people to understand their interaction patterns, and also user tests to gauge people's responses to designed interactions. However, its principal qualities, dynamicism and demonstration, make it unique from other human-centered approaches. For instance, previous work on product personalities (Desmet, 2008) and interactive characters incorporate physical interaction and animated behaviours into interactive product design, but they employ action or embodiment to convey intrinsic qualities, such as character, personality or purpose, rather than the changing dynamic qualities, such as mood, readiness or availability, that implicit interactions would communicate, and they tend to focus on subjective concerns as opposed to pragmatic issues about how to communicate to enable joint action.

The use of physical movement and other implicit means of signaling might be thought of as an extension to theory of affordances. Affordances are variously described as the actual (Gibson, 1979) or perceived (Norman, 1988) properties of an object that relate its potential for use by the perceiver. Gaver extended the notion of affordances into the realm of the interactive with the concept of sequential affordances, which are revealed over time (Gaver, 1991). Objects employing these complex affordances may be thought of as dynamically communicating potential for action through their unfolding behavior. While there is substantial overlap between the design principles suggested by the theory of affordances and that of implicit interaction design, there remains an important distinction between the two: affordances rest on people's perceptual abilities as a means of discovering potential use, whereas implicit interactions rely on people's communicative abilities regarding potential use. To improve an affordance to enter a building, a designer would focus on making the passability of the doorway more obvious; to improve an implicit interaction to enter a building, a designer would focus on making the doorway express that the passerby was welcome to enter.

The aforementioned example also illustrates the social aspects of implicit interaction. The non-verbal communication channel employed in implicit interactions is often used by people to express feelings, emotions, motivations, and other implicit messages (Argyle, 1988). Indeed, the instinctive reflex to interpret emotional expression in perceived actions causes people to attribute emotional motivations to non-human and even non-animal actors. For instance, Heider & Simmel (1944) found that people interpreted moving objects in the visual field "in terms of acts of persons." Subsequent studies by Michotte (1962) involving simple depictions of two moving balls showed that while some movements elicited "factual" descriptions, others caused people to attribute motivations, emotions, age, gender and relationships between the two objects. This suggests that designers can design interactive environments to signal both subtly and expressively, much as animators create subtle expressiveness in otherwise inanimate objects (Lasseter, 1987). This socio-emotional aspect of implicit interactions is notably absent from discussions about affordance. As a consequence, implicit interactions are a natural and powerful way to communicate messages about engagement or avoidance, approval or rejection.

STUDY 1: PHYSICAL PROTOTYPE PILOT

Study Design

As an exploratory pilot study, we employed a field experiment on gesturing doors. We used Wizard of Oz techniques (Dahlbäck, 1993) to gesture a physical building door at participants who happened to be walking near the door during its deployment (N=48). The primary interests of this pilot study were (1) how people interact with the door and (2) how do they interpret the dynamic motions of the gesturing door. We took note of whether the participant was walking toward the door or walking by the door at the time of the encounter with the gesturing door. Over a three-day period, we tried three different door trajectories: open, open with a pause, and open, then quickly close. Each participant only saw one of the door trajectories; hence, it was a between-participants study.

Materials

For this experiment, we selected one of a set of double doors that featured a large pane of glass that enable people to see into the building. A human operator stood to the side of the door, out of view from passers by, and acted as a wizard, pushing the door with a mechanical armature attached to the door's push bar. We used gaffer's tape to hide the armature and Contact Paper to obscure the windows to the sides of the door to create the illusion that the door was opening on its own. (See Figure 1 for the experiment as seen from inside the building and see Figure 2 for the view from outside the building.)

