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# The Role of Physiological Cues during Remote Collaboration

## Abstract

Empathic communication allows individuals to perceive and understand the feeling and emotion of the person with whom they are interacting. This could be particularly important during remote collaboration (such as remote assistance or distance learning) to enhance the social and emotional understanding of geographically distributed partners. However, supporting awareness in remote collaboration is very challenging especially when the interaction with the remote parties results in less information that can be communicated than in a physical interaction. We explore the effect of visualization using physiological cues that allow users to interpret emotional behaviors of remote parties with whom they are interacting in real time. The proposed visual representation allows users to infer emotional patterns from physiological cues that can potentially influence their communication approach toward a more aggressive style or maintain passive and peaceful interaction. We conducted a study involving participants who were paired up for a collaborative assessment task, interacting via voice only, videoconference, or a visual representation of the physiological measurements. Participants perceived the usage of our visual representation with higher group cohesiveness than using voice-only interaction. Further analysis shows that the visual representation significantly increases the positive affect score (i.e., participants are perceived to be more alert and demonstrate less distress) during remote collaboration. We discuss the possibilities of the proposed visual representation to support empathic communication during remote collaboration, and the benefits to the remote partners of having positive affect and group cohesiveness.

## 1 Introduction and Motivation

This paper explores the visualizing of data obtained from physiological sensors to increase empathy during remote collaboration. We primarily investigate empathy formation through the implementation of a specific visual representation entailing physiological measurements, which allows for a more lucid and rationalized communication between participants during remote collaborations.

We compare this visual representation to videoconferencing and voice-only communication conditions. Remote video and, to a lesser degree, voice communication convey some of the emotional subtleties that people articulate during conversation but often lack the rich information we typically get when performing colocated communication (Gutwin & Greenberg, 2004). The interaction between remote parties and the virtual workspace generates less in-

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formation than in a physical one. Further complications are reported by Fiore, Salas, Cuevas, and Bowers (2003) when teams are distributed and using computer-mediated communication rather than face-to-face interactions.

We study the impact of different conditions for supporting empathic communication during collaborative assessment of complex models; specifically, our objective is to determine the effects of visual representation and how it can influence empathy formation in remote collaborative work. Our study involves participants pairing up as a team, discussing and judging constructed models, in an assessment process within a desktop videoconferencing setting.

## 2 Supporting Empathic Communication Using Physiological Cues

### 2.1 What Is Empathy?

Empathy is commonly referred to as the ability to detect what others feel and building up an understanding of that emotion ourselves. Thompson (2001) denotes empathy as a sense of similarity between the feelings an individual experiences and those expressed by others. We envisage empathy to be crucial for the establishment of building consensus and seeing a situation from the other person's point of view to improve working relationships. In other words, the value of empathy comes not from understanding others' feelings, but what we do as a result of this.

Empathy has been shown to affect the way people interact and influence each other. Empirical evidence indicates that accurately expressing empathy can lead to positive psychological, physical, and health outcomes; e.g., helping people cope more effectively with problem situations. It can induce moral reasoning (Eisenberg et al., 1994), and maintain positive self-esteem, sense of social inclusion, and adherence to treatment regime (Bickmore & Picard, 2005). On the other hand, Greene and Burleson (2003) found that inept expressions of empathy could also lead to many undesirable outcomes.

Numerous studies have reported that empathy affects relationships. Englis, Vaughan, and Lanzetta (1982) found that competitive relationships lead to asymmetric affective responses which are counterempathic, while cooperative settings result in symmetric emotions that are empathic in nature (Lanzetta & Englis, 1989). Empathy plays a role in improving intergroup relations (Stephan & Finlay, 1999), motivates both prosocial and cooperative competent behavior (Eisenberg & Miller, 1987), and inhibits aggression toward others (Eisenberg, Spinrad, & Sadovsky, 2005). Miller and Rollnick (1991) noted that the building of trust is attributed to empathy and most importantly leads to strengthening of the relationship between the helper and the worker.

### 2.2 How Can Empathy Influence Communication?

The results of the aforementioned studies indicate that empathy affects the way people interact with each other and the crucial role it plays in the satisfaction of relationships. A model of how emotion can be communicated through empathy, induction, and contagion was described by Scherer and Zentner (2001). The model assumes a process of event appraisal that models the way in which an individual assesses the personal significance of an event. The emotion that results from the appraisal process is then externalized in physiological symptoms and subsequently through motor expressive movements in the face, body, and voice. As a result, the observer is able to connect with the person through a process of identifying and establishing an understanding for a similar emotion that originates from the person.

However, mediated systems provide users with only limited awareness information, as the input and output of a computer provide less information than the action in the physical world (Gutwin & Greenberg, 2004). We integrate the Scherer and Zentner model (2001) to our approach for supporting empathic communication by incorporating our proposed visual representation, which informs the observer about a person's emotional behavior (as presented at the top of Figure 1).

