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SOCIAL PSYCHOLOGY OF PERSUASION APPLIED TO HUMAN–AGENT INTERACTION

Shenghua Liu
Department of Computer Science & Information Systems
University of Jyväskylä
Finland

Sacha Helfenstein
Agora Center
University of Jyväskylä
Finland

Ari Wahlstedt
Department of Computer Science & Information Systems
University of Jyväskylä
Finland

Abstract: *This paper discusses and evaluates the application of a social psychologically enriched, user-centered approach to agent architecture design. The major aim is to facilitate human–agent interaction (HAI) by making agents not only algorithmically more intelligent but also socially more skillful in communicating with the user. A decision-making model and communicative argumentation strategies have been incorporated into the agent architecture. In the presented content resource management experiments, enhancement of human task performance is demonstrated for users that are supported by a persuasive agent. This superior performance seems to be rooted in a more trusting collaborative relationship between the user and the agent, rather than in the appropriateness of the agent's decision-making suggestions alone. In particular, the second experiment demonstrated that interface interaction design should follow the principles of task-orientation and implicitness. Making the influence of the agent too salient can trigger counterintentional effects, such as users' discomfort and psychological reactance.*

Keywords: *human-agent interaction, user-centered design, decision making, persuasion.*

INTRODUCTION

Wide employment of agents in human–computer interaction (HCI) design has proven to be an effective way to construct robust yet flexible software architecture, in which information communication between the user and the technical system is mediated by many kinds of agents. The new interaction paradigm, evolved from traditional HCI, can be called human–agent interaction (HAI). In HAI, users are provided with a novel social collaborator during their tasks: the software agent (Wooldridge & Jennings, 1995). Obviously, this new interaction element opens a series of design considerations. At its core, HAI invites a more consequent evaluation and application of social psychological concepts to guide the agent's behaviors during interaction.

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Hence, a key question is what we can learn from social interaction research in the human context in order to design user-friendly, adaptive, and effective HAI (e.g., Nass & Moon 2000; Reeves & Nass, 1996). This exploitation of social psychological concepts in interaction design is a logical extension of the user psychological approach to human–technology research (Moran, 1981; Oulasvirta & Saariluoma, 2004)—a paradigm approach that is especially effective in projects where the product or technology is new or where the audience characteristics and habits are not yet well defined (Goschnick & Sterling, 2002; Murray, Schell, & Willis, 1997). Thus, it is ideal for contemporary HAI research pursuing psychologically-based, integral agent architectures (Pasquier, Rahwan, Dignum, & Sonenberg, 2006; Rahwan, 2005). In this vein, it is essential to evaluate core issues such as interpersonal communication, influence, persuasion, and decision making in interaction (e.g., Cialdini, 1984; Eagly & Chaiken, 1984; McGuire, 1969, 1985; Petty & Cacioppo, 1981; Sewell, 1989; Zimbardo & Leippe, 1991).

For instance, one may argue that the way by which agents interact with people should be considerate and comfortable. This applies naturally to the presentation or communication of information to the user in general. Another criterion is to design for effective, that is, influential agent support of user deeds. Because one of agent's crucial roles is that it can enhance or substitute human user decision making when encountering points of judgment during system tasks, the exertion of persuasive influence is quite central. Therefore, communication skills, including argumentative rhetoric, dialogue strategies, and verbal proficiency, are highly relevant for the agent to effectively argue for its decisions, and to achieve the user's trust.

The present research concerned agent communication skills and the influence of such in the buildup and sustainment of a trusting collaborative relationship between the user and the agent. The core interest was the agent's ability to effectively persuade users during decision-making tasks in system interaction (e.g., Fogg, 2003; Parise, Kiesler, Sproull, & Waters, 1999; Stiff & Mongeau, 2002; Stock, Guerini, & Zancanaro, 2006). Persuasive design is an important complement to the traditional usability concept because it specifically addresses socioemotional dimensions of interaction. One problem with the traditional usability perspective is that it presupposes user need or motivation to utilize a tool. However, with the mushrooming of technological solutions, and ever-increasing functionalities built into them, it becomes of growing importance not just to allow users to do in a simple and effective manner what they essentially want to do, but to go above and beyond that, to influence their desire and inclination regarding what they want to do or use.

Agents, as sophisticated extensions to the interaction interface, are of core concern in this context. Agents are conceptualized as supports to user tasks in various ways, but often their use is based on a freedom-of-choice model. As a result, legitimate concerns are not so much whether users can in principal profit from agent use or in what way agent support is beneficial but, rather, whether users are willing to make use of the agent and how this is expressed in human–agent collaborative decision making. Hence, HAI is a suitable and interesting subject in persuasive interaction design research, especially in the context of the spreading relevance of agent technology in industrial applications (e.g., Luck, McBurney, Shehory, & Willmot, 2005; Wooldridge & Jennings, 1995).

Previous research has, for instance, investigated the potential of recommendation agents for electronic shopping to influence the human decision making by shaping user preferences (Häubl & Murray, 2001). Other research projects, such as those pertaining to the RPDenabled (recognition-primed decision) agent, focus on supporting decision-making teams by anticipating information relevant to their decisions based on a shared mental model (Fan & Yen, 2004). The results indicate that human teams, when supported by agents, can perform better in highly time-sensitive situations. Pasquier et al. (2006) developed an argumentation framework for an agent that is best suited to persuade other agents in a particular situation with a given standpoint. Social psychological insight is hereby applied to help in the exploration of belief/decision formation within a single agent and "social" interaction among many agents (Rahwan, 2005), yet not agent–user interaction. Finally, Katagiri, Takahashi, and Takeuchi (2001) reported on two preliminary experimental studies focusing on the nature and the effectiveness of social persuasion in HCI environments. In these types of studies, social factors, such as affiliation, authority and conformity, have been taken into account in interface agent design. Nguyen, Masthoff, and Edwards' (2007) experiment also suggests that dialog-based systems with the visual appearance of a conversational agent are preferred over systems that use text only. The former are perceived to be more personal and caring, less boring, and, to some extent, easier to follow. However, in spite of these valuable efforts, more research on the issues of collaboration and persuasion in HAI is needed.

CONCEPTUALIZING A PERSUASIVE AGENT IN A DECISION-MAKING TASK ENVIRONMENT

The major paradigm for the distribution of interaction roles between users and machines is that humans make decisions while machines carry out automated processes and routines. However, with user task complexities increasing and technology becoming more sophisticated, machines progressively enter the domain of decision making. Agents are the premier example for this latter development, geared at supporting user decision making on different authority levels, from merely offering useful information, to serving in advisory functions (e.g., decision support systems), to making decision in place of the user.

