# Touching Virtual Agents: Embodiment and Mind

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**Abstract.** In this paper we outline the design and development of an embodied conversational agent setup that incorporates an augmented reality screen and tactile sleeve. With this setup the agent can visually and physically touch the user. We provide a literature overview of embodied conversational agents, as well as haptic technologies, and argue for the importance of adding touch to an embodied conversational agent. Finally, we provide guidelines for studies involving the touching virtual agent (TVA) setup.

**Keywords:** Embodied conversational agent, Touching virtual agent, Simulated social touch, Haptic feedback, Augmented reality.

## 1 Introduction

Embodied conversational agents (ECA) attempt to approximate human face-to-face communication through the use of, for instance, facial expressions, vocal expressions, and body postures. Different communication channels are used to give the virtual agent a more lifelike appearance. For example, an ECA can display realistic listening behavior by using head nods and vocal utterances (e.g. "uhuh") while listening to a user telling a story [57]. Other examples include the use of facial expressions to express the agent's emotional state [68], and the use of laughter by an agent to appear more human-like [93]. All of these signals affect the way users interact with the virtual agent [3]. However, one communication modality that is known to have strong effects on face-to-face communication between two human conversation partners, and that has been largely overlooked in ECAs, is touch [4]. Though social touch occurs less frequently between co-located individuals than other forms of social communication (e.g. head nods), it can have profound effects on the interaction [22][28]. For example, touch affects compliance to requests [34], can reduce stress [18], and can be used to communication discrete emotions [42][43]. These effects

are strongly dependent on the context in which the communication takes place [12], such as the relation between conversation partners [11], the body location of the touch [46], the type of touch [24], and the communication partner's culture [67]. Effects can range from very positive affective responses, such as in the case of receiving a hug from a loved one, to very negative, for example when standing shoulder-to-shoulder in a busy train. Here we present a project in which we developed an ECA that has the capability to touch the user, while displaying a number of realistic touch behaviors (e.g. body posture, hand movement, and tactile sensation): a *touching virtual agent (TVA)*. We will refer to any system which uses some form of virtual representation of an agent, in combination with social touch capabilities by the agent, as a TVA.

The goal of the here presented project is twofold: first, by adding the tactile modality to an ECA we extend the communicative capabilities of the agent. We take another step towards ECAs that can display all the communicative subtleties of human-to-human communication, in an attempt to make communication with ECAs more lifelike. This has benefits for the use of ECAs in a range of scenarios such as training, therapy, and entertainment [13]. Second, a TVA (an ECA with social touch capabilities) would allow for the controlled study of tactile social behavior. Social touch by the agent could be studied in conjunction with other communication channels, such as facial expressions, and vocal utterances. The advantage of studying social touch using a TVA platform is that each communication channel can be minutely controlled, allowing for studies that disentangle the role of social touch in relation to other communication channels. This could provide valuable insights into the role of social touch as it occurs between co-located individuals, as well as social touch by virtual agents and social robots.

In the next section (Section 2) we outline related work on ECAs. We provide a brief overview of research into communication channels used in ECAs and describe different application areas. Furthermore, we outline research on the neurophysiology of touch, especially it's relevance for social touch. Next, we provide an overview of work on the effects of social touch. Finally, we outline research on touch mediated by technology and early attempts of introducing touch to virtual characters. In Section 3 we describe our proposed TVA system. We outline design decision based on literature, and describe the features of the system, and potential application areas. Section 4 contains a detailed description of all the technical components of the system. In Section 5 we provide guidelines for experiments to be conducted with our TVA system. Section 6 conclude the paper, and provide suggestions for improvements of the system and future research directions.

## 2   Related Work

In this section we provide an overview of research on ECAs, dealing with specific communication modalities (e.g. facial and vocal expressions), effects of agent behaviors on communication with the agent, as well as examples of applications

of ECAs. In addition, we describe research on haptic perception, specifically dealing with social touch, effects of social touch on behavior, we give a brief overview of existing devices that mediate touch, and finally describe early work on TVAs.

## 3 Embodied Conversational Agents

Embodied (virtual) conversational agents should be able to display behaviors and skills similar to humans to be considered human-like. To accomplish this, they should meet the following six requirements as mentioned in the literature [25][47]. Social agents should be able to:

1 Express and perceive emotions;
2 Communicate with high-level dialogue;
3 Learn and recognize models of other agents;
4 Use natural cues (gaze, gestures, etc.);
5 Exhibit distinctive personality and character;
6 Learn and develop social competencies.

However, it is important to recognize what the agent will be used for. An agent that is to autonomously interact with humans (e.g. a receptionist) requires a bigger skill-set than an agent that is used in a controlled lab-experiment. In a lab setting, it is common that an experimenter controls the behavior of the agent through a "Wizard of Oz"-like setting and the agent only generates the behaviors selected by the experimenter.

In this chapter we focus on an agent for controlled experiments. However, to provide some more background on ECAs, we give a brief overview of the components required for an autonomously interacting agent.

### 3.1 Complete the Loop

A human-like autonomous agent needs at least three general components: 1) some form of sensing. For example, sensing the environment and the (social) signals in this environment that are relevant. 2) mechanisms and models that can reason about the (social) environment and the role the agent has in this environment in order to come to goals the agent wishes to accomplish, and 3) a way to interact with the environment to attain its (social) goals. The actions by the agent influence the environment which leads to a new loop of perceptions, reasoning and actions by the agent.