The creation of the visual representation involves the process of capturing the physiological cues from one's symptom and providing them as visual information to the observer. Features extracted from human faces and

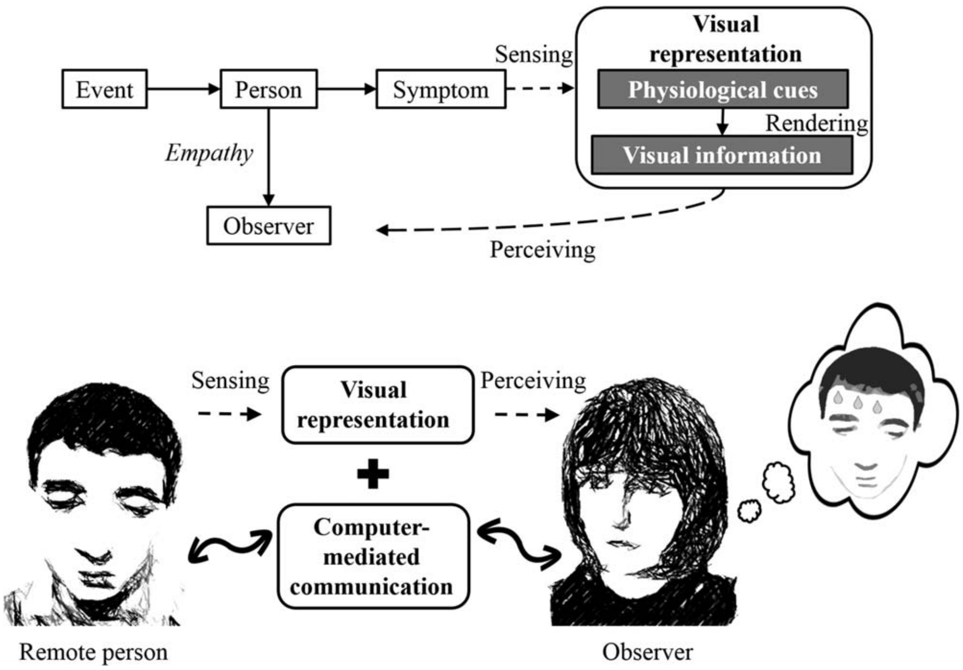


**Figure 1.** *(Top) Empathic communication, which informs the observer about a person's emotional behavior. Visual representation provides the necessary component for supporting empathic communication and is presented in relation to the Scherer and Zentner (2001) model that is shown on the left. Physiological cues are rendered in an appropriate visual representation as indicated in the shaded boxes. (Bottom) An illustration for empathic communication showing how visual representation can be used with computer-mediated communication to affect remote interaction. The observer will be able to infer emotional patterns from visual representation that can potentially influence her communication approach toward a more aggressive style or maintain passive interaction.*

bodies, utterances, and physiological signals may be exploited to provide cues related to emotion. Ekman and Davidson (1994) considered these cues as affective arousal, which are essential to modulate human communicative signals. Physiological cues are fundamental cognitive triggers, which can be used to inform how the person can infer another's emotion and act on one's own social behavior. For instance, similar physiological cues that match with the person's experience can be used to infer the corresponding emotion. Physiological coupling is essential for empathic communication as it relates closely to empathy. People who accurately evaluated the negative emotions of others also displayed a high degree of shared physiology (Levenson & Ruef, 1992). Our visualization will thus highlight existing symptoms (through the related physiological symptoms) that can be sensed and rendered so that an observer is able to perceive and understand another person's feeling.

We are not representing a mental model; we merely show the readings of sensor data in an "accessible" way that allows understanding of what others are experiencing. The proposed visual representation allows users to infer emotional patterns from physiological cues, which can potentially influence their communication approach toward a more aggressive style or maintain passive and peaceful interaction. This knowledge of others' emotional behavior can impact our future interaction with them. For example, during emotionally charged conversations, we will be able to decide on the best way to mediate our emotion to more closely relate with our conversational partners in order to favorably connect using their emotional expression. There is some degree of similarity between our work to support empathic communication and the idea of contingency (as described by Bailenson, Yee, Merget, & Schroeder, 2006) that involves tracking all performed behavior by the user and rendering it on an avatar.

We visualize the information obtained from physiological measurements and focus on types of information that are difficult to be sensed by humans directly. The purpose of this visualization is to enable nonexpert users to interpret large-scale, real-time sensor data without specialist knowledge. The visualization should ideally emphasize the remote person's state of mind or point of view in the collaborative environment. For instance, indications of cognitive state should be dynamically highlighted by the relevant physiological information in real time. This assumes a cognitive synchronization process involving the user to make sure that the remote person is aware of facts pertinent to attaining their common objective and any knowledge needed to understand the situation (Darses, Détienne, Falzon, & Visser, 2001). With this visualization, the users will be able to perceive the visual representation as an additional channel for supporting empathic communication. The visual representation augments their ability to interpret and understand physiological cues of someone with whom they are communicating. The users may then adapt their communication approach to others based on this new information.

Although recognizing appropriate empathic response through language and nonverbal gestures such as affective facial expressions is viable (Vincent, 2005), the main drawback of language and nonverbal gestures, as pointed out by Greene and Burleson (2003), is not being able to provide emotional support or better emotional experience for the users. This is where the proposed visual representation aims to make a difference.