In the type of suggestive agent architectures explored here, users should maintain the dominant role during interaction; that is, the agent leaves the final decision to the user but tries to persuade the user to accept its decision. As noted above, this also means that HAI confronts users with a new type of decision, in addition to the ones concerning the actual use task: whether and how to utilize the agent and its suggestions during interaction. Whereas agent development traditionally focused on the technical elements, such as highly sensitive and thorough algorithms, somewhat less effort has gone into understanding how users can be convinced to utilize an agent's suggestions and support offers. Logically, however, the latter must precede the former concern. And thus, we need to be concerned regarding how to make agents not only algorithmically intelligent, but also socioemotionally so.

Ultimately, agent participation in system interaction tasks should award users with processing capacity and accuracy benefits. However, gaining people's trust and will to collaborate are vital requirements for smooth and effective HAI. It is expected that people may doubt or feel reluctant to accept an agent's decision or the information the agent provides, especially when they are not convinced and cannot validate the trustworthiness of the agent. On the other hand, due to the limited information-processing capacity of the human working memory, users may also feel tempted to overrely on agent recommendations in order to reduce the cognitive load of decision making (Häubl & Murray, 2001). This tendency may backfire on well-functioning HAI within the context of system disturbances or other disagreements between user and agent assessments. In any case, acceptance or refutation of a given agent's standpoint may critically depend on the availability and form of presentation of the information.

Generally, we believe that the way agents influence people's thinking and behavior must exploit evidence from human–human interaction skills. This belief is based on the fact that people regard HAI as having similar social dynamics as human–human interaction (Katagiri et al., 2001; Nass & Moon, 2000; Reeves & Nass, 1996). Consequently, HAI design needs to consider the social dimension and significance of such interface agent traits as appearance, voice, and communication style (e.g., Guadagno, Blascovich, Bailenson, & Mccall, 2007; Hargie, 1997).

Architecturally, the present design of a persuasive agent was based on the BDI (beliefs, desires and intentions) agent model (Rao & Georgeff, 1992), which calls upon mental notions to encapsulate the hidden complexity of the inner functioning of an individual agent, and was further developed into a Procedure Reasoning System (PRS) by Ingrand, Georgeff, and Rao (1992). Although the cognitive BDI agent and its PRS applications have been well studied within the recent decade (Brazier, Jonker & Treur, 2002; Georgeff, Pell, Pollack, Tambe, & Wooldridge, 1998; Huhns & Singh 1998; Ingrand, Chatila, Alami, & Robert, 1996; Maes, 1994), current HAI research still continues in the design of the social BDI agent that has the ability to model human behaviors (Guzzoni, Cheyer, & Baur, 2007; Lokuge & Alahakoon, 2005; Pasquier et al., 2006; Peebles & Cox, 2006). In a broad sense, our research aims to enhance the agent's ability by incorporating social communication skills into the BDI agent decision model structure (see Figure 1). In this structure, the plan library holds the rules that ultimately govern decision making based on input and in accord with its beliefs and goals components, while the intentions component formulates the agent's decisions. Here, the architecture is essentially improved by

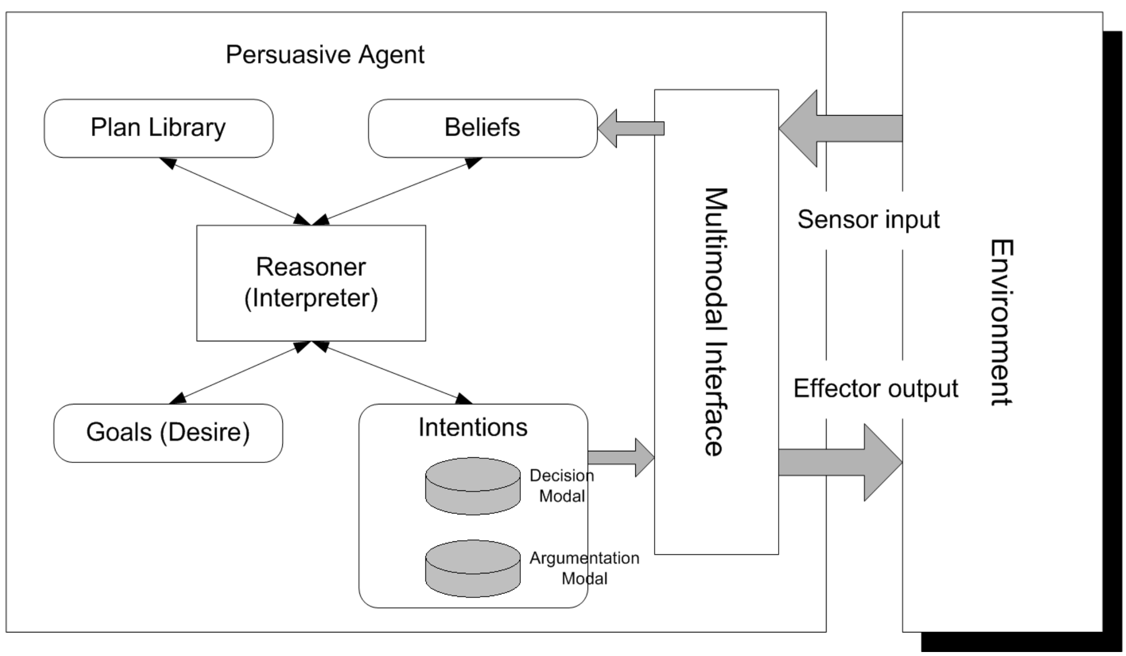

Figure 1. The architecture of the persuasive agent (adapted from Ingrand et al., 1992).

adding a decision model and an argumentation model to the intentions component so that the agent can argue for its decisions in a persuasive manner.

In operationalizing the decision and argumentation model outputs, we relied on various insights gained from original social psychology research. Considering that HAI is situated in the wider context of a user's task-oriented interaction with a system, time and processing resources are two obvious constraints to persuasion. This argues for the use of the heuristic model of persuasion (Chaiken, 1980) and Petty and Ciacoppo's (1981) "central versus peripheral framework." According to these theories, people's compliance with appeals often follow simple decision-making rules that are based on little-evaluated (contextual) persuasive cues, such as the likability of the message source, the connotations of expertise, or social (e.g., majority) reference. Other design-relevant findings concerning social collaboration are the positive correlation of people's willingness to cooperate with the frequency and richness of communication: For example, a visible collaboration partner is preferred over an invisible one (e.g., Deutsch, 1958; Wichman, 1972). In addition, friendliness, social liking, and request justification, among many others, have clearly shown to positively affect cooperation motives (e.g., Cialdini, 1984; Langer, 1978; Swingle & Gillis, 1968).