**Perception.** An effective agent can perceive and comprehend its environment and interactants at a level that compares to that of real humans. This means that all human modalities need to be sensed by some sensor (e.g. camera for vision, microphone for sound, or a touch sensor for touch) and interpreted by some system.

Computer vision can provide object recognition [65] which can give the agent the ability to discuss the environment and make its conversational contributions grounded in the environment. Also, computer vision can give information about the social interaction itself, for example by recognizing human actions [80], detecting emotions from facial expressions [21], or recognizing the person that the system is engaged with [92].

Speech recognition can provide the agent with an understanding of the words or utterances made by the user, what the words (literally) mean, and what is meant with the words [75][82][91]. For example, if the agent requests something of the user and the user responds with the positive word "Sure", it makes a world of difference whether the user responds with sarcastic or enthusiastic tone of voice.

Speech and visual recognition are two important modalities for virtual (conversational) agents to perceive but there are of course more. This chapter focuses on touch, but there is little work on agent perception of touch. Some preliminary work has been done by Nguyen et al. [74] where the hand of a user is detected in relation to a virtual agent's body and the agent could give an (arbitrary) emotional response to a touch. Another example of a (robotic) agent that detects touch is [89], where a robotic pet can distinguish between different types of touch. The perception of touch by a TVA might be important for an autonomous agent, however the interpretation of the touch as well, would be paramount for meaningful tactile social interactions between an autonomous TVA and a user.

**Integration and Reasoning.** Hearing a string of words, seeing a set of objects, or feeling pressure on ones arm does not make a meaningful interaction. An agent needs to integrate the information from its different modalities and reason about the world around it to determine how to interact with the world.

The information that comes from different senses needs to be represented in some 'world representation', an information state [60]. Relating different 'pieces' of information is crucial to understand the world. The linking of information can have profound consequences. For example, the sound of a voice and the movements of lips are likely related, meaning that the words said by this voice are uttered by the person with the moving lips. The consequence is that this person is responsible for the content of the message and any appraisal of this message can be attributed to this person. So, if the system likes the message it could decide to like the person. Attributing words to a person and having an appraisal on what is said is not enough. Humans check if they understood the other and if they themselves are understood. The process of constructing a shared understanding is called "grounding". Only when an interaction is grounded it becomes social as both parties are talking about the same thing, their utterances are influencing and interacting with each other in a meaningful manner [16].

In social interactions, humans have an understanding of the beliefs, intents and desires of the other. This *theory of mind* [81] can inform the appraisal of the other's actions or lack of actions. For an agent it is important to have some

form of appraisal of the other's actions to maintain a consistent and human-like interaction.

Theories on how to model social interactions in agents often come from psychology. For example, Leary's interactional stance theory [61] describes the interaction between dominance and affiliation and how interactants influence each other on these dimensions. This theory has been used for modeling and motivating the social behavior of an artificial agent [9][10]. An agent that has emotions and a personality, that has an understanding of the world around it, and that can reason about this world is a more believable agent [3].

**Behavior Generation.** Once an agent 'has made up its mind' on what to say or do, it should have some way of expressing itself through its embodiment. A wide variety of agent embodiments exist ranging from very abstract (e.g. text-only dialog systems) to photo-realistic avatars with speech recognition, text-to-speech and real-time turn-taking [54].

The human communicative repertoire uses all the affordances of the human body. For example, we use our prehensile hands to gesture and touch, our eyes to (not) gaze at each other, our facial features to convey emotion, and modulate our voice to emphasize or clarify what we say [13]. An agent can but does not necessarily have to use the same repertoire when interacting. It might use text or abstract symbols to convey its message, it might use more realistic representations of these human communicative channels, or use a combination of abstract and realistic ways to communicate (for example text-to-speech and subtitles). For an agent to engage in social touch behavior however, it would need some way of 'reaching out' of the virtual world and entering a user's personal space, in order to deliver a touch.

In this chapter we discuss adding the touch modality to the behavioral repertoire of an agent. The limited amount of work on TVAs shows that users are able to interpret the agent's touch in terms of affect arousal and affect valence. Although other modalities are dominant, an agent that can touch can lead to a better relationship with the user [4].

## 3.2   Agent Frameworks

Several open-source frameworks are available to generate virtual human's including their visualization, behavior and voice. It is becoming more and more easy to tailor these frameworks to specific needs. For example, Virtual Human Toolkit [40], ASAP [96], and using crowd sourcing [84]. In this chapter we discuss a touching virtual agent where the agent embodiment (upper body, head and voice) is generated using the ASAP framework [96]. The ASAP behavior realizer (a SAIBA compliant BML 1.0 realizer [87]) is capable of incremental behavior generation, meaning that new agent behavior can be integrated seamlessly with ongoing behavior.