### 2.3 Implementing Visual Representation in Remote Collaboration

Various authors have proposed displaying visual information for collaborative tasks that involve sharing information or common ground, that is, mutual knowledge, mutual beliefs, and mutual assumptions; and this shared ground is being updated moment by moment (Clark & Brennan, 1991). This is evident in recent systems using different levels of visual information to engage remote parties in a distributed setup. For example, Mackay (1999) gives insight into the roles of presence in Media Spaces, which convey subtle cues such as emotional states for supporting distributed collaborative work.

Kraut, Fussell, and Siegel (2003) demonstrate that visual information together with a videoconferencing interface is capable of playing two correlated roles: it helps participants maintain an up-to-date mental model of the task's state and the others' activities; and it helps participants communicate about the task by participating in the development of a mutual understanding during the conversation. In a similar vein of research, Fussell, Kraut, and Siegel (2000) capture cognitive attention of remote users to improve collaboration and task performance in a bicycle repair scenario. Their system captures the users' level of awareness on the videoconferencing interface, which serves as a bridge to interact with other users. Their results suggest that the advantage of working in physical copresence is related to the ability to share visual information about the objects, environment, and collaborators' behavior.

Another example of implementing visual representation for collaborative tasks is the Lighthouse system developed by O'Neill et al. (2011). Lighthouse provides a link for self-identification within the task by displaying visual pointing from the user in a mixed reality projection to solve technical problems related to printing machines. The link for self-identification within the task can also be observed in an avatar. Bailenson, Yee, Merget, and Schroeder (2006) differentiated avatars from embodied agents and described avatars as digital models of people that either look or behave like the users they represent.

An exemplary implementation of avatars is the Mission Rehearsal Exercise (MRE) system (Marsella, Gratch, & Rickel, 2003), which provides training for peacekeeping missions. Realistic virtual humans are computer-generated avatars derived from motion-capture images of real actors assuming the role of a mentor or a teammate. The authors then base their characters on an architecture for task-oriented behavior, emotion appraisal, and coping behaviors.

Embodied agents, for instance emotional and believable agents, are artificial models embedded with life-like characteristics (Bates, 1992, 1994). Bickmore (2003) investigated these agents in the role of assistants for health behavior change (exercise adoption) and reported the relational response produced by the users leading to an increase in liking or trust in the agent. The impact of animated agents has been investigated along the dimensions of motivation and helpfulness for the presence of a life-like character in an interactive learning environment (Lester et al., 1997). The common goal of these approaches is to improve the visual representation by increasing the usability of artificial characters suitable for collaborative interaction.

We can summarize an important point from these studies: that users interact only through each other's video and visualization during remote collaboration. Since visual representations are playing an increasing role in collaborative environments, it is important to investigate the suitability of different types of archetypal cues for representing the user and an intuitive way to inform others of what to expect from their (emotional) behavior.

### 2.4 Using Physiology Components for Visual Representation

Ekman and Friesen (1976) and Izard (1971) argue that a series of biological events following the occurrence of an emotion will result in changes in a person. For example, changes in facial expressions are correlated with physiological changes such as increasing heart rate or heightened blood pressure (Ekman & Friesen, 1976). Cacioppo, Berntson, and Crites (1996) study the neurophysiological processes undergone by emotions and highlighted measures of physiological changes, which will affect the quality of emotion-oriented approaches.

Although Plarre et al. (2011) and Fernaeus et al. (2011) reported several challenges for using physiological measures to understand users and their situation, they are being recommended by Cacioppo and Tassinary (1990) to provide objective measures and ground truth on human cognitive performance. We list three limitations emerging from current physiological sensing and use the principles of cognitive engineering defined by Vicente (1998) to guide our implementation (a visual representation informed by physiological measurements) for supporting empathic communication.

1. *Emotional experiences*: human–human interaction causes different emotions that are subjective and unique experiences. The embodied nature of emotions is derived from our understanding, which is based on a mixture of our own experiences and prejudices. To address for coherence along these cognitive aspects, we use a strict lab protocol that maintains real-life personality of the participants and ensures that the task-induced emotion we wanted to measure is caused by factors intrinsic to the task (such as dialog communication, cognitive pressure, and attention overload).
2. *Between-person differences*: the wide range of physiological responses to emotion in each individual can make it difficult to build an affective classifier that works on a large population (Plarre et al., 2011). Instead, we provide a simple visual representation for the users to draw their own interpretation and determine the high-level emotional patterns that can emerge. We based the sensitive settings on the physiological measures that allow communication of different biological functions (i.e., blood pressure, respiratory rate) for highlighting an emotional and behavioral change.
3. *Use setting*: emotion can be considered as a socially constructed way of interpreting and responding to particular classes of situation. From this perspective, emotion can mirror one's real-life personality and probably differs from session to session. We calibrate the visual representation using different physiological modalities to provide an understanding of a person's emotional behavior. The visual representation relates physiological cues about a specific task response and provides a basis for the users to develop their own interpretation; for example, the use of sweat drops to indicate the difficulty experienced by the remote person in a work-related task (as shown at the bottom of Figure 1).