In contemplating such findings, we propose a design model for a persuasive agent that comprises five communication skill-relevant dimensions: agreeableness, anthropomorphism, informativity, persuasiveness, and adaptivity. They are explained more fully here.

1. *Agreeableness*. The agent should be agreeable, which is in line with most conventional criteria in interface design, requiring a friendly appearance and eloquent communication style. As an effect, users should feel willing and comfortable in interacting with the interface agent.
2. *Anthropomorphism*. Agents with human traits may be more attractive to users than machine-like ones. The anthropomorphic representation allows for a rich set of easily identifiable behavioral cues for social interaction (Hargie, 1997; King & Ohya, 1996; Takama, Dohi, & Ishizuka, 1998). Especially at initial exposure to the agent, these representations may make the agent seem more intelligent, capable of a higher level of agency, and more trustworthy.
3. *Informativity*. The agent's advice or decisions should be useful (necessary and sufficient) to the user and justified. Thus, when there is need for more information, the agent should provide more assistance. It is also valuable to accompany suggestions with some explanation or rationale. However, exhaustive information should be avoided since it can cause people to become impatient or overloaded.
4. *Persuasiveness*. Although all dimensions of communication skills affect the agent's persuasiveness, this dimension is concerned with more specific elements inducing social influence. Foremost, these include persuasive cues pertaining to the influence schemes of request justification, reciprocation, commitment and consistency, social proof, liking, authority, and scarcity (Cialdini, 1984). Persuasive behaviors should nevertheless be subtle enough so that people will not feel that they are being directed and apparent enough that people can understand it.
5. *Adaptivity*. Collaborative style and skill are usually not predefinable in absolute terms but must evolve and adapt to the HAI setting, especially the style and preferences of the user. Therefore, all of the above-mentioned dimensions outlining

the communication skills of the agent must be modifiable to take into account user goals and actions.

In order to apply this model to interface agent interaction design, and test the effect of agent communication skills on user persuasion, user–agent collaboration, and task performance, we constructed two experimental scenarios. Within such, we varied different HAI parameters according to the communication skill-relevant dimensions presented above.

EXPERIMENTATION

Investigating psychological dimensions of HCI is always tricky, especially when they pertain to socioemotional issues. A key challenge concerns the apt calibration of the task nature (e.g., difficulty) and setting in order to relate the elicited user actions and reactions in reliable ways to the experimentally chosen variations in stimuli, and not to peripheral (artifactual) or even external influences.

Our research primarily focused on the HAI element of persuasion. This emphasis on user motive and intention, rather than mere necessity and sophistication of implemented agent support, demands a task setting that favors the aspect of user preference over that of task operation requirements. For instance, it is a rather intuitive result that people would rely on agent support for a very complex task, where agent information processing capacities are evidently superior. However, when users notice (or have) almost no alternative to system or agent reliance, the value of persuasive design is obviously greatly undermined.

The real challenge is to persuade users in the context of relatively uncomplicated task requirements, because then users are given a true choice between working autonomously or collaboratively. On the other hand, it is worth noting that seemingly easy, repetitive tasks may pose their own performance challenges, due to impending lack of concentration or users' underestimation of the task demands.

The task chosen for the current study was easy enough (in terms of reasoning demands) to make the choice realistic, yet sufficiently challenging (in terms of operational demands, such as speed) in order to substantially afford the allocating of the user's attention to either the agent's suggestions or autonomous performance. This dilemma in deciding whether and how to employ the agent opens up an ideal influence space for persuasive agent design measures.

Experiment 1

Participants in our experiment needed to manage materials in a learning content management system (LCMS), with and without the help of various communicatively skillful interface agents. In order to make the task more natural, we also simulated agent performance failures.

Our general expectation was that users would benefit from agent assistance and, beyond this, that a persuasive agent design will be superior in its enhancement of HAI collaboration and task performances compared to a nonpersuasive agent design. Specifically, we assumed a communicatively skillful agent design to promote trusting HAI, which potentially jeopardizes user performance when the agent does not perform at optimal level, yet would enable quick collaboration restoration after such disruptions.

Method

Participants. The experiments were conducted in English by competent non-native speakers of English. We employed three experimental groups (H: no agent support, HAI: nonpersuasive agent support; and HA2: persuasive agent support), each containing 10 volunteer participants with university education backgrounds. There were 19 males and 11 females, aged 21 to 35, balanced across the experimental groups.

Materials. The task scenario was described to the participants as follows: A resource manager (i.e., human user) maintains a LCMS database that holds a number of local content files that frequently need to be updated. The user's task is to evaluate incoming files, that is, updates to existing files, and decide whether the current local copy should be replaced by the update or not (i.e., confirm or not confirm the update).

A new update announcement was received every 10 seconds, 72 in total. Each update was visible in a list for 30 seconds, after which it expired. During these 30 seconds, the participant needed to evaluate the incoming update, by comparing its attributes to those of the related local copy, and reach a confirmation decision. The unique relation of an incoming update to a file in the local database was expressed by a common ID. Further, the files had four attributes: *date* (the publication date, e.g., 13/06/2007), *size* (the file size, e.g., 1200 units), *rating* (i.e., the recommendation rank of this update, from 1 as the lowest to 5), and *cost* (the total cost of managing the file, e.g., 400 units). The ideal update for confirmation had four positive attribute values: It was newer, smaller, higher ranked, and cheaper than the local copy of the corresponding file. A clearly undesirable update had four negative attribute values; it was older, bigger, lower ranked, and more expensive. As a rule of thumb, participants were instructed to confirm an update when there were more positive attribute values than negative ones, compared to the local copy. Otherwise it was wise to not confirm the update.

The interface of the experimental group receiving the persuasive agent is depicted in Figure 2, using a female avatar (Elina) to symbolize the agent. No avatar was used in the nonpersuasive agent condition. The general interface further contained a table displaying the active incoming updates, interaction buttons and, in the agent-supported conditions, there was a text field containing the agent's messages. All user actions were performed with a mouse.

For each update, the two main operations participants could do were to confirm the update, by clicking the CONFIRM button, or to not confirm the update, by clicking NOT CONFIRM. In the agent-supported conditions, participants could also click the DO AS AGENT SAYS button to adopt the agent's suggestion. The psychological aim of this button was to attract and underscore the momentum of direct user-agent collaboration.