## 3.3    Application Areas

ECAs are being used in many areas, ranging from training and coaching [10][40], to adherence to therapy [55] and social training [13], to receptionist tasks [58]. The very first ECA (a chatbot named ELIZA) had a therapeutic role that was intended to be a parody of an actual therapist [95]. It is clear that ECAs are broadly deployable. Research into new abilities of ECAs can result in ECAs being applied in new scenarios and for new purposes. In the current work we integrated the tactile modality into the communicative repertoire of an ECA, creating a TVA. In combination with other communication modalities, a TVA could be more successful in certain therapy settings. For example, a TVA could enhance expressions of empathy [4]. Furthermore, a TVA might be used in therapy with people suffering from Autism Spectrum Disorder who experience anxiety being in close proximity to, or being touched by others [26].

## 3.4    Touch: Tactual Perception

The sense of touch as it is employed in, for example, the exploration of objects with the hands, or when giving someone a hug, is comprised of different sensory sensations that, combined, are referred to as tactual perception [64]. Tactual perception can be functionally divided into cutaneous perception (also called tactile perception) and kinesthetic perception (also referred to as proprioception) [37][64].

Kinesthetic perception refers to the awareness of the relative position of one's limbs in time and space, as well as one's muscular effort [37][64] which mainly draws on information from mechanoreceptors in the skin and muscles, as well as from motor-commands executed in the brain [37]. Through kinesthetic perception, a person can, for example, get information about the size and weight of an object.

Cutaneous perception pertains to sensations that are a result of stimulation of different receptors in the skin. The human skin contains thermoreceptors that sense temperature, nociceptors that sense pain, and mechanoreceptors that sense deformations of the skin [37][51][64]. Relatively recent findings demonstrate that the hairy skin, such as that found on the forearm, contains a type of receptive afferent (i.e. nerve carrying information to the central nervous system), called C Tactile afferent (CT afferent), which is not found in the glabrous, or hairless skin, such as that found on the palms of the hand. These CT afferents respond particularly strongly to gentle, caress-like touches, resulting in a positively hedonic, pleasant perception [5][62][63]. Furthermore, CT afferents offer poor spatial and temporal resolution [5][76]. This has lead researchers to propose the social touch hypothesis, which states that the caressing touches to which CT afferents are sensitive, are particularly pertinent in affiliative interactions with other humans [5][62][63][76]. This may be especially the case between mothers and infants. Furthermore, CT afferents have not been found in genitalia, supporting the distinction between CT afferent touches and sexual functions [62]. Considering social touch, these findings are important in that they highlight

aspects of cutaneous perception that play a vital role in social interactions. CT afferents might serve as a "filter", that operates in conjunction with other mechanoreceptors in order to determine if a certain touch has social relevance or not [70].

It has to be noted here that because cutaneous perception, in the form of mechanoreceptive sensations during, for example skin stretch, also plays a role in kinesthetic perception. Therefore cutaneous and kinesthetic perception can only be distinguished functionally, and not mechanically [64]. Indeed, situations where both cutaneous and kinesthetic perception play a central role are more common. This combination of cutaneous and kinesthetic perception is referred to as haptic perception [37][64].

Haptic perception is vitally important for the forming of one's "body schema" which refers to a postural model that is continuously modified and updated whenever the body moves or adopts a new posture [27]. As the body schema is important in the organization of movement, it must integrate information of cutaneous (e.g. information from skin receptors) and kinesthetic (e.g. position of limbs) perception. In order to integrate information from the surface of the skin (i.e. cutaneous perception), with kinesthetic information, stimuli presented on the body's surface must be transformed from locations on the body to locations in external space [27]. Moreover, multisensory integration (i.e. integration of information of other senses such as vision) can occur before the haptic sensation becomes conscious. This may either facilitate or impair one's perception of the haptic stimulus, depending on the spatial localization [27]. A well known example of this is the 'rubber hand' illusion [6]. In this illusion, participants see a rubber hand in front of them that corresponds to their own left or right hand. When the participants' hand is hidden, and the rubber hand as well as the hidden hand are stroked at the same time, and with the same velocity, most participants will experience the rubber hand as their own hand. When asked to point towards their hand participants who experienced the illusion will point more towards the rubber hand, an effect known as proprioceptive drift [6]. This finding lends strong support to the notion that the rubber hand is incorporated in the participants' body schema. Important in the triggering of the illusion are congruent mulitmodal cues (i.e. tactile and visual) and prior internal body representations [66]. The strength of the illusion is strongly dependent on a first person perspective, synchronous stimulation, and an anatomically believable rubber hand [66].

These findings are highly relevant considering the multimodal nature of the TVA setup presented in this chapter. The augmented reality setup might be used to elicit visuotactile illusions similar to the rubber hand illusion. Here the question would be, to what extent participants experience their own arm, as viewed through the augmented reality setup, to be touched by the virtual character.

### 3.5    Touch: Social Touch

As was outlined in Section 3.4 the human skin contains specialized receptors that serve a selective function in distinguishing social touches from all other

kinds of touch. This highlights the importance of touch as a modality in social communication. Social touch has been found to play a role in the communication of support, appreciation, inclusion, sexual interest, affection, playfulness, and attention getting [52]. Moreover, a large body of experimental research in psychology has demonstrated a number of effects of social touch on social interactions.