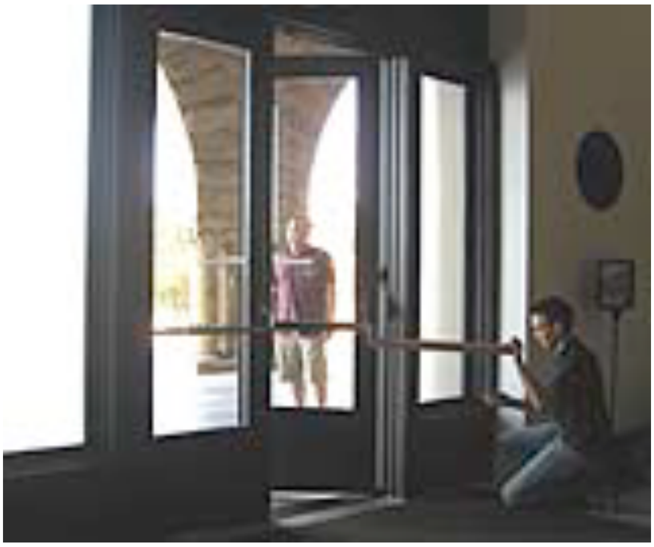

Figure 1. Wizard of Oz setup. A hidden door operator uses a mechanical armature to gesture

The paper questionnaire contained two open-ended questions: "What did you think was happening when you saw this automatic door move?" and "Assuming it functioned properly, how did you interpret the door's movement?" The questionnaire also included closed-ended questions that queried participants on 10-point scales with the following questions and anchors:

How did you feel about the door?
(1) very negative – (10) very positive

The door seemed to intend to communicate something to me.
(1) strongly disagree – (10) strongly agree

The door seemed to think when it communicated with me.
(1) strongly disagree – (10) strongly agree

The door was reluctant to let me enter.
(1) strongly disagree – (10) strongly agree

The door was welcoming me.
(1) strongly disagree – (10) strongly agree

The door was urging me to enter.
strongly disagree – (10) strongly agree

Procedures

The procedure for the study required three to four experimenters. One was the door operator mentioned earlier. Another experimenter acted as a monitor, waiting casually outside of the building and surreptitiously triggering an alert to the door operator inside via walkie-talkie when pedestrians neared the door. The other experimenter(s) approached the pedestrians with the paper

Figure 2. Person walking (a) by and (b) towards the door. Note the monitor on the right.

questionnaire after they had seen the gesturing door move.

Only those people who approached the door from the direction shown in Figures 1 and 2 were chosen to encounter the gesturing door because anyone approaching from the other direction might have seen the door operator and armature. Experimenters approaching people first queried participants to gauge whether they had noticed the door's motion before giving them a paper questionnaire. Some people declined to fill out the questionnaire; the most common explanations for non-participation were lack of time and inability to speak English. Most people (48 out of 64) opted to fill out the questionnaire and many even discussed the study with us at some length. Date, time, participant gender, and experimenter condition were noted on the back of each questionnaire.

Data Analysis

We used univariate analysis of variance (ANOVA) to analyze the data, using door trajectory as the independent variable and participant walking direction as a covariate. Because participants were not randomly assigned to walking direction conditions, walking direction was not used as a full independent variable. Each questionnaire item was analyzed as a dependent variable in an ANOVA.

In addition to the statistical analyses, we present descriptive statistics and observations from this pilot study that fed into the next iteration of this study design.

Study 1 Quantitative Results

During the experiment, 64 people nearing the door noticed its motion; 48 of them opted to fill out the questionnaire. An additional 38 people did not notice the door's motion. Distributions of door motions and walking trajectories for participants who noticed the door move and filled out the questionnaire are reported in Table 1.

Door trajectory had a significant influence on valence of feelings toward the door, perceptions of reluctance, welcoming, and urging on the part of the door. Walking direction had a significant influence on perceptions of the door as urging one to enter. These results are presented in Figure 3 (mean and standard error values), Tables 2 (main and interaction effects), and are further described in this section. Differences in sample sizes are due to non-responses by some participants to some questions.

Table 1. Frequency distribution of pilot study participants for conditions

	Door Trajectory			
	Open	Open w/ pause	Open, then closed	Total
Person walking by	11	7	19	37
Person walking toward	2	4	5	11
Total	13	11	24	48

Table 2. Study 1: Analysis of Covariance Summary for Influences of Door Trajectory (Independent Variable) and Person Walking Direction (Covariate) Upon Valence of Feelings Toward the Door, Perceived Reluctance of the Door, Perceived Welcoming by the Door, and Perceived Urging by the Door