Design. Participants were naive to the purpose of the experiment, as well as to which experimental group they belonged. We employed a design with agent-support conditions as a between-subject factor (i.e., H, HA1, HA2) and three distinct task phases as within-subject factor applied to HA1and HA2. As illustrated in Figure 3, group H performed all 72 update decision tasks under unchanged conditions. In HA1and HA2, however, three task phases were differentiated: Phase 1, updates 1-24 (normal agent support), Phase 2, updates 25-48 (disrupted agent support, including misleading suggestions), and Phase 3, updates 49-72 (normal agent support). From the point of view of collaborative and trusting HAI, we may denote Phase 1 as

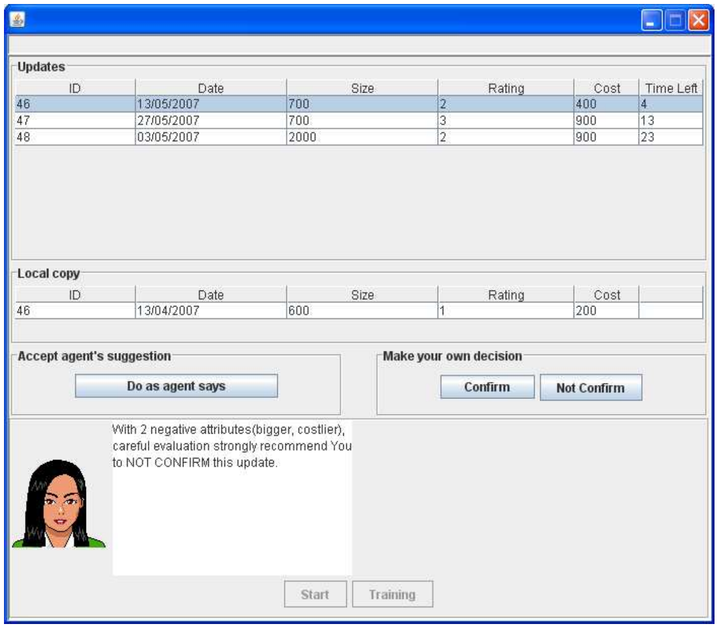

Figure 2. Interface in group HA2 (persuasive agent) for Experiment 1.

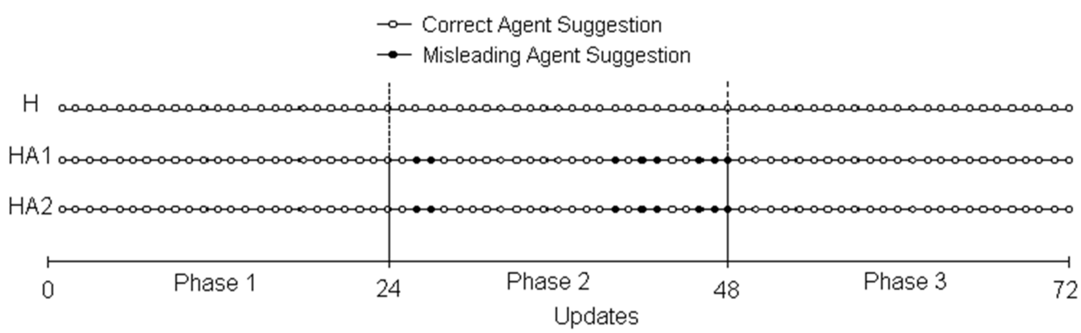

Figure 3. Experimental design: 3 experimental groups H (no agent), HA1 (nonpersuasive agent), and HA2 (persuasive agent), across experimental Phases 1-3.

the *collaboration and trust build-up* phase, Phase 2 as the *collaboration and trust disruption* phase, and Phase 3 as the *collaboration and trust restoration* phase.

In order to implement distinct agent behavior, the phases in HA1and HA2 differed with regard to the rules the agent used in deriving its decisions. We defined two main rules: R0 (i.e., confirm the update when there are more positive attribute values than negative ones, otherwise not confirm) and R1 (i.e., confirm the update when a selected attribute compares positively to the local copy). In Phases 1 and 3, the agent always made decision by using default R0, and its suggestions can thus be considered as correct throughout. In Phase 2, the agent made decision by using the adaptive R1. This meant that the agent's suggestion were at times incorrect and therefore misleading (e.g., one attribute was positive, but the three others were negative). Which of the four attributes the agent selected depended on the most frequently featured positive update attribute in the confirmatory decisions the participant made during Phase 1. For example, if the users had made 10 confirmatory decisions and 7 of these updates featured a newer date, which was more than for any other attribute, then the date attribute was selected to express R1. The rational behind this R1 design was to keep agent failures as credible and suggestive as possible.

In sum, the experimental task for group H was straightforward and did not include any agent support. Agents in HA1 and HA2 had the same adaptive decision-making algorithm but differed in the communicatively skillful presentation of arguments used to persuade users. Compared to the pragmatic agent in HA1 the agent in HA2 was more human-like and more eloquent in "promoting" its intentions to participants. Communication skills varied in line with four of the five dimensions presented earlier (see Table 1), the exception being adaptivity, to maintain equality between the agent-supported persuasion groups in this dimension. .

In HA2 the agent presented its suggestions by elaborating reasons in logical argumentation statements, set forth in a persuasive, friendly, personalized, and convincing way. Elina (the agent) also introduced herself before the task started, with the intention to obtain a sympathetic impression. Persuasive cues, like "certain," "most safe," "ideal choice," "should," "best," and expert reference, were used to make the statement more impactful. We sought to keep the argumentative message structure consistent throughout the experiment because of its effect on increasing the processing speed and thereby enhancing persuasiveness.

Feedback was implemented as the final element in the communication skill and persuasion factor. In HA1, a brief verbal feedback was given only when participants instantiated their decision by clicking CONFIRM or NOT CONFIRM. The feedback simply restated the user's decision. The agent in HA2 reacted specifically when the participant clicked the DO AS AGENT SAYS button by saying, "Good. Well done!" but did not give feedback when participants made their decision by clicking CONFIRM or NOT CONFIRM. The intention of this was to further promote direct compliance with the agent through a kind of positive, reciprocal reinforcement.

Procedure: Experimentation was implemented on a PC in a quiet laboratory. Participants first received written instructions of the task and the decision rules. The actual test session lasted 12 minutes, after which the posttest questionnaire was completed and participants were debriefed. The questionnaire items inquired about general reactions to the experiment, such as task complexity and time pressure, as well as four main aspects of their HAI experience (agent-supported conditions only): agreeableness, anthropomorphism, persuasiveness, and usefulness. Finally, HA2 participants also answered questions concerning the agent's appearance.

Table 1. Agent's Social Communication Skills in the Two Experimental Groups.