**(a) Voice only** **(b) Videoconference** **(c) Visual representation**

**Figure 2.** *The three conditions in the experimental design.*

## 3 Hypotheses

We argue that the appropriate visual representation of sensor data is important to support empathic communication. Emerging research in human–computer interaction (HCI) suggests that errors in system design (other than human error during the incident) is particularly due to those features that fail to account for psychological states such as stress, frustration, inattention, and boredom (Hernandez, Morris, & Picard, 2011; Kapoor, Burleson, & Picard, 2007; Hudlicka, 2003). This is highlighted by Sproull and Kiesler (1986), who reported that the removal of social context cues (apparel, location, nonverbal behavior, and rules of space proxemics) during video-mediated communication influences the nature of the social situation and the individuals' behavior. More specifically, people tend to be more self-centered, and have a negative perception of others when these cues have been removed (Sherman, 2001). Our proposed visual representation informed by physiological cues aims to increase empathy by reestablishing hierarchical relationships between remote parties, which might otherwise be erased due to the absence of such cues in remote voice-only or videoconference interaction.

A higher level of perceived team interdependency and a broader shared mental model of the team's present task are reported by Driskell, Salas, and Johnston (1999) when teams complete the task collaboratively compared to teams that worked independently. Group cohesiveness and emotions are also known to have interrelated effects on empathic cognition at the individual level. Teams in happy moods showed enhanced team awareness, as revealed by more anticipatory communication patterns and more detailed verbal responses to geographically distributed partners, than those in sad moods (Pfaff, 2012). In this study, we tease out the contributions from each communication condition, as shown in Figure 2 (i.e., voice-only interaction, videoconference, and visual representation of the physiological measurements) by making the following hypotheses and illuminating any mediating or moderating relationships between the two, which draws on our discussion on empathic communication as well as considerations for remote collaborative tasks:

**Hypothesis 1 (H1):** Using a direct visual representation informed by physiological cues will produce higher levels of empathy (in terms of group cohesion and positive affect) than using voice-only interaction for remote collaboration.

**Hypothesis 2 (H2):** Using videoconference for remote collaboration will result in higher levels of empathy (in terms of group cohesion and positive affect) than using voice-only interaction.

**Hypothesis 3 (H3):** Using a direct visual representation informed by physiological cues for remote collaboration will yield higher levels of empathy (in terms of group cohesion and positive affect) than using videoconference.

**Figure 3.** *(Left) Physiological sensors are placed on the fingers and strapped around the body of the assessor for collaborative assessment of constructed model. (Right) The leader provides the consensual result on the scoring list while subjected to different conditions shown in Figure 2.*

## 4 Method

### 4.1 Study Design

Our study involves pairs of participants discussing and judging the K'Nex models[1] in an assessment process within a desktop videoconferencing setting. Participants were paired up to complete a set of tasks during remote collaboration. For each trial, one participant was assigned the role of team lead (leader) and was tasked to lead the assessment process with the other participant, who is assigned the role as part of the assessment team (assessor). Before starting, the leader was given the scoring list and the order of the models to evaluate; in contrast, the assessor has no prior knowledge. The participants were situated at two locations for the study.

We used an experimental design with different conditions for showing display configurations to the leader. The purpose of the conditions is to catalyze rational group communication during remote collaboration. We were interested to determine the effects of visual representation on empathy formation while participants remotely assessed the models in a collaborative manner. The interactions were initiated with the first condition showing a blank screen and voice-only stream, as shown in Figure 2(a). Video streams on facial view, as shown in Figure 2(b), and visual representation informed by physiological measurements, which is depicted in Figure 2(c), are subsequently used as the main interface in different display configurations. These conditions correspond to the conditions mentioned in the hypotheses. Other factors, like the screen size and resolution, remained unchanged. In all the conditions, the participants interacted through a desktop videoconferencing setup that provided audio communication, as shown in Figure 3.

1. http://www.knex.com/Building-Sets/

### 4.2 Participants

Eighteen participants (13 men, 5 women) between the age of 22 and 32, median age of 27 years old, participated in the study; all had prior experience using videoconferencing tools and used them regularly at least once 1 to 2 hours a week for work-related purposes. In each randomly assigned pair, we selected the participant with higher educational and research experiential background as the leader, which implied their role of remote expert. For example, a post-doc researcher is assigned the role of leader, while a masters student filled the role of assessor. Note that we also had participants with other backgrounds, and the participants in each pair did not know each other prior to the experiment.

### 4.3 Apparatus

The pairs of participants were connected through a videoconferencing call during the experiment. The leader was located in a conference room and used a laptop with a 15.4-inch screen, whereas the assessor was in a meeting room at the end of the hallway and sat behind a work station with a 17-inch LCD monitor. We used the Skype application for remote communication between participants. The videoconferencing webcams were configured to capture the faces of both participants during the study.

We used Procomp hardware and Biograph Infiniti software from Thought Technology[2] to measure the assessor's galvanic skin response (GSR), blood pressure (BP), and respiratory rate (RR). All these sensors were attached to the fingers on the nondominant hand of the assessor to reduce noise contamination. The GSR was measured on the last two fingers at 10 Hz. The blood pressure was measured on the middle finger at 10 Hz. A belt was attached above the abdomen to measure the chest expansion for respiratory rate. The chest expansion was sampled at 60 Hz.