One of the most thoroughly researched effects of social touch, pertains to compliance to requests [28][44]. The general premise is that when a person requests something from another person, while at the same time briefly touching the other person's arm, hand, or shoulder, the receiver of the request is more likely to comply to the request than when the request would be made without a touch. This effect has been demonstrated in numerous ecologically valid settings, and with recipients being either aware or unaware of the touch. One of the first studies on the role of touch in compliance found that when touched, uninformed participants were more likely (51%) to return a lost dime in a phone booth, than participants that were not touched (29%) [56]. Moreover, a different study found that a brief touch on the customer's forearm by the waitress, would increase the amount of money left as a tip by the customer in a bar [34]. Similar effects have been found in a restaurant, where a touch by the waiter or waitress to the customer's forearm increased the customer's compliance to menu item suggestions by the waiter or waitress [35]. Furthermore, a brief touch to the forearm increased the chances that people would spontaneously help a confederate to pick up dropped diskettes [33], and increased the chances that students would volunteer to write down an answer on the blackboard during class [31]. In addition, touch increases the duration that participants are willing to spend on a repetitive task, such as filling out bogus personality questionnaire items [78], or giving an opinion on difficult social issues [73]. In most of the cases described thus far, the touches were applied to the arm of the participant. Indeed, touches to the arm, and particularly the upper arm, may yield the strongest positive effect on compliance, though this effect may be mediated by the gender of the toucher and receiver of the touch [79]. Moreover, the type of request may be important in gaining compliance [98]. Touch may have little effect on requests that require psychologically more costly behaviors, such as signing up for blood donations [32].

In medical settings research has shown that a touch by a medical practitioner increased the chances that a patient would adherence to their medication [36]. When touches given to elderly clients by caregivers in an elderly home were combined with verbal encouragements, calorie and protein intake by the elderly increased [20]. Touch by a nurse prior to a patient's surgery, can decrease a patient's stress level, both measured through self-report and physiological measures [19][97]. Similar effects of touch on the reduction of stress in patients' in intensive care units have been observed [41]. Beneficial effects of touch in the alleviation of stress in health care settings, may be stronger for more intense types of touch. Message therapy has been found to be both successful in the release of pain, as well as the improvement of the mood of cancer patients [59].

For a more complete overview of the effects of message therapy the reader is referred to [23].

The effects of social touch, as outlined above, are numerous, and occur in diverse contexts. However, the exact nature of the underlying mechanisms responsible for these effects of social touch, are still unclear [28][44]. One explanation is that the touch signals to the recipient that the toucher likes, and trusts him/her. The perception of need, or the elicitation of positive feelings would in turn increase compliance [28][78]. However, this does not explain those situations in which the recipient is unaware of being touched. An alternative explanation is that the positive effects of social touch are related to the sensing of pleasant touch by CT afferent nerves and the encoding of social touch in the posterior insular cortex [28][69][70]. Still, contextual factors such as the relation between the recipient and the toucher, could play a vital role. Indeed, whereas touch in collaborative settings enhances helping behavior, touch in competitive settings can reduce helping behavior [12].

Finally, touch does not only communicate positive or negative affective states, but the nature of the touch itself can be used to communicate discrete emotions. Studies have shown that participants in Spain and the United States could decode certain discrete emotions communicated to them solely through touches to the forearm [43]. Participants could decoded anger, fear, disgust, love, gratitude, and sympathy at above chance levels, whereas happiness, surprise, sadness, embarrassment, envy, and pride were decoded at less than chance levels. Accuracy ranged from 48% to 83% which is comparable to the decoding accuracy of facial expressions. Specific touch behaviors were observed for communicating distinct emotions. For example, anger was mostly communicated by hitting, squeezing, and trembling, whereas love was mostly communicated by stroking, finger interlocking, and rubbing. Moreover, when the encoders of the touches were allowed to touch the decoders of the touches anywhere on their body, an additional two emotions, namely happiness and sadness, were decoded at above chance level [42]. However, in a recent reanalysis of the arm-only experiment [43] it was found that some of the recognition rates were dependent upon specific gender combinations in the encoder-decoder dyads [45]. This again indicates the importance of contextual factors in social touch.

## 3.6   Mediated Social Touch

Since two decades, researchers have attempted to communicate a sense of touch at a distance, using haptic feedback technology. This can be referred to as remote, or mediated social touch [37]. Mediated social touch can be defined as "the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology" [37, p. 153]. Generally speaking reasons to add touch to remote communication are, that the communication itself becomes richer through the addition of an extra modality [8][14], that touch is particularly well suited for intimate communication [77], and that touch can be used in situations where other modalities might be inappropriate or overly distracting [29].

With these reasons in mind, numerous devices have been constructed that allow for two or more people to touch each other at a distance. For example inTouch consists of two devices of three rollers each. When one person manipulates the rollers on their device the rollers on the second device move accordingly. The idea behind inTouch was to offer people separated by a distance a playful interaction possibility [8]. ComTouch was conceived as a way to add tactile communication to telephone conversations. A force sensitive resistor would communicate the finger pressure on a mobile phone to vibrotactile feedback on a second phone. This way the tactile channel could be used for turn-taking, mimicry, and adding emphasis during a phone conversation [14]. Similarly, the Poke systems augments a mobile phone by adding an inflatable air bladder to the front and back of a mobile phone. During a phone call, force exerted on one bladder, results in inflation of the bladder on the other phone, which 'pokes' the cheek of the recipient. In a long-term study with couples in long-distance relationships, the Poke system was found to enhance emotional communication, and to add a sense of closeness to the partner [14]. Other systems that aim to provide a sense of closeness through mediated social touch are for example 'hug over a distance' [71], and 'huggy pajama' [90]. Both systems consists of a vest that allows a person to receive a hug at a distance from another person. A more general approach was taken with the design of the TaSST (Tactile Sleeve for Social Touch). The system consists of two sleeves each with a force sensitive input layer, and a vibration motor output layer. Touches to the input layer of one sleeve are felt as a vibration pattern on the second sleeve. The idea behind the TaSST was that it would allow users to communicate different types of touch at a distance [49].