Dimension of Communication Skills	Agent in Group	
	HA1: Non-persuasive	HA2: Persuasive
Agreeableness	neutral	friendly, supportive feedback
Anthropomorphism	no appearance, robotic	human face, personalized (Elina)
Informativity	low (suggestion-only)	high (decision justification)
Persuasiveness	no (suggestion-only)	high (persuasive cues, facial cues)
Adaptivity	minimal	minimal

Results

Definition of performance parameters: For each update, users either clicked a button or missed out on it. Recorded click actions translated into a user instantiated decision action (DA), which could be either correct (CDA), that is, corresponding to the update evaluation rule, or incorrect (IDA), that is, not corresponding to the update evaluation rule. The performance of the participants could now be expressed by the degree of correctness of their decision making and the speed by which they instantiated their decisions. For *decision-making correctness,* we calculated the ratio RCDA = CDA/DA. The click action latency for each update served as the measure of the decision-making speed.

The complete descriptive statistical data of each group in each phase is depicted in the Appendix. It shows that, overall, participants averaged 56.8 CDAs (i.e., RCDA at over 80%, while on average 1-2 updates expired without participant action) and spent 11.2 seconds per update before instantiating a decision.

In order to test for statistically relevant effects, we applied a variance analysis of group decision-making correctness and speed averages. We did so first for Phase 1 only. Because Phases 2 and 3 introduced clearly distinct conditions in HA1 and HA2, when compared to H, a comparison of the total performance across all three groups was not reasonable. The variance analysis for average decision-making correctness supported significant group differences, $F(2,19) = 13.63$, $p < 0.01$[1]. Post-hoc, Bonferroni-corrected tests confirmed a superiority only when HA2 is compared to H, $t(14) = 4.51$, $p < .01$. This means that having an agent making correct suggestions is substantially more effective only when the agent communicates its suggestions in a skillful, persuasive manner (cf. Figure 4).

A variance analysis of decision-making speed group averages also hinted at the situation that agent support necessitated slightly longer interaction times, Welch's statistic $F(2,14.52) = 6.01$, $p < .05$[1]. However, no differences were found between the two agent groups (cf. Figure 4). This means the superior performance of the persuasive-agent-supported group (HA2) did not necessary come at the cost of a longer interaction time, when compared to HA1. Note, however, that heterogeneity in variances may overestimate the significance of group differences and therefore agent use may not at all be more time consuming.

Next, we prepared the analysis of agent communication skill effects in the context of the distinct task conditions over the three experimental phases. Because group H performed all 72 update decision tasks under unchanged conditions (see Figure 3), we can use these participants' performances as a base line during the first, second, and third set of 24 updates. For instance, the explanation of possible performance differences over the three phases in the light of a change in the collaborative nature of HAI necessitates the consideration of other sources for variability, such as learning or fatigue effects, or effects of variation in update difficulty. A repeated measure analysis revealed no significant differences in decision-making correctness or speed over the three phases, $F(2,18) = 2.69$, $p = .10$ and $F(2,18) = .99$, $p = .39$, respectively (see Figure 4). Merely looking at the trend, we found a noteworthy increase in correct decision actions after the first 24 updates, to a level that was maintained until the end of the experiment. Concerning the decision-making speed, we noticed an improvement for the second 24 updates, and, probably a fatigue-induced decline towards the end of the experiment (see Figure 4).

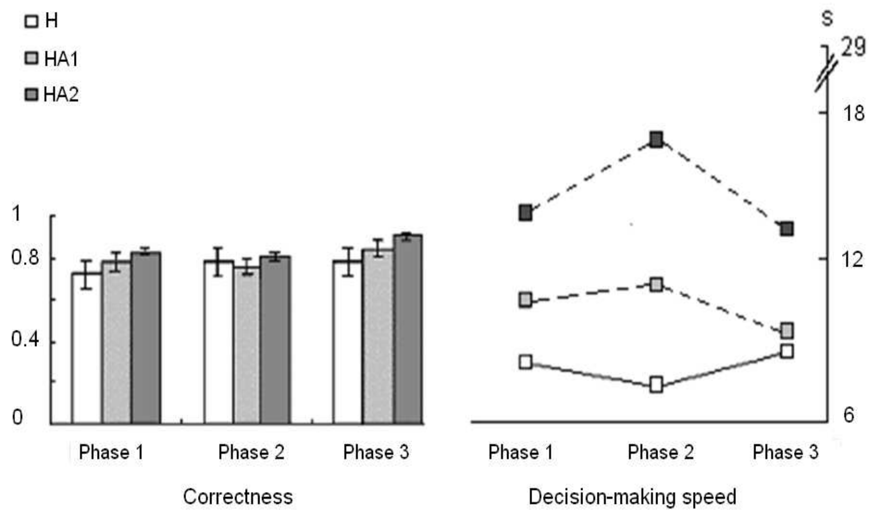

Figure 4. The experimental groups' (H: no agent; HA1: nonpersuasive agent; HA2: persuasive agent) mean ratio of correct decision actions (RCDA) and average speed of decision actions (TDA) across experimental Phases 1-3.

We then contrasted participants in the agent-supported groups (HA = HA1∪ HA2) to those receiving no agent support (H). Due to eight[2] misleading suggestions included in Phase 2 of the HA groups, we expected their performance to suffer somewhat in regard to both correctness and speed of decision making. Recovery from the collaboration disruption of Phase 2 would only occur in the final part of the experiment (i.e., Phase 3). As Figures 4 and 5 illustrate, this is exactly what we found. In Phase 2, the HA groups' mean ratio of correct decision actions dropped to the same level as observed for group H (see Figure 5). Remarkably, however, correctness did *not drop below* the level of H in Phase 2 despite the fact that, for participants in HA1and HA2, every third update was associated with a misleading (i.e., inapt) suggestion from the agent. This could mean that the agent support had helped these participants to develop greater decision-making proficiency during the first phase. Correctness of decision making by the HA groups recovered and improved in the third phase of the experiment. Associated with the drop in decision-making correctness during Phase 2, we noted a visible increase in interaction time (Figure 5) for the HA groups, which regressed in Phase 3. Statistically, we found a significant interaction between the phases and the factor of agent-support, however, only for correctness, $F(2,42) = 3.57$, $p < .05$[1], but not for speed of decision making, $F(2,46) = 2.13$, $p = .13$[1].