Measure	*Source of Variance*	*Sum of Squares*	*df*	*Mean Square*	F
Valence of Feelings Toward the Door	Walking Direction	1.309	1	1.309	0.516
	Door Trajectory	27.255	2	13.627	5.37**
Perceived Reluctance of the Door	Walking Direction	4.874	1	4.874	1.018
	Door Trajectory	64.437	2	32.219	6.728 **
Perceived Welcoming by the Door	Walking Direction	18.293	1	18.293	2.081
	Door Trajectory	60.727	2	30.363	3.454 *
Perceived Urging by the Door	Walking Direction	40.678	1	40.678	5.858 *
	Door Trajectory	19.157	2	9.578	1.378

** $p < .01$, * $p < .05$

Door trajectory significantly affected the valence (negative to positive) of participants' feelings toward the door, $F(2,44)=5.37$, $p<.01$: open ($M=6.62$, $SD=2.06$), open with pause ($M=6.55$, $SD=1.57$), and closed ($M=5.06$, $SD=1.27$). Bonferroni post hoc comparisons of door trajectory revealed significant differences between "open" and "open, then close" door trajectories, $p<.05$. No significant main effect for walking direction was found.

Door trajectory also significantly affected how reluctant the door seemed to be, $F(2,43)=6.73$, $p<.01$: open ($M=1.67$, $SD=0.78$), open with pause ($M=2.18$, $SD=1.66$), and closed ($M=4.25$,

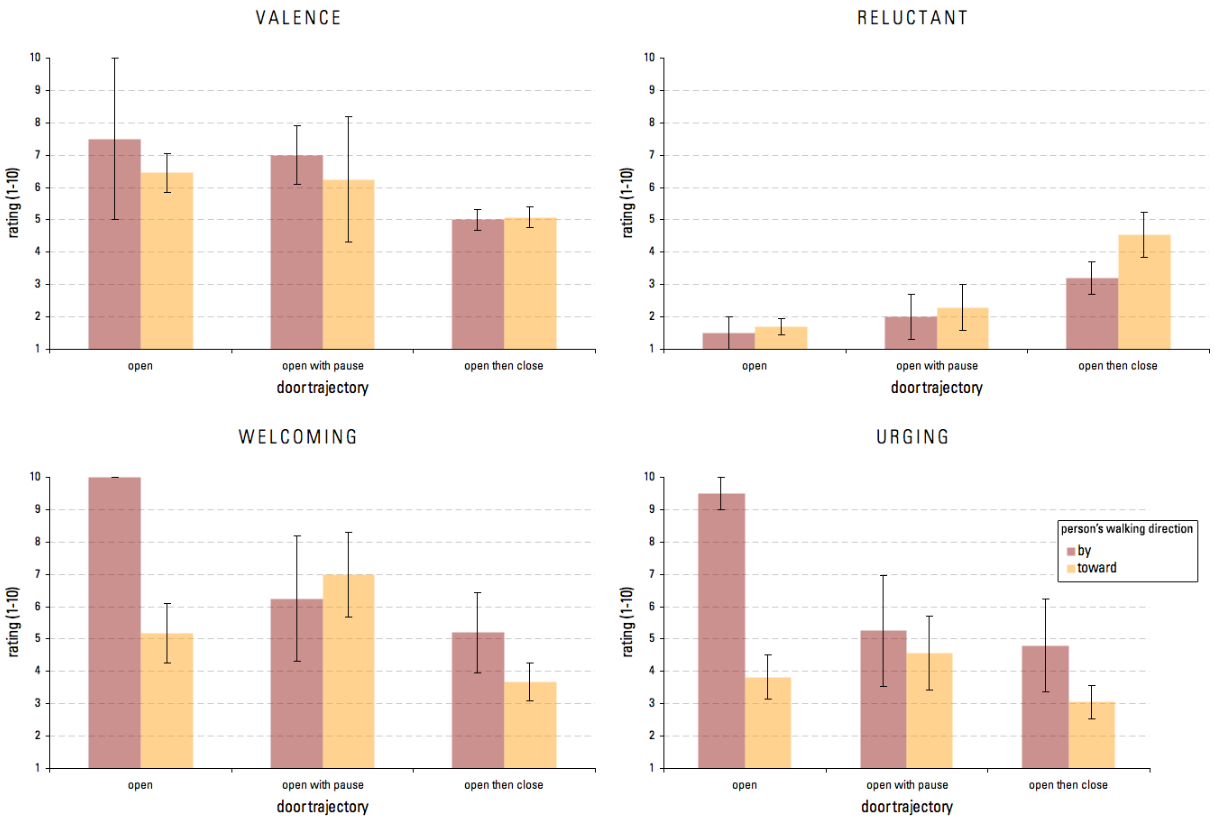

Figure 3. Mean +/- std. error values for Study 1 Door Perception Factors

SD=2.77). Bonferroni post hoc comparisons of door trajectory revealed significant differences between "open" and "open, then close" door trajectories, $p<.01$. Again, no significant main effect for walking direction was found.