Though many of the devices aimed at mediated social touch are promising, there has been a lack of empirical research into the effects of mediated social touch [37][48][94]. Still, studies have shown that mediated social touch, in the form of vibrotactile stimulation of the upper arm during a chat conversation, can have effects on compliance, that are similar to those in unmediated situations [38]. Using a similar 'haptic messenger' where participants could be touched on different body locations by either a same, or different gender conversation partner, it was found that mediated social touch was perceived as inappropriate when applied to certain body locations such as the stomach. Dyad composition in terms of gender did not have any effect [39]. Similar to studies on the tactile communication of emotions in co-located space [42][44], some studies have found that haptic feedback can be used to communicate diffuse affective states [88], or even discrete emotions using a force feedback joystick to simulate a handshake [2]. Moreover, the way people think about expressing emotions using mediated social touch, is relatively similar to what they would do to express those emotions in unmediated situations [50].

Mediated social touch is often used in conjunction with other communication channels, such as the visual and auditory channels. In a study, where mediated social touch in the form of a squeeze to the upper arm was used in conjunction with a verbal story, it was found that touches applied during emotional stories

enhanced feelings of closeness to the storyteller [94]. However, in a replication study investigating the effect of mediated social touch, at emotional and random moments during a verbal story on perceived social presence of the story teller, no effects of the touches were found [53]. Others found that touch applied in an immersive collaborative virtual environment did not enhance compliance to the request to sing [7]. Although this may be due to the psychological demanding nature of the request [32]. Conversely, a number of studies that used force feedback joysticks in collaborative virtual reality settings, found that the addition of haptic feedback of another person's actions enhances feelings of presence [15][30][85][86].

### 3.7   Touching Virtual Agents

The previous section outlined work on social touch mediated through haptic feedback technology. In most cases communication took place between dyads of participants, or participants were led to believe that they were communicating with another participant. However, the Media Equation theory suggests that humans interact with a perceived intelligent system as if the system is a human social actor [83]. Indeed, research into ECAs suggests that humans can engage in lifelike communication with virtual characters. Following this line of reasoning, touches applied by a TVA could be perceived by the user as social touches. Potential effects of co-located [28][44], and mediated social touch [37] might also apply here.

Some evidence for the notion that people indeed engage in realistic social touch behavior with virtual humans was found in a study into the way people touch digital objects [1]. Participants were tasked with brushing off 'dirt' from a virtual object using a force feedback joystick. Participants were presented with virtual humans, who would have dirt on their torso or face, and non-human objects such as geometric shapes. Results showed that participants touched virtual humans with less force than non-human objects, and that they touched the face of a virtual human with less force than the torso. Moreover, male virtual humans were touched with more force than female virtual humans [1].

In another study a TVA with a partially physical embodiment had the capability to squeeze a participant's hand through an air bladder system [4]. The TVA's face was displayed on a computer monitor situated on top of a mannequin body. The hand of the mannequin enclosed the participant's hand allowing the agent to squeeze it. In a series of experiments it was found that participants could perceive squeezes as expressions of affective arousal and valence by the agent. However, facial displays dominated the perception of affect. In an experiment where the agent expressed empathy for the participant, touches were found to enhance perceptions of the relation with the agent, but only for participants that felt comfortable being touched by others.

Social touch by ECAs, might be especially beneficial for interactions with physically embodied agents, such as social robots. In a study where participants observed videos of tactile interactions between a human and a social robot, it was found that social touch made the robot seem less machine-like and

**Fig. 1.** The components of the TVA setup. The monitor displays the agent's upper body, allowing the agent to gaze at, and talk to the user, as well as show body movements in accordance with the touch. The tablet computer displays the agent's hand touching the user. The user wears a vibrotactile sleeve to generate a tactile sensation in accordance with the agent's touch.

more dependable [17]. Other research, in which a social robot actually touched participants, found that social touch by a robot can enhance compliance to requests. After having their hand stroked by a robot, participants spent significantly more time on a repetitive task, and performed significantly more actions during the task [72].

## 4   Innovation

In the Section 2 we provided an overview of work on ECAs, and what is required to make them autonomously engage in human-like interactions. We detailed the concept of tactual perception, indicated that humans have specialized receptors for detecting social touches, and highlighted the importance of multimodal integration for haptic perception. In addition, we outlined some of the main effects social touch can have on interactions between co-located individuals. We drew parallels between social touch in co-located space, and social touch mediated through technology. Finally we described some early work on TVAs. In this section we built on the thus far discussed literature, to outline our TVA system.