The reason for the lack of statistical proof for the phase effect on decision-making speed between H and HA groups may be due to the special collaborative relationship in HA2, which brings us to the comparison of the two agent groups. Indeed, we found a statistically significant greater time cost for decision making in HA2 as compared to HA1, but only in Phase 2, $t(2) = 1.81$, $p < .05$ (one-tailed). In contrast, HA2 experienced in absolute terms the

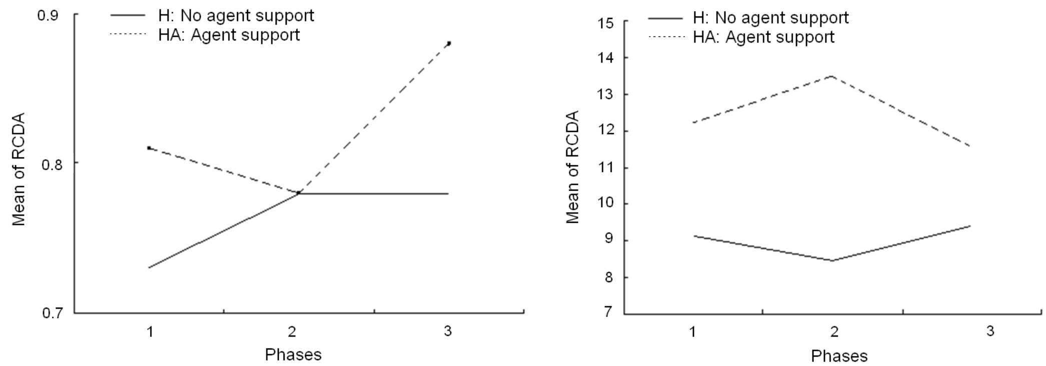

Figure 5. The comparison of correctness and time cost between the group with agent support and the group without agent support.

greatest performance improvement during the trust restoration Phase 3, that is, the greatest increase in decision-making correctness and speed (see Figure 4).

Comparing the total performances in HA1 and HA2, we found an expected overall superiority of the persuasive agent-supported users, $t(22) = 1.75$, $p < .05$, but no significantly greater time cost, $t(22) = 1.32$, $p = .10$ (both one-tailed). This decision-making correctness advantage is, in absolute terms, most substantial during Phase 3, that is, after the critical disruption of collaborative HAI and, thus, when trust restoration is most relevant, $t(18) = 1.42$, $p = .09$. Indeed, absolute mean differences in the ratio of correct decision actions grew steadily with each phase. This is a clear sign that collaborative HA1 with a persuasive agent is built up gradually, and not halted even by a disruption in the reliability of agent suggestions.

Next, we explored the posttest questionnaire results to attain an enriched picture of the participants' performances and their experiences. The majority of participants agreed that the decision-making demands in the experiment were at an appropriate (slightly easy) level. Interestingly, the participants in HA2, when compared to H and HA1, appeared to have found it easier and more unhurried to make the decisions, and noted agent support as most appropriate. This was despite the fact that the information complexity was clearly highest in HA2.

The answers of the agent-supported groups concerning the agent's agreeableness were overall strongly in favor of comfort, but friendliness also was widely attributed. There was no evident group difference here (HA1 vs. HA2), which may be caused by the circumstance that neither agent was particularly *un*friendly. Regarding anthropomorphism, the majority of the participants in the agent-supported groups[3] felt additional human-like features were undesirable. Nevertheless, participants in HA2 indicated that the appearance of Elina was comfortable and did not affect their decisions or how much they trusted the agent's advice. Agent-supported participants in general acknowledged the agent's persuasive traits, although many believed that the agent was not always right about the updates. However, a clear majority did not believe that the agent persuaded them to make wrong decisions. No difference between groups was evident. Participants in HA2 responded substantially more frequently to having used the agent's suggestions in order to assess their own decision making. Finally, the agent's usefulness was considered as good. Ninety percent agreed that the agent's advice was easy to understand and reading the suggestions was not a waste of time.

Finally, taking a glimpse at the click action logs, we noticed an unexpected result according to which participants in HA1 clicked the DO AS AGENT SAYS button more often than those in HA2. By checking the recorded experimental data, we found this was mainly caused by one participant in HA1 who used the DO AS AGENT SAYS button most of the time during the task. HA2 participants, however, were more likely to click the DO AS AGENT SAYS button when the agent provided a misleading suggestion, and thus seemed to be more strongly persuaded and to exhibit more blind trust. This strong collaboration was especially evident in Phase 2, where HA2 participants achieved considerably worse performance results by clicking the DO AS AGENT SAYS button, as compared to HA1 participants (see Appendix).

Discussion

The results of Experiment 1 substantiated the claim that people's performance, when supported by an agent, could be improved and, importantly, that an agent with persuasive communication skills could be superior to a communicatively less skillful agent. Accordingly, we conclude that the effectiveness of agent support could be achieved best when the agent communicates its suggestions in a skillful, persuasive manner.

Apart from this, we observed that the participants' task learning curve generally benefited from agent support. This helped participants develop a greater decision-making proficiency during the initial phase of the experiment, which made them partly immune to the disruptions in agent support introduced in Phase 2. As an effect of this, the agent-supported task performance did not decline below the level of the group without agent support, despite the fact that the agent provided misleading suggestions, on average, in every third update during that phase.

As a clear display of the deeper collaborative relationship between the user and the agent in HA2, we interpret that these participants were most sensitive and thus more negatively affected by the disruption in HAI collaboration and trust during Phase 2. We explain this in terms of heuristic processing's cognitive downside, such as error vulnerability and negligence (see, e.g., Shiffrin & Schneider, 1977), as well as cognitive dissonance (Festinger, 1957) induced by a persuasive agent making misleading suggestions. On the other hand, the subsequent trust restoration during Phase 3 was most impressive for participants who had a persuasive agent (the difference between HA1 and HA2 here was most substantial), which means that, although dissonance may be greatest for participants in HA2 in the context of the agent making flawed suggestions, trust and effective HAI is thereafter also most quickly restored.

Finally, the positive collaboration with the persuasive agent was also reflected in user experience. Although participants working with the persuasive agent received the largest amount of information, in principle demanding more interaction time, they experienced least task time pressure, and found the information given by the agent most appropriate.

Further examination of these issues was warranted. Two questions that especially demanded further clarification were the ones concerning the function of the interaction buttons used (i.e., CONFIRM, NOT CONFIRM, DO AS AGENT SAYS) and the proper level of task difficulty.

Experiment 2

The second experiment was designed to further substantiate and complement our findings from Experiment 1. Three issues were addressed. First, we wanted to shed more light on the effects of the different interaction buttons in the interface design. Second, we wanted to isolate the impact of the message style (persuasive vs. nonpersuasive) by alternating randomly between them within a single user. And, third, we decided to increase task complexity, in order to raise the value of the agent support.

To recapitulate, participants in the first experiment were provided with different, yet partially redundant, interaction options: (a) They could instantiate their decision concerning the update confirmation by pressing either the CONFIRM or the NOT CONFIRM button; or (b) In the case of agreement with the agent's suggestion, they could instantiate their decision as a confirmation of the agent's decision by using the DO AS AGENT SAYS button. We termed the button functionality in the former interface interaction design as *task-oriented*, the latter as *agent-oriented*.