Door trajectory also significantly affected how welcoming the door seemed to be, $F(2,44)=3.45$, $p<.05$: open ($M=5.92$, $SD=3.33$), open with pause ($M=6.73$, $SD=3.44$), and closed ($M=4.00$, $SD=2.59$). Differences approached significance between the "open with pause" and "open, then close" door trajectories, $p=.08$. No main effect for walking direction was found.

Finally, walking direction significantly affected how urging the door seemed to be, $F(1,44)=1.38$, $p<.05$: walking by ($M=3.57$, $SD=2.44$) and walking toward ($M=5.82$, $SD=3.31$). However, door trajectory was not found to significantly affect perceptions of the door as urging one to enter the building.

These data analyses also did not reveal significant results for questions about apparent intention or apparent cognition of the door.

Qualitative Results

Written responses to the open-ended questions were too short for any meaningful response coding. The average length of response was 29 characters for the first question ($M=29.4$, $SD=14.8$), and 19 characters for the second ($M=19.0$, $SD=15.9$). The likely cause for the brevity of response is that participants filled the questionnaires out while standing, and on their way to another destination.

Discussion

The results of the pilot study were promising in that they suggested systematically predictable in interpretations of door motions. Even in the noisy world of people going about their everyday lives, people showed consensus in their responses to the door motions.

Other insights gained from this pilot study came from qualitative observations and discussions with participants after they finished the questionnaire. One participant was a retail designer who was interested in the study because the door's motion caught his attention and made him curious about what was inside of the building; the goal of shops is to entice potential customers to walk through their doors.

One important observation for consideration in real field deployments of such systems are those people who did not notice the moving door. They tended to be walking and talking with others, talking on their mobile phones, listening to music players with headphones or walking very quickly, seemingly in a rush to some other destination. People are not always strolling idly down the street; they are often preoccupied, even during the summer on a nearly empty college campus.

One issue with this pilot field experiment was that participants who walked through the door also ended up seeing the door operator before they filled out the questionnaire. Fortunately, the majority of the data came from people walking by the door rather than toward it.

Another issue with this pilot field experiment was that participants who were unhappy with the door were also quite unhappy with the experimenter who requested their time to fill out the questionnaires. In particular, those participants who were walking toward the door and had the door shut in their faces seemed personally offended; several people were consequently unwilling to fill out a questionnaire "for the door."

Using a field experiment for this study gave us the benefit of seeing how people would respond to gesturing doors in a natural setting, particularly how they would respond the first time they encountered such a door. However, with this experimental setup, it was difficult to ask people to evaluate their reactions towards different door gestures in the context of other possible gestures; once they saw how the door was actually operated, it would be harder to interpret the movements as coming from the door itself. In addition, we were concerned about the effect that the natural variations in door gestures might have on people's interpretations. Finally, we found that the people encountering the door were usually enroute from one place to another, and were generally too impatient to write more than a couple of words in the written responses. Thus, for a secondary experiment, we decided to use video prototypes of gesturing doors, so that participants would be able to compare the different door gestures and scenarios, so that they would all be looking at the same door gestures, and so that they would have more time to explain what they felt different door gestures meant and how they responded.

STUDY 2: VIDEO PROTOTYPE EXPERIMENT

Based on the findings and identification of weaknesses in pilot study, we decided to conduct a more controlled experiment to further test people's responses to door gestures. In the video prototype study, participants were shown 12 different types of gestures using video clips embedded in a web-based questionnaire.