The measurement for each physiological modality was obtained from a customized Biograph physiological measurement script and subsequently computed as animations for visual representation. To overcome the limited range of physiological responses, we normalized the physiological signal for each modality with scale differences as a function of each participant. For example, certain participants who exhibited higher variability in a physiological variable than others were transformed on the measures of scale calibration for equal means and standard deviations. We applied logarithmic transformation on the data to equalize variances and differences across conditions, and produced a scale that has linear properties to maintain the effects to be proportional to the original value. For a discussion of several procedures for comparing conditions with different base rates, see Wainer (1991).

We transformed the physiological measures directly to regular intervals in a sigmoid distribution so that the range of values for each physiological measure could be easily interpreted as a visual form with correlation realism, for example, no perspiration to indicate a normal GSR reading while having five drops of fluidly flowing perspiration to indicate extremely high intensity in the GSR reading. Note that the fluidly flowing perspiration is designed to convey a metaphoric indication of the degree that the assessor is sweating profusely. The sigmoidal nonlinearity can also account for abrupt changes in an emotional response (Picard, 1997).

Distributing information in this way simplifies the interpretation of interval scales for each physiological signal. Our basic assumption of interval scales is that differences between intervals at any level of the scale are directly comparable, which allows us to subtract common terms and to compare the data directly. Likewise for blood pressure (BP) and respiration rate (RR), their animations are represented with different intensities of pulsating heartbeat and elastic chest movement, each corresponding to the actual measurement. They are normalized with settings at 60 to 180 heartbeats per minute and 12 to 24 breaths per minute for the BP and RR, respectively. The individual component changes according to its assigned biofeedback (e.g., heart size increased for BP alone). An example of the visual representation is presented in Figure 4. The other intensities (which are not shown) can be interpolated from the illustrated three intensities.

### 4.4 Materials

In order to measure the effect of empathy formation, several self-report measures to determine group cohesiveness and emotion change were administered. Before exposure to the treatment conditions, two self-report measures known as the "Empathy Quotient" (EQ) and "Interpersonal Reactivity Index" (IRI) were used to control for variation in individual empathy traits. The clinical interviews by Baron-Cohen and Wheelwright (2004) reported that people with a lower EQ

2. http://www.thoughttechnology.com

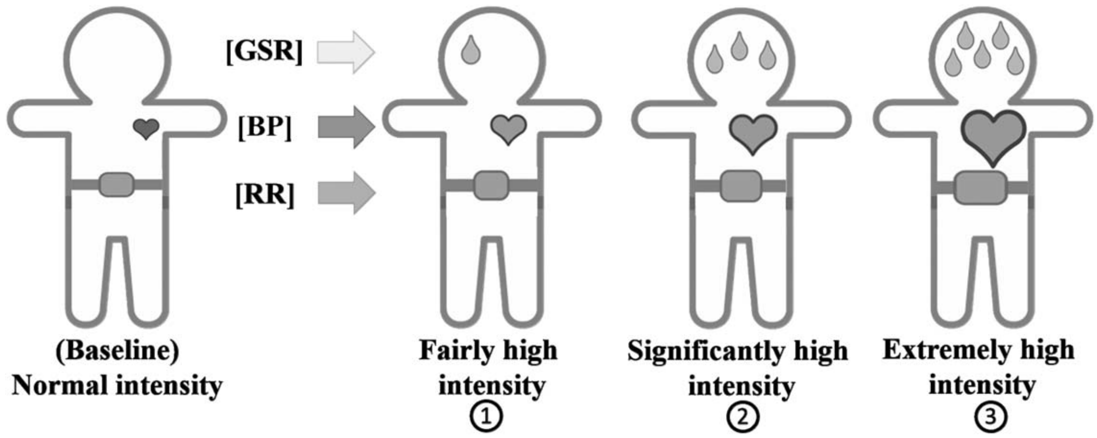


**Figure 4.** *Examples of animations used for visual representation. The animations for each physiological modality are mapped using a customized Biograph Infiniti physiology measurement script. The animation of galvanic skin response (GSR) measure is represented as fluidly flowing perspiration at the top followed by blood pressure (BP) as pulsating heartbeat and respiratory rate (RR) as elastic chest movement. The intensity of each animation varies correspondingly to the actual measure on the assigned physiological modality alone.*

score have difficulty judging, explaining, anticipating, or interpreting another's behavior.

We wanted to ensure that the collaborative performance of participants in the study were not affected by difference in EQ for each pair. We measured the EQ in all participants to ensure that their empathy conformed to the median distribution range of the useful cut-off (Baron-Cohen & Wheelwright, 2004) for mean EQ score in healthy adults. Lawrence et al. (2004) found that the EQ scale displays good construct validity and positive correlations with the IRI. As such, we had the latter as a second measure for EQ for the purpose of affirming normal social functioning on the measured individual empathy of the participants in our study.

In our analysis, both EQ and IRI are used as a group comparability check between the leader and assessor in each pair to have similar ability to interpret each other's social and communicative behavior. However, EQ and IRI should not be used to measure empathy formation toward another person. Actual effects of empathy formation were measured using the "Entitativity Questionnaire" and "Positive and Negative Affect Schedule" questionnaire. The Entitativity Questionnaire was designed to measure group cohesiveness in a collaborative environment and the Positive and Negative Affect Schedule is a measure of emotion to determine the inclination toward positive or negative affect.