The DO AS AGENT SAYS button, as is our belief, underscores the collaborative element of HAI specifically because it can be used only in instances of decision convergence and compliance. It also allows executing the task in a blind manner, by making one's own performance completely dependent on the agent. On the other hand, if the participant derives his or her own assessment of the update, the use of the special button necessitates a conscious comparison and concluded agreement between the personal decision and that of the agent. Further, informal comments of users after completion of Experiment 1 indicated that the DO AS AGENT SAYS button may also trigger discomfort, mainly because it forces the participants to read the agent's message, which in a subtle way undermines their autonomy. This means that although the DO AS AGENT SAYS button can free a user's cognitive resources in the case of (fully) trusting human–agent interaction, it can also increase cognitive complexity and instigate discomfort in users' interaction experiences.

Therefore, we believe that an agent-oriented interface interaction design potentially triggers counterbeneficial effects, such as user discomfort and psychological reactance, and thereby resistance against agent's suggestions. This could easily be tested by designing an agent that performs at 100% correctness level. Hereby, greater reactance and, thus, a higher disagreement rate would logically result in a lower task performance.

A side effect of using randomized persuasive and nonpersuasive messages within a single interaction design (see the Design subsection) would, in our opinion, be a weakened buildup of the collaborative relationship between the user and the agent. This could possibly undermine the positive effects of persuasive agent communication upon decision-making correctness. We therefore caution that research on collaborative HAI is not easily reducible to single interaction instances. Concerning intra-individual variances in decision-making speed, we believed that the longer, persuasive agent messages would tend to increase necessary interaction time. In spite of this all, we hoped to secure some positive effects of persuasive messages upon performance.

Finally, increasing the task's information load would, in our opinion, display little influence on the core social psychological effects of persuasion. On the one hand, it may accentuate the utility of the agent, while on the other hand lower the overall performance level due to time pressure.

Method

Participants. We recruited 24 voluntary participants with university education backgrounds. The age range was from 20 to 32, and there were overall 14 males and 10 females, balanced across experimental groups.

Design. We used a mixed design with two experimental groups, featuring the critical interface interaction design differences (agent-oriented vs. task-oriented button design) as a between-subject factor and two types of messages accompanying the updates (persuasive and nonpersuasive) as a randomly applied within-subject factor. Randomization was used in order to avoid confounding the agent–message types with particular updates. As dependent variables, we included decision-making correctness and speed, as well as questionnaire-based indicators of HAI experience.

Materials and Procedure

The materials and procedure were largely identical to the first experiment. However, we made obvious modifications to the interface design and adjusted the task demands. As in Experiment 1, this experiment was conducted in English with competent users of English as a second language.

We used the same agent interface as in Experiment 1, but without the agent avatar, and only two interaction buttons. In the agent-oriented interface interaction design, the buttons featured were AGREE WITH AGENT and DISAGREE WITH AGENT. In the task-oriented interface interaction design the buttons stated CONFIRM and NOT CONFIRM this update.

The agent's message contents were directly adapted from the HA1 condition in Experiment 1 for nonpersuasive messages, and from the HA2 condition for persuasive messages. The number of updates was reduced to 50, while the attributes rose from 4 to 7. This clearly increased the task complexity and raised the value of agent support. The added update attributes were *scalability* (i.e., the ease of updating from the old version to the new version), *security* (i.e., the level to which the update is safe against unauthorized use), and *maintainability* (i.e., the quality of being easily maintained). The value range of these attributes was 1 (*lowest*) to 5 (*highest*).

In the posttest questionnaire, we focused on participants' assessment of the agent's performance (e.g., "The agent was probably always correct"), their appreciation of the agent's support (e.g., "The agent distracted me from the task"), their evaluation of the agent's influence on their own performance (e.g., "The agent's messages strongly guided my decision making"), their comfort with the agent's assistance (e.g., "Having an agent helping during decision making was comfortable"), and the task difficulty (e.g., "There were too many [update] attributes to consider"). Participants were given the opportunity to provide additional comments and remarks at the end of the questionnaire.

Results

Of the 50 updates, participants instantiated, on average, 44.6 decision actions (DA), of which 32.3 were correct (CDA). Thus, average decision-making correctness dropped to 72.75%, when compared to Experiment 1. Participants averaged 17.2 seconds per update, with every tenth (but for some participants, as much as every second) update expiring before a decision was instantiated. Both results reflected well the increased task demands.

Mixed design variance analyses confirmed that the agent-oriented group performed, overall, inferior to the task-oriented group in terms of decision-making correctness, $F(1,20) = 3.15$; $p < .05$ (one-tailed). This group difference was, in absolute terms, most pronounced for updates with persuasive agent messages. In fact, although this was a statistically nonsignificant interaction effect, there were strong indications that participants in the agent-oriented interface condition suffered from persuasive agent messages, as compared to non-persuasive ones, while this relation was contrary in the task-oriented condition (see Figure 6). Message persuasiveness showed no main effect on decision-making correctness.

Concerning task speed for all updates, we found a strong overall tendency for persuasive messages to increase task time, $F(1,22) = 4.11$, $p = .06$. This seemed easily explainable based on the lengthier message texts involved, and affected both groups in a comparable manner (i.e., no group or interaction effect was found).

However, from a psychological perspective, it was interesting to look at the correct and incorrect decision-making outcomes separately, since only the latter would trigger cognitive dissonance due to the implication that the user had to disagree with the agent's suggestion. As apparent from Figure 6 (right side), time-cost increase for persuasive messages was limited to and strongest for participants in the agent-oriented interface interaction design, who had to *explicitly disagree* with the agent's suggestion. During correct decision making, persuasive messages, although richer in syntax, actually decreased interaction costs ($F(1,22) = 9.62$, $p < .01$), here in comparable manner for both groups.

Finally, looking at the posttest questionnaire results, we found that the task, as intended, was judged overall as challenging, yet not too difficult. Participants did not indicate that they sensed the flawless functioning of the agent, which supported the natural validity of the experiment. Two thirds said that they could keep up their concentration until the end. We further found that the majority of participants experienced the agent's assistance as helpful and rather comfortable, and thus not annoying or distracting, or strongly seductive as such.

Concerning group differences, and consistent with our expectations, we found nevertheless a significantly lower level of interaction comfort in the group with agent-oriented interface interaction design, $U = 29.58$, $Z = 2.71$, $p < .05$. No other significant findings emerged.