As in existing research (Heider, 1944; Michotte, 1962), these studies engage participants in an "interpretative" role (where they are asked to read the interaction) rather than an "interactional"

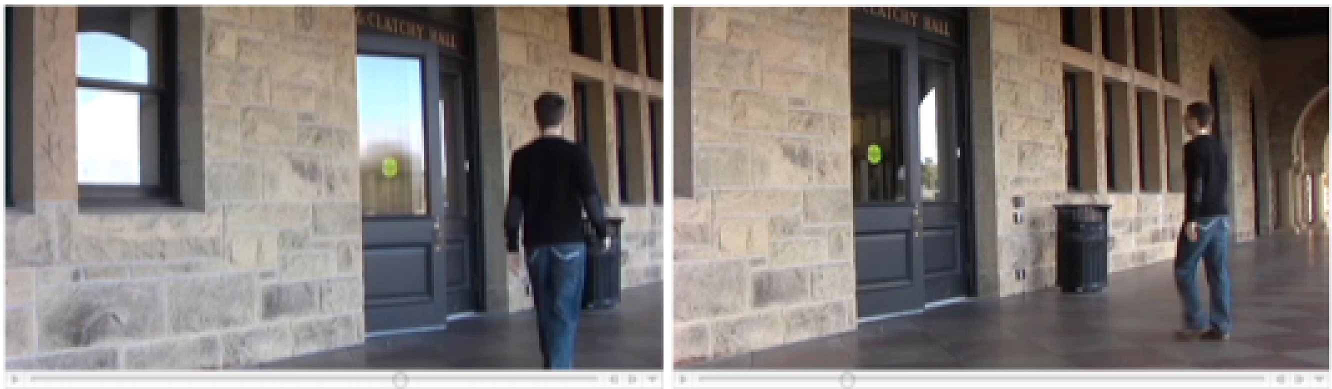

Figure 4. Screenshots of video of person walking by (left) and toward (right) the gesturing door

role (where they are asked to engage in the interaction). Although this method sacrifices some ecological validity, the video-prototype study enables better "participant" and door interactions, and cleaner isolation of feelings toward the door rather than toward the experimenter or study. In addition, this video prototype could be run as a within-participants study, thus reducing the possibility that our inadvertent participant selection and individual difference effects might be skewing our results across the conditions.

Study Design

This study added one new dimension, door speed, to the previous study design. Using a 2 (person walking direction: walking by vs. walking toward) x 2 (door speed: slow vs. fast) x 3 (door trajectory: open vs. open with pause vs. open then close) within-participants experiment design, we investigated the effects of both the door and the passerby's actions in this human-door interaction. Participants were recruited from a university community (N=51).

Materials

We performed a web-based experiment in which participants were shown 12 web pages that each contained an embedded video of a human-door interaction and questionnaire items. The clips were randomly ordered to address ordering effects. These 12 videos included every combination of our three independent variables: person walking direction, door speed, and door trajectory. Like the pilot study, the videos showed door gestures performed by a hidden door operator. On each page, participants were asked to play the video, imagining themselves as the person in the video. To prevent participants from merely reading the person's reaction as opposed to imagining what their reaction would be, we chose a camera angle that hid the walker's face and ended the clip before the person walked through the door or physically reacted to the door's gestures. Video clips ranged from 4 to 9 seconds in length, were sized at 540 x 298 pixels, and were encoded using Apple Quicktime format. (See Figure 4.)

Procedure

Participants who volunteered for the study were directed to the web page with gesturing door videos and questionnaire items. After watching each video, participants were asked to describe their experience with the door from the perspective of the person in the video, and to describe what they thought the door was communicating. They were then asked to rate the strength of their agreement or disagreement with three statements about the door, including how reluctant, welcoming, and urging the door seemed. These factors were selected because they were significant factors in the first study.

Data Analysis

Because indices are more robust to variance of individual items, we opted to create a single index of “approachability” for Study 2. Using Principle Component Analysis, we found that the three Likert indices (welcoming, urging, and reverse-coded reluctant) constituted a single factor, with Cronbach's α =.91. Therefore, we combined them into an unweighted averaged single factor, approachability.

Open-ended responses were coded and averaged across coders for valence (negative, neutral, or positive), apparent cognition (0 or 1), and apparent intent of the door (0 or 1) by two independent coders, who were blind to the experimental conditions. Valence was judged as an apparently positive, neutral, or negative feeling toward the door. Apparent cognition was judged according to how much the response made it seem like the door was thinking. Apparent intent was judged according to how much the response made it seem like the door wanted or meant (i.e., intended) to do things. Table 7 presents examples of real responses from participants in this study and how they were rated.