The TVA setup consists of three components (see Figure 1) that are used in the social touch behavior of the agent. First, a visual representation of the upper body of the TVA. Second, using an augmented reality application, a visual representation of the hand of the TVA touching the user. And last, a tactile sensation that matches the location of the TVA's touch. To our knowledge, this is the first augmented reality TVA setup.

Where others have opted for a mannequin to represent the agent's body and extremities [4], our setup combines an augmented reality display showing the agent's hand with a monitor showing the agent's body. This setup allows for animated movements of the agent's body, arm, and hand to create a more realistic touching illusion. Moreover, by using a virtual representation of the agent rather than a physical representation, such as a social robot [72], we can incorporate more sophisticated facial facial expressions, as well as more easily manipulate the appearance of the agent. Also, the technical components required, are less cumbersome than those typically used in virtual reality [7], which requires a head mounted display and head tracking. As physical simulation of the agent's touch we opted for a vibrotactile display, attached to the forearm. Vibrotactile stimulation is often used in mediated social touch devices [14][49], and has been found to have the potential to elicit effects similar to co-located social touch [38][39]. We chose to apply the touches to the forearm because it is an appropriate location for social touch to occur [79]. Moreover, we did not want the user to be focussed on the touch in itself, as is the case with, for example, a handshake [2] which is a very conscious and deliberate touch. A touch to the forearm may be less obtrusive than a handshake, potentially allowing for the study of the effects of touches of which the recipient is unaware [28]. In addition, touches to the forearm might be more appropriate as a form of affective expression [43]. Finally, the combination of visual and tactile feedback was considered to be important in creating the illusion of the agent touching the user. Research suggests that for, for example, the rubber hand illusion to occur congruent multimodal cues are important [66]. While the illusion created by the touching virtual agent system does not pertain to body ownership per se, congruent feedback from both the visible agent's hand, and the tactile sensation might be important in creating a believable illusion of the agent's touch.

In the next section we outline the technical architecture of the system, and provide technical details of all of the system's components.

## 5   Technical Architecture

Building a TVA requires a virtual agent and a haptic device that can deliver the touching sensation. However, for the touch sensation to be believable, the integration of the the virtual world where the agent lives and the physical world where the user lives, is important. Specifically, the touch should consistently be attributed to the agent. This requires building consistent and believable agent behavior so that the touch is supported by the rest of the behavior (e.g. eye-gaze). Also, the setup of the entire agent system should allow for a believable presence of the agent. It should feel like the agent is actually there (albeit virtual).

### 5.1   A Virtual Touch

The agent's touch illusion is created using the setup depicted in Figure 1. A user that is interacting with our TVA wears a vibrotactile sleeve on his/her left
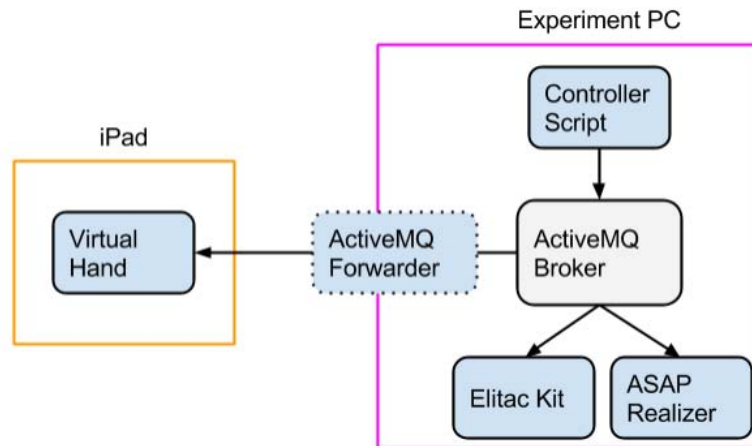
**Fig. 2.** An overview of the system components

forearm. This arm is placed under a tablet, meaning the user sees his/her arm 'through' the tablet. The virtual agent is displayed on a computer screen placed behind and above the tablet. The tablet and the computer screen are aligned so that, for the user, the shoulder of the agent lines up with the user's arm as seen on the tablet. When the agent touches the user, the agent first looks at the 'to-be-touched' area. Next, the shoulder and arm of the agent (on the computer screen) rotate and move forward towards the user's arm. At the time that the agent's virtual hand would reach the tablet's view, a virtual hand and arm enter the tablet's screen. When the virtual hand reaches the user's hand, it stops and hovers for a moment before going in for the touch. At the moment of contact between the virtual hand and the user's arm, the vibrotactile sleeve vibrates.

## 5.2    Components

The TVA system consists of four main components: a tablet computer, a vibrotactile sleeve, a virtual human, and a controller program. The components communicate over an ActiveMQ message broker (Figure 2).

**Controller.** The controller times and sends the commands to the different components for each agent action. Timing is important to create and maintain the illusion of a virtual presence that can touch the user. The controller is set up for easy manipulation of the timings of messages to different components. For example, if the tablet is moved further away from the computer screen the virtual hand should take slightly longer to reach the user, as the distance between the agent's hand and body becomes longer. Thus the timing of the touch should be altered accordingly.