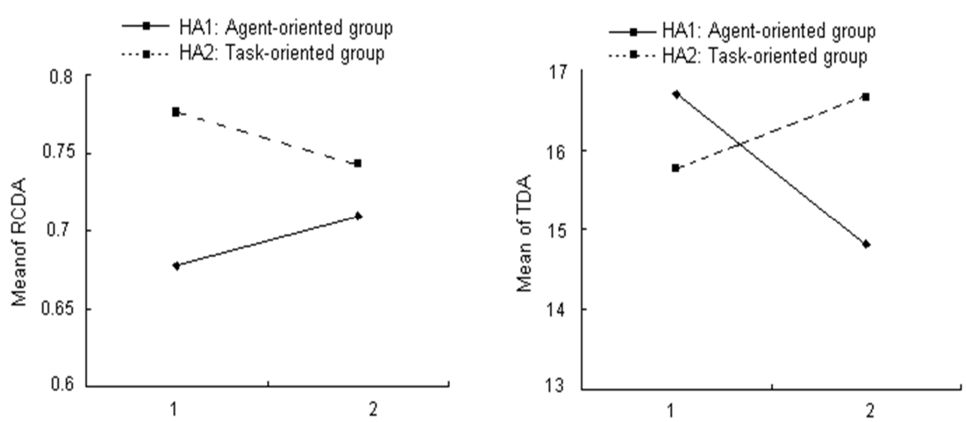

Figure 6. The comparison of correctness and time cost for incorrect decision making between the agent-oriented and task-oriented groups for different agent message types (1: persuasive; 2: nonpersuasive).

Discussion

Both the number of updates handled and the decision-making correctness diminished in the second experiment, as compared to the first, which reflected the increased complexity of the task (i.e., nearly double the number of update attributes to consider). The agent's message type (persuasive vs. nonpersuasive), which alternated randomly for each participant during the test session, did not seem to affect user decision-making correctness. This would confirm our view that the positive performance effects of HAI collaboration depends on the relatively slow process of trust buildup based on consistent persuasive agent behaviors. Persuasiveness is not visibly effective when message types vary arbitrarily.

However, although both experimental groups received the same updates and agent messages, participants in the agent-oriented interface interaction design chose more frequently to disagree with the agent, resulting in inferior task performance. This was very interesting, considering that this group had the opportunity to click simply the AGREE WITH AGENT button every single time in order to score a 100% correct result. We interpret this finding in terms of psychological reactance, that is, the natural human reluctance to accept external authority and the need to retain a sufficient level of autonomy during decision making (cf. Brehm's theory of psychological reactance, 1966). The finding was also in line with these participants' more critical evaluation of HAI comfort.

Further, the results suggested that reactance is especially fueled by persuasive agent messages, and thereby also triggering interaction time costs. Rejecting the agent's decision by clicking the DISAGREE WITH AGENT button, of course, raised the salience of the contradictory action and may have been experienced as psychologically more distressing. The length of the persuasive messages had no negative effect on decision-making speed when the user's decision conformed to that of the agent. Indeed, we found here that persuasive messaging actually increased interaction speed.

The findings give rise to an important HAI-design criterion, according to which the nature of collaboration with agents should be subtle rather than explicit or overly salient. We should avoid situations in which users experience the agent as a central actor, and thereby retain a human-centric feel to the interaction.

GENERAL DISCUSSION AND CONCLUSIONS

The presented empirical facts substantiated our claim that HAI could be enhanced through the use of elements of persuasive agent design, for example, persuasive message cues familiar from research on social influence. The results overall demonstrated that a communicatively more skillful agent can boost user task performance without the legacy of slower interaction time. The most appropriate interpretation of these effects hinted at an augmentation of users' trust and collaborative attitude regarding the employment of the agent. The findings of Experiments 1 and 2 suggested that absolute performance superiority induced by the persuasive agent grew steadily from update to update and phase to phase, and that beneficial task performance effects were not tied to single persuasive messages alone. This means, as in social reality, collaboration buildup is not instant, but evolves gradually. Hence, it is a persuasive agent using consistent, social psychologically sophisticated communicative cues, not the persuasive messages per se, which achieves the best effects.

The findings also revealed two valuable constraints or downsides to persuasive agent design. The first pertains to agent inaccuracies and system failures or disruptions, which are always a real threat in HCI settings. In such circumstances, trusting HAI may, as was shown, have negative performance implications. Nevertheless, the findings of Experiment 1 also showed that such disruptions, even if the agent's suggestions are outright false, do not need to be catastrophic. Indeed, positive collaboration can be restored well by a persuasive agent.

The second challenge concerns establishing a social psychologically apt level of persuasive influence. Experiment 2 in particular suggests that the interaction design should refrain from making the persuasive nature and collaborative demands too salient or agent-centered. Human users want to retain a healthy degree of autonomy; influence exertion easily can go overboard and trigger user discomfort and reactance.

In sum, the effectiveness of HAI is often questioned on the level of trust that people would grant to agents. This means that research on agent design should focus not only on the agent's algorithmic sophistication in solving a problem, but also on its ability to communicate in an apt manner with human users. The present work explicates an improvement to the conventional BDI agent structure by incorporating two important models into the intentions component (see Figure 1): decision making and argumentation. The decision-making model helps the agent formulate its intention according to the input from the environment and the reasoner's actions. The argumentation model handles the presentation of the intention to the user, applying social psychologically based communication skills in order to make the agent's arguments more persuasive. This kind of persuasive agent design, if applied with consideration, is user-task effective and best suited for building trusting, long-term HAI relationships.

We challenge future research to generate more insight into these issues. In particular, we encourage extension of our work by attending to matters such as user personality effects, including user-versus-agent-avatar gender interaction.

ENDNOTES

1. Outliers, defined as observations departing more than 1.5 inter-quartile ranges from the first and third quartiles, were excluded from analysis.
2. In groups HA1 and HA2, the agent also provided misleading suggestions, depending on the decision rule extracted from participant's prior decisions. Interestingly, we found that all participants followed without exception the date rule, meaning that the date attribute featured most frequently as a positive attribute in those updates the user confirmed. It also meant that all participants received the same number (8) of misleading suggestions for the identical updates during Phase 2 (see Figure 3). This conformity was despite that other update attributes (i.e., size, rating, and cost) were more likely to be featured in the confirmatory updates. We explain this in terms of a primacy effect (Asch, 1946): Because the date attribute was displayed as the first (furthest left) attribute in the interface, it might have been the first to be compared between the file's local copy and its update.
3. In the posttest questionnaire, only the agent-supported group participants were asked about the appearance of an agent. HA2 participants were asked about the human appearance of the agent in their testing, while HA1 participants were asked what they would have thought about an agent with human appearance.

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Authors' Note

All correspondence should be addressed to:
Shenghua Liu
Department of Computer Science & Information Systems
P.O. Box 35
FIN-40014 University of Jyväskylä, Finland
shliu@jyu.fi

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