### 4.5 Procedure

Participants were first greeted and welcomed to our study upon arrival at their designated time slot. They were given a brief description of the study, including assurances on the anonymous nature of their responses. They were then asked to sign a consent form and were led to separate rooms to complete the general survey and pretask questionnaires, which included the Empathy Quotient, Interpersonal Reactivity Index, and Positive and Negative Affect Schedule questionnaires. A pretask Positive and Negative Affect Schedule was administered prior to the display conditions so that we could determine the change in emotion after each condition. The order of the conditions for each pair was counterbalanced, as were the tasks that were randomly assigned to them. After exposure to the conditions, we employed two different self-report measures.

The experiment lasted approximately one hour for each pair of participants. Prior to the start of the lab procedure, the visual representation corresponding to each physiological modality was functionally described to the

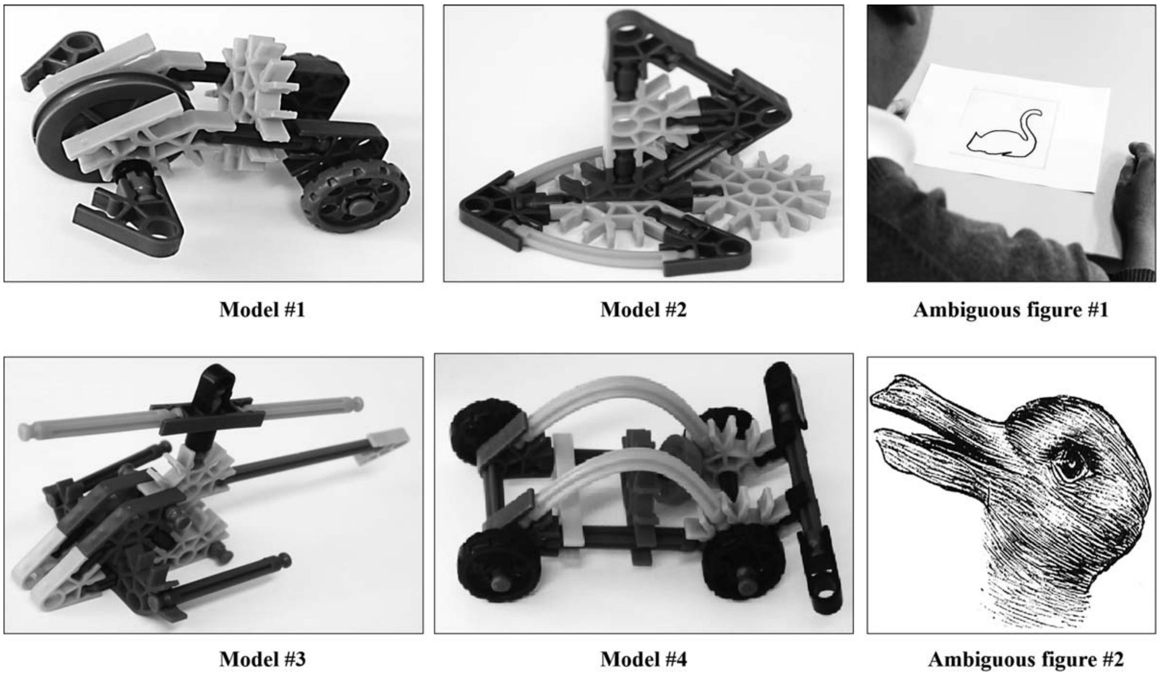


**Figure 5.** *Models used for joint assessment during remote collaboration. Ambiguous figure images are used as control cases.*

participants. In addition, the experimenters discussed the meanings of each physiology modality with the participants and also answered any questions related to the interpretation of the animations in the visual representation. A physical copy of Figure 4 was provided to each participant as a look-up reference.

After the assessor was fitted with the physiological sensors, a three-minute baseline recording was performed using a customized Biograph Infiniti physiology measurement script. The assessor relaxed in a sitting position while focusing on a distant nature scene outside the window. We ensured that relaxation allowed the physiological readings to reach the baseline levels respecting the different amounts of time that participants needed for this before starting the baseline recording.

Subsequently, both leader and assessor were given the task of evaluating the images of constructed K'Nex models (as shown in Figure 5). The participants were required to communicate in a comprehensible manner and reach a consensus on the final decision for the total score for each model. The models were randomly assigned to each pair of participants. In the control cases, the participants just had to agree on an animal type as shown in the ambiguous figure image. The ambiguous figures (cat/swan and duck/rabbit) have been used to study autism (Ropar, Mitchell, & Ackroyd, 2003) and perception of physical stimuli (Delwiche, 2012), respectively.

The leader was equipped with the scoring list to lead the model assessment and also given the responsibility to provide a total score for each model. The leader had to lead the discussion and communicate the scoring criteria to the assessor. The scoring list consisted of three different scoring requirements on function, design, and performance. The sessions were videorecorded using a video camera.

## 5 Measures

### 5.1 Empathy Quotient Questionnaire

The EQ was developed by Baron-Cohen and Wheelwright (2004) to measure individual empathy. The EQ is a Likert scale with 60 items and returns a score from 0 to 80. Each item presents a statement (e.g., "Other people tell me I am good at understanding how they are feeling and what they are thinking" and four choices (i.e., "strongly agree," "slightly agree," "slightly disagree," and "strongly disagree"). The EQ has been widely used to measure empathy as a personality trait.