Table 3. Study 2: Example responses from participants and how they were coded in this study

Response	*Valence*	*Apparent Cognition*	*Apparent Intent*
I like the door because it differentiates between different people and I’m one of the people it lets in	Positive	Yes	No
The door opened automatically	Neutral	No	No
Frustrated that the door closed on me	Negative	No	No

The door decides to open for me	Neutral	Yes	No
When it recognizes that it is me, it decides it wants me to come in and opens all the way	Neutral	Yes	Yes
It wants to open for me, but it is having difficulties.	Neutral	No	Yes

Inter-rater reliability was reasonable: Cronbach's α values of .714, .616, and .723, for valence, apparent cognition, and apparent intent, respectively.

Study 2 Results

Unlike the pilot study, the video prototype study elicited far more descriptive responses to the open-ended questions. Average length of responses was 75 characters for the first question (M=75.1, SD=51.2), and 53 characters for the second (M=53.1, SD=42.1). This far exceeds the lengths from the previous study, despite the fact that each participant filled out 12 times as many open-ended questions.

After all of the descriptions were coded and averaged across coders, we used a within-participants full-factorial repeated-measures analysis of variance to investigate the effects of each of the three independent variables (person walking direction, door speed, door trajectory) upon each of the four dependent variables (approachability factor, valence of person's response, apparent cognition attributed to door, apparent intent attributed to the door). They showed systematically different responses amongst participants as shown in Table 4.

Table 4. Study 2: Repeated Measures Analysis of Variance Summary for Influences of Person Walking Direction, Door Movement Speed, and Door Trajectory Upon Perceived Approachability of the Door, Valence of Feeling Toward the Door, Perceived Intent of the Door, and Perceived Cognition of the Door.

Sources of Variance for Approachability of the Door	*Sum of Squares*	*df*	*Mean Square*	*F*
Walking Direction (WD)	4.688	1	4.688	2.337
Door Speed (DS)	2.225	1	2.225	2.071
Door Trajectory (DT)	481.949	2	240.975	70.917**
WD x DS	5.787	1	5.787	6.939*
WD x DT	4.014	2	2.007	2.607
DS x DT	5.838	2	2.929	2.761
WD x DS x DT	7.727	2	3.863	4.443*

**p < .01, *p<.05

Sources of Variance for Valence Toward the Door	***Sum of Squares***	***df***	***Mean Square***	***F***
Walking Direction (WD)	1.896	1	1.896	2.411
Door Speed (DS)	0.896	1	0.896	1.371
Door Trajectory (DT)	84.104	2	42.052	43.313**
WD x DS	0.474	1	0.474	1.102
WD x DT	8.715	2	4.357	6.40**
DS x DT	6.826	2	3.413	6.546**
WD x DS x DT	2.670	2	1.355	2.892

**$p < .01$, *$p<.05$

Sources of Variance for Perceived Intent of the Door	***Sum of Squares***	***df***	***Mean Square***	***F***
Walking Direction (WD)	3.879	1	3.879	5.001*
Door Speed (DS)	0.379	1	0.379	0.786
Door Trajectory (DT)	3.235	2	1.617	3.588*
WD x DS	0.061	1	0.061	0.287
WD x DT	1.008	2	0.504	0.927
DS x DT	1.326	2	0.633	1.621
WD x DS x DT	0.371	2	0.186	0.594

**$p < .01$, *$p<.05$

Sources of Variance for Perceived Cognition of the Door	***Sum of Squares***	***df***	***Mean Square***	***F***
Walking Direction (WD)	0.321	1	0.321	0.739
Door Speed (DS)	0.000	1	0.000	0.000
Door Trajectory (DT)	4.692	2	2.346	5.638**
WD x DS	0.628	1	0.628	1.490
WD x DT	1.949	2	0.974	1.481
DS x DT	1.000	2	0.500	0.980
WD x DS x DT	0.026	2	0.013	0.029

**$p < .01$, *$p<.05$

As seen in the repeated measures ANOVA results in Table 46, the door's trajectory had the most far-reaching effects across all dependent variables: approachability ($F(2,30)=70.91$, $p<.001$), valence ($F(2,88)=43.31$, $p<.01$), apparent intent ($F(2,42)=3.59$, $p<.05$), and apparent cognition ($F(2,50)=5.64$, $p<.01$). In general, the door that opened and then closed before the person got to the door made the door seem more negative, more intentional, and less approachable, whereas the door gesture that simply swung open was read as approachable but not necessarily cognitive or intentional. (See Figure 5, Row 1.)