**Fig. 3.** The vibrotactile sleeve with 12 vibrationmotors

**Vibrotactile Sleeve.** To generate the tactile sensation of the agent's touch we used an Elitac Science Suit.[1] The Elitac Science Suit is a modular system consisting of several eccentric mass vibration motors that can be attached to elastic bands of different sizes using Velcro. The intensity of vibration of each vibration motor can be individually controlled, with four levels of vibration intensity available. We attached 12 vibration motors to an arm-sized elastic sleeve, with approximately half a centimeter spacing between each motor, creating a high resolution tactile display (Figure 3).

**Virtual Hand.** The tablet (iPad, 4th Generation, Apple Inc., Cupertino, California) runs a Unity project that can track the position of the user's arm and the position of the tablet relative to the table, and thus where the screen with virtual human is, using visual markers. Next, an augmented reality overlay is used to display a virtual hand and a shadow of this hand. The position of the tablet provides the information necessary to determine the starting point for the virtual hand. The position of the user's arm determines the target location for the virtual hand. Also, to give visual feedback of the distance of the virtual hand to the user's arm, the shadow of the virtual hand was overlaid on the user's arm.

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[1] http://elitac.org/products/sciencesuit.html

**Virtual Human.** The virtual human is an instance of the ASAP-realizer [96]. The virtual human is controlled by sending BML-scripts that stipulate what it should do and when. The ASAP platform gives feedback on the progress and completion (or failure) of its actions. Such information might be used to time the actions of other components.

## 6    Research Applications

In this section we describe some of the benefits of our TVA setup. We focus specifically on the research domain. We discuss two future studies and provide the results of one pilot study, showing the feasibility of our setup as a research application.

### 6.1    Bug Demo

In the first technical demonstration of our system, the user can see a virtual bug walking on his/her arm. The tactile sleeve generates a tactile sensation of the bug walking on the arm. When the virtual agent detects the bug, she moves in to squash the bug on the user's arm. This slap is accompanied by an intense tactile stimulation.[2]

In this demo we investigated whether a "general" (i.e. discriminative) tactile sensation in the form of a bug walking on the arm can feel different from being touched by the agent. The participants in this demo reported that they felt the bug moving and that the tactile and visual stimuli created the illusion that a bug was walking on their arm. One participant stated he felt the urge to roll up the sleeve of his blouse because: "there was a big bug on my arm." The virtual agent's slap was reported to be effective. Participants reported things like "she got it!". This demo shows that the combination of visual and tactile stimuli can create the illusion of touch. The statements of the participants showed that they felt at least somewhat immersed in the scenario and as such could distinguish between discriminative touch and social touch.

### 6.2    Perception of Touch

The timing of the stimuli for the different modalities involved in detecting touch is a sensitive issue, as mentioned earlier. However, varying the timing of each stimulus can give us insights into elements that are important in 'building' certain touch behaviors. Incongruent visuotactile stimulation might 'break' the illusion of the TVA's touch. It would be of interest to investigate how much of a delay between the vibrotactile stimulation and the visual touch, would still constitute a touch be the TVA.

An extension of such a study, would be to present different types of touch (e.g. taps vs. strokes) to users. The modalities (visual and tactile) could be

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[2] A video of this demo is available at: `http://vimeo.com/71094353`

either congruent or incongruent For example, an incongruent stroke would be a stroking tactile stimulus combined with a visual tap. By varying the time of the behavior modalities and asking the participant to press a button as soon as they experience being touched, would give us insight into which modality is predominantly responsible for the perception of different touches. Also, it can show if the first notion of a touch (irrelevant whether this is visual or haptic) or if the complete package (user responds when the entire touch, both visual and tactile is perceived) is determinative.

## 6.3  Negotiation Task

As was outlined in Section 3.5, social touch can have numerous effects on social interactions. It would be interesting to investigate the role of social touch in a controlled manner with our TVA setup. De Melo et al. [68] used the iterated prisoners dilemma to investigate the effect of emotion on cooperation. In the iterated prisoners dilemma was described by [68] to their participants as: *"You and your partner are arrested by the police. The police have insufficient evidence for a conviction, and, having separated you both into different cells, visit each in turn to offer the same deal. If one testifies for the prosecution against the other and the other remains silent, the betrayer goes free and the silent accomplice receives the full 3-year sentence. If both remain silent, both prisoners are sentenced to only 3 months in jail for a minor charge. If each betrays the other, each receives a 1-year sentence".* They showed that participants cooperate more with a virtual human that displays emotions and that they perceive the virtual human as more human-like. In conjunction with varying emotional displays, the virtual human could apply a touch. The question here would be: do touches by the virtual human, in combination with certain facial expressions, alter a participant's decision in the prisoners dilemma?

## 6.4  Compliance Pilot Study

Social touch has been found to increase compliance to requests, both for co-located social touch [43] and mediated social touch [38]. Also, a previous study indicates that touch by a robot can increase the time and effort spend on a boring task [72]. In the current pilot study we wanted to see whether the TVA was able to increase compliance to a request when combining the request with a light touch on the arm. The TVA would make a request that the user perform a repetitive task, and combined this request with a touch to the arm of the user, or would make the request without a touch. For this study a task similar to [72] was constructed. The task consisted of the user using a computer mouse to drag a circle from the left side of the screen to a square on the right side of the screen. In the touch condition the TVA accompanied it's request with a touch to the user's forearm, and stated that the user could stop the task by pressing the "stop task button" that would be present on the screen. During the performance of the task every 20 seconds the TVA gave a verbal encouragement accompanied by a light touch to the user's arm. In the no-touch

condition the same instructions and encouragements were given, but without the TVA touching the user. The task ended when the participant stopped the task by pressing the "stop task button". To measure performance level we measured the number of circles which were successfully dragged to the square (counted as a single trial). We also measured the total amount of time spend on the task.