### 5.2 Interpersonal Reactivity Index Questionnaire

The IRI is a self-report measure developed by Davis (1983) to assess specific dimensions of empathy, and consists of four subscales for measuring unique components of empathy. The subscales of the IRI are Personal Distress (PD), Fantasy Scale (FS), Empathic Concern (EC), and Perspective Taking (PT). PD and EC are forms of affective empathy, while FS and PT are considered to be cognitive forms of empathy. The IRI is a Likert scale and includes 28 items. As our aim was to correlate emotional aspects of empathy with individual ability to perceive emotional information, we focused on the component of the IRI that reflects the affective component of empathy (e.g., "When I see someone who badly needs help in an emergency, I go to pieces").

### 5.3 Entitativity Questionnaire

The first measure to determine the empathy formation is the Entitativity Questionnaire, which measures cohesiveness of a group in a collaborative environment. It was introduced in Bailenson and Yee (2006) with a Likert scale and includes ten items. Six items present a statement (e.g., "Please indicate to what extent you would use the term by circling the appropriate number") and a seven-point response scale with content-specific endpoints (e.g., "not at all" and "extremely"). Three items are similar to the other six, but on a nine-point scale. In addition, one item presents the participant with seven diagrams of two circles of varying overlap. It asks the participant to circle which set of circles best represents the pair. The Entitativity Questionnaire returns a score of 0 to 76.

### 5.4 Positive and Negative Affect Schedule Questionnaire

Our second measure for empathy formation is the Positive and Negative Affect Schedule (PANAS) questionnaire, which measures the emotional change toward positive or negative affect. The PANAS is a Likert scale with 20 items (10 positive- and 10 negative-affective adjectives) developed by Watson, Clark, and Tellegen (1988). For each adjective, participants are asked to rate the extent to which they have experienced each particular emotion within a specified time period (in our case 10 minutes). Negative Affect (NA) and Positive Affect (PA) reflect dispositional dimensions. For example, emotions such as interest and alertness are indicative of high PA, whilst jittery and hostile characterize low PA.

## 6 Results

### 6.1 Emotion Quotient and Interpersonal Reactivity Index

The first two measures of the analysis were the calculated Empathy Quotient and the Interpersonal Reactivity Index for each participant. Each participant's score was considered individually. The results show no statistically significant difference between the Leader ($M =$ 41.1, $SD = 3.573$) and Assessor ($M = 41.8$, $SD =$ 3.011) as determined by one-way ANOVA, $F(1,14) =$ .224, $p = .641$.

The paired-samples $t$-test for the IRI also show no statistical difference in the respective subscales between the Leader and Assessor: PT ($M = -1.5$, $SD = 3.807$) yielded $t = -1.246$ and $p = .244$, FS ($M = 3.0$, $SD =$ 5.333) recorded $t = 1.779$ and $p = .109$, EC ($M = -.5$, $SD = 5.986$) recorded $t = -.264$ and $p = .798$, and PD ($M = 1.8$, $SD = 2.044$) has $t = 2.785$ and $p = .21$. A closer examination on the paired-samples $t$-test for the IRI reveals that there is a strong correlation between Leader and Assessor in terms of PT and FS ($r = .975$ and .978, respectively). We can conclude that there is no statistically significant difference for the EQ and IRI within the pairs of participants, which might otherwise affect our study due to impairment of participants to judge others' social and communicative behavior.

### 6.2 Entitativity Questionnaire

One of our main analyses was to consider how display conditions affect the empathy formation in each pair of participants. We first assessed for the strength of agreement from the participants' subjective response using Cronbach's alpha. The result indicates a fairly high strength of agreement score (Cronbach's alpha = .619) on the internal consistency for the set of data from the pair's interaction and no questions were excluded in the analysis.

We analyzed the participants' group cohesiveness obtained from their Entitativity Questionnaire. Our analysis using Wilcoxon signed-rank sum test on the self-report of entitativity reveals that both visual representation ($Z = -2.098$, $p = .036$) and videoconference ($Z = -2.51$, $p = .012$) had a significant effect on group cohesiveness when compared to the voice-only condition when the $p$-values were within the significance level of 0.05 and confidence level of 95%. However, considering a more stringent significance level at 0.01 and at 99% confidence level, only the videoconference ($Z = -2.51$, $p = .009$) had a small but significant effect on group cohesiveness when compared to the voice-only condition. Visual representation ($Z = -2.098$, $p = .033$) did not record any significant difference when compared to the voice-only condition.

The entitativity scores, which are illustrated in Figure 6, show that visual representation has an average of 44.25 ($SD = 10.08$), videoconference reported an average of 48.63 ($SD = 12.63$), and voice-only had an average of 43.5 ($SD = 10.22$). No significant difference was found between the visual representation and the videoconference conditions ($Z = -1.953$, $p = .051$). This set of results indicates that the visual representation is perceived to have higher group cohesiveness than using the voice-only condition. It is perceived as having similar group cohesiveness as using the videoconference condition.