Several two-way interactions were significant or nearly significant. Faster door speeds showed a trend toward exaggerating the effects of door trajectory. It significantly influenced valence, $F(2,88)=6.55$, $p<.01$, and nearly significantly influenced approachability, $F(2,30)=2.61$, $p<.09$. Similarly, the walking direction of the “participant” showed a trend toward exaggerating the effects of the door trajectory. It significantly influenced valence, $F(2,88)=6.40$, $p<.01$, and nearly significantly influenced approachability, $F(2,30)=2.76$, $p<.09$. (See Figure 5, Rows 2 and 3.) Bonferroni post hoc comparisons revealed significant differences in approachability of the door and valence of response toward the door between each of the pairs of conditions, all at the $p<.01$ level. Bonferroni post hoc comparisons revealed significant differences in perceived intent and cognition of the door at the $p<.05$ level between the “open” vs. “open with pause” and “open” vs. “open then close” door trajectories.

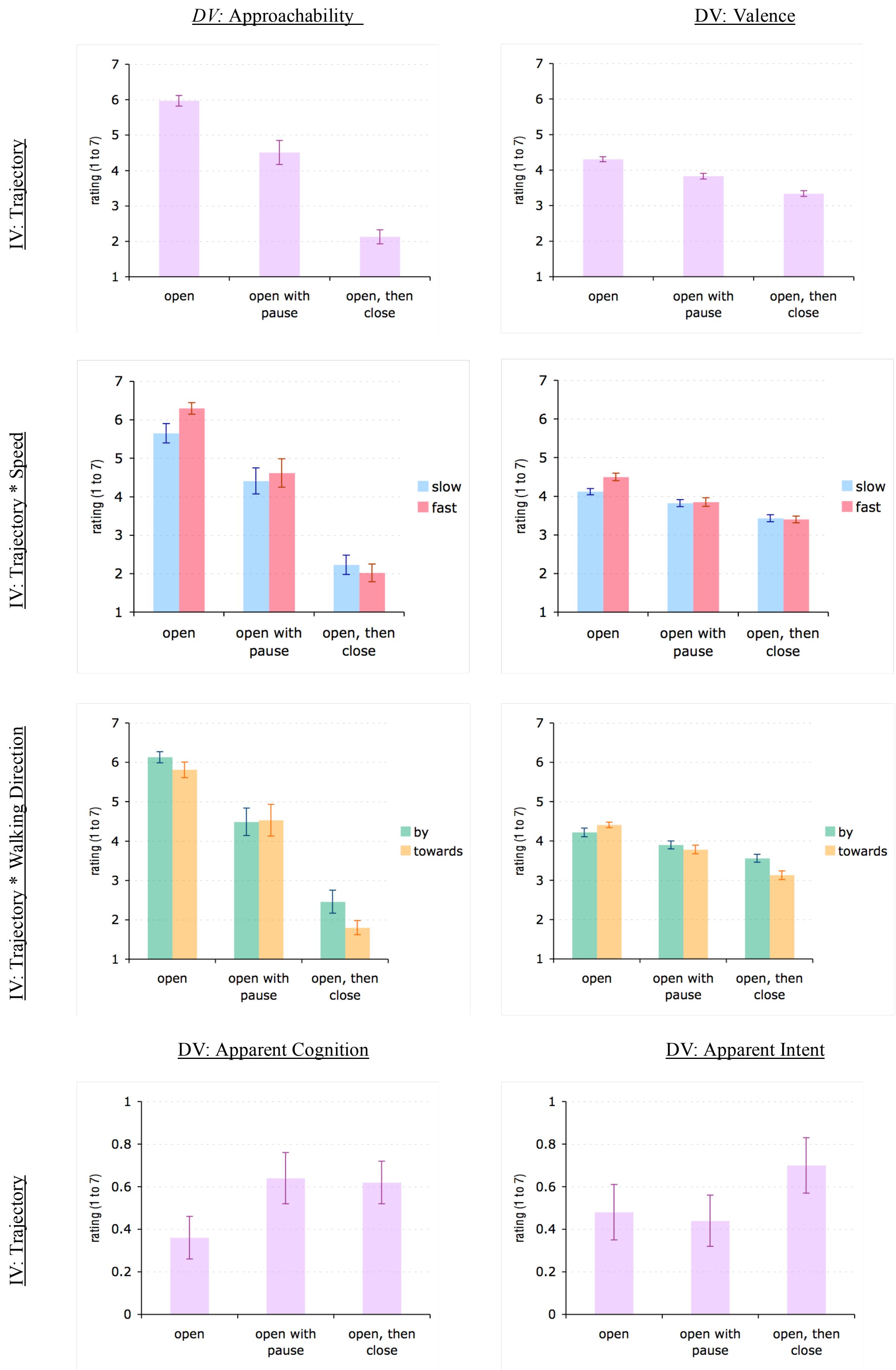

Figure 5. Mean +/- std. error values for Study 2 Door Perception Factors

Discussion

The core finding of this study is that people's interpretations of door gestures are highly systematic across several dimensions of door motion; despite the novelty of gesturing doors, untrained interactants "intuitively" read the gestures in systematic ways that were very consistent with the findings in pilot study 1. This suggests that people have a common understanding of door interaction and interpretation of the meaning of door gestures, possibly comparable to interpretations of human gestures (McNeill, 2005). This agreement supports the notion that door motion can provide an effective means of implicit communication.

The correspondence between the findings in studies 1 and 2 also point to the ways that employing different experimental methods can address or mitigate potential limitations inherent to each method. The field study had the benefit of being realistic, and querying people's first-hand experience of an interaction. However, it was difficult or impossible to perform as a within-subjects design, and was subject to a high degree of variability; if people's reactions to the door movements had not been so strong, this experiment could well have overlooked the effect. The video prototype study addresses the issue of variability and increases the likelihood of identifying causal relationships between interaction factors and people's reactions; however, absent the first study, it would be natural to question whether the fact that people are interpreting someone else's experience rather than having an experience first-hand might limit the validity of the experiment.