In a pilot test on 8 participants we found large individual differences. Most participants (5/8) quitted before the 5th trial, while the other participants continued up to 777 trials. Looking at the data the large differences were reflected in large standard deviations of completed trials in both the touch condition ($M = 51.50, SD = 95.67$) and the no-touch condition ($M = 203.50, SD = 382.56$). An independent samples t-test showed no significant differences between both conditions in completed trials ($t(6) = .77, p = .47$) and time spend on the task ($t(6) = .75, p = .48$).

Our results strongly contrast findings by [72], who found clear differences in performance when active touch (comparable to our touch condition) was applied compared to passive touch and no-touch. A potential explanation is that in [72], participant's could more easily attribute the touch to the robot. In our TVA setup, this attribution might not always be as straightforward. Furthermore, cultural differences could explain the different findings. All participants in our pilot study were European, while the aforementioned study was conducted in Japan. During the experiment we also encountered some problems. First, the instructions were not clear to some of the participants. Despite the instruction given by the virtual agent it was unclear for some participants that *they* had to stop the task (2/8), whereas others tried the task one or two times, and then clicked the stop task button to see what would come next. Second, some participants had difficulty understanding what the virtual agent said (3/8). The pilot study would suggest that touch by a TVA might not affect compliance in the same manner as does co-located or mediated social touch. To further investigate this issue, a follow-up experiment would have to use a measure of trait compliance to tease out individual differences between participants. Furthermore, embedding the agent's request in a more elaborate scenario might give the participants more time to get used to the agent's voice, and touch, and the setup in general. Finally, a task such as filling out bogus personality items [78] might be considered more realistic by participants. It could be argued that participants would not simply try to fill out a few questions and see what comes next, as was the case with dragging the circles, but would take filing out the questionnaire more seriously, thus reducing initial differences between participants.

## 7   Conclusions

The TVA project set out to develop, from scratch, a setup in which a virtual character would be able to engage in communication with the user through facial expressions, speech, body movements, and, in this project most importantly, touch. The use of touch in social communication with an ECA has thus far been largely overlooked. An extensive body of work in psychology demonstrates

clear effects of social touch in co-located space on compliance, stress reduction, as well as communication of affect. Moreover, social touch mediated through haptic feedback technology has been found to have similar effects on compliance, and can be used to communicate emotions. Finally, some initial work on TVAs showed promising results.

Our approach differs from current efforts in creating touching virtual agents in that we combine a tactile sensation, with a visual representation of a hand touching the user in augmented reality, and other social communication from the agent (e.g. facial expressions and speech). With this setup we can introduce certain elements in the personal space of the user that could prompt the virtual agent to react and touch the user, as was for example the case in the bug demo. Moreover, the setup allows for the study of a number of effects of social touch by a TVA. We proposed experiments that could be conducted with the current setup. We conducted a pilot study in which we attempted to influence participant's compliance to a request made by the agent. Unfortunately, large individual differences in trait compliance negated any effects of the agent's touch.

Despite a current lack of empirical studies using the TVA setup, the setup does offer a good starting point for further exploration of touch by TVAs. We are confident that the combination of the virtual agent displaying other social signals (e.g. facial expressions and speech) with the application of touch using augmented reality and tactile sensations, is a viable approach to TVAs.

In this sense, eNTERFACE 2013, organized by the New University of Lisbon, Portugal, provided an excellent kick-start to the project. We came into eNTERFACE with a basic outline of the setup, required hardware, and ideas about the requirements for the setup. For this reason, much of the available project time was spent on constructing the setup, and working out all manners of technical difficulties. A preferable approach would have been to have already constructed some of the components, and than expand them during eNTERFACE, allowing time for conducting more studies with the setup. Nonetheless, the setup constructed allows for some interesting future studies, as described in Section 6, and offers a springboard for more elaborate TVA setups.

We suggest three specific improvements. First, the augmented reality area of the current setup is limited to the size of the tablet computer used (i.e. 9.7 inches). Expanding the visible augmented reality area would allow for a larger work-space in which the agent could interact with the user, and allowing the user more freedom of movement. Furthermore, a larger augmented reality area would enable us to display the agent's entire arm, making it easier for the user to attribute the touches to the agent. One approach would be to cover the area of the desk where the user's hands would be located, with a horizontally oriented opaque screen, with a wide-angle camera attached to the bottom of the screen. A projector could then project the image of the camera onto the opaque screen, expanding the augmented reality area. As a second improvement, using sensors, and possibly a fake limb in combination with an augmented reality overlay to simulate the agent's arm, we could allow the user to touch the agent. This would allow for bidirectional tactile communication. An interesting question in

this regard would be, if touch by the agent elicits similar tactile social behavior in the user. Third, the current setup makes use of a controller script that ties all of the separate system components together. A future refinement would be the construction of an ASAP engine to control all components of the system and replace the current control script. Specific BML commands could be defined, to make the system more robust and flexible.

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