Since one of the major obstacles to implicit interaction development is the catch-22 that it is difficult to assess people's interpretations of implicit actions without distorting the effect by asking about them explicitly, the video prototype technique employed in this study is a methodological contribution to this area of research. While it will take more subsequent studies to see if people evaluating these interactions in an interpretative role are reasonable predictors of how people would feel in an interactive role, the coherence of these two studies provides promising indication that testing with video prototypes could provide a good approximation of people's real-world responses to an interaction design.

CONCLUSIONS

These two experiments indicate that door trajectory is a key variable in the doors expression of welcome, with door speed and the interactive context in which the door is opening acting as amplifying factors influencing how the door's gestures are interpreted emotionally. The wide range of expression available with only one physical degree of freedom suggests that designers can trigger emotional appraisal with very simple actuation; unlike previous systems, which employed anthropomorphic visual or linguistic features, our interactive doors were able to elicit social response by using only interactive motion to cause attributed cognition and intent. If designers can convey different "messages" in such a highly constrained design space, it seems reasonable to extrapolate that more information could be conveyed with more complex ubiquitous computing and robotic systems.

While this study focused on doors, our broader goal was to experiment with welcoming users to engage in joint action. The techniques explored here could be extended by other interaction designers in a variety of applications: in interactive kiosks patterns to proactively indicate to users what services are provided (Buxton, 1997), in word processors interfaces to proactively offer assistance formatting letters or printing without use of insufferable talking paperclips (Xiao, 2003), or by future work environments to indicate selective access to different badge holders (Weiser, 1991).

This research will assist designers of interactive devices by expanding the repertoire of implicitly communicative conventions that can be employed in the design of interactive systems that welcome users. Moreover, our implicit interaction approach takes an important step acknowledging that emotional responses to interactive devices may play a *functional* role, as well as an aesthetic one. The approaches we have employed, field studies and video prototype studies, can be very useful when designers need interactions that prompt consistent and objective interpretations, as opposed to the subjective reactions that might be desirable in applications with a more purely aesthetic purpose.

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