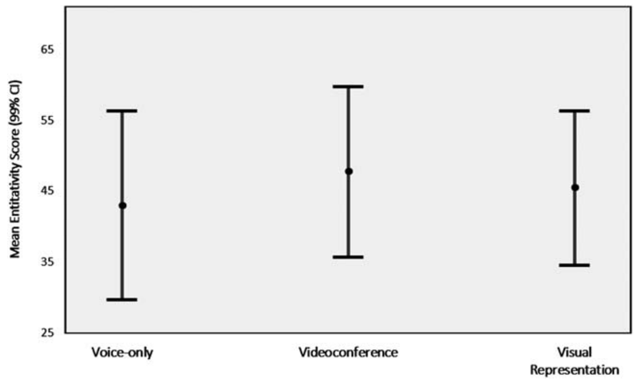


**Figure 6.** *Mean entitativity score by condition. Statistical analysis shows that visual representation is perceived to have significantly higher group cohesiveness than using the voice-only condition. The results also show that visual representation is not perceived with group cohesiveness that is significantly higher when compared to the videoconference condition.*

### 6.3 Affect Change Measurement Using Positive and Negative Affect Schedule

We then performed a set of quantitative analyses on the participants' subjective affective states, which is obtained from their Positive and Negative Affect Schedule (PANAS). The participants' Likert scale ratings were examined to determine how well the conditions match their emotional experience and whether the conditions cause any change in their overall affect. A paired-samples $t$-test of the participants' self-ratings PANAS across the three conditions shows a significant increase in positive affect and a significant decrease in negative affect as compared to their pre-task self-report measures. The statistical details are shown in Figure 7. The one-way ANOVA also shows a significant effect of intervention on the participants' attitude toward visual representation and the voice-only conditions ($p < .01$). The participants' attitude toward videoconference and voice-only interactions also yielded a significant effect ($p < .01$). No significant effect is found between visual representation and videoconference conditions ($p = .084$). These results show that the visual representation is perceived to have a significant increase in positive affect over voice-only interaction and yields the highest overall affect change as compared to the videoconference and voice-only conditions.

Further analysis using the Wilcoxon signed-rank sum test on the self-report emotions in PANAS shows that alertness and distress have statistically significant differences when using visual representation as compared to the voice-only condition. Alertness increases significantly when using the visual representation ($M = 0.9$, $SD = 1.165$) as compared to the alertness of the voice-only condition ($M = 0.65$, $SD = 1.387$, $Z = -2.114$, $p = .034$). On the other hand, distress shows a significant

| | Voice-only | Videoconference | Visual Representation |
|---|---|---|---|
| Positive Affect | $M = 2.45$, $SD = 0.100$ [$t = -4.765$, $p < .01$] | $M = 2.85$, $SD = 0.022$ [$t = -4.531$, $p < .01$] | $M = 2.95$, $SD = 0.130$ [$t = -5.684$, $p < .01$] |
| Negative Affect | $M = -1.30$, $SD = 0.172$ [$t = 2.487$, $p < .01$] | $M = -1.40$, $SD = 0.238$ [$t = 2.819$, $p < .01$] | $M = -1.25$, $SD = 0.173$ [$t = 2.63$, $p < .01$] |
| **Overall Affect Change** | **Positive Affect** $M = 1.15$, $SD = 0.136$ | **Positive Affect** $M = 1.45$, $SD = 0.130$ | **Positive Affect** $M = 1.7$, $SD = 0.152$ |

**Figure 7.** *Change in PANAS for the Positive Affect and Negative Affect caused by the conditions. Statistical analysis shows that visual representation yields more significant change in Positive Affect than using the voice-only condition. The result did not show any significant change in Positive Affect when comparing the visual representation to the videoconference condition.*

drop when using the visual representation ($M = -0.5$, $SD = 1.1$) when compared to distress in the voice-only condition ($M = -0.8$, $SD = 0.768$, $Z = -2.121$, $p = .034$). In other words, our analysis revealed that the participants using visual representation found their emotional experience to be more alert and less distressed than using voice-only interaction for remote collaboration.

# 7 Discussion

## 7.1 Summary of Results

In our study, we systematically investigated the empathy formation for each pair of participants in a remote collaborative task. From the analysis on EQ and IRI, we determined that there is no statistically significant difference for the EQ and IRI within the pairs of participants, which might otherwise affect our study due to impairment of participants to judge each other's social and communicative behavior.

The user study produced support for Hypothesis H1 and Hypothesis H2: that empathy level (in terms of group cohesiveness and positive affect) was higher in both visual representation (see Figure 2c) and videoconference (see Figure 2b) than voice-only interaction (see Figure 2a) during remote collaboration. Results were significant based on the overall affect change obtained from the Positive and Negative Affect Schedule as presented in Figure 7. However, there was no support for Hypothesis H3, that visual representation produces higher levels of empathy than the videoconference condition. This is shown by the one-way ANOVA, $F(1,14) = 1.487$, $p = .084$, which signifies no significant difference between visual representation and videoconference conditions.

Based on the Entitativity Questionnaire, there was support for H2 but not H1. The hypotheses are evaluated at a significance level of 0.01 and a 99% confidence level. A summary of mean entitativity score is shown in Figure 6. Since H2 is almost as strong a hypothesis as H1 (as there is no significant difference for group cohesiveness between visual representation and videoconference conditions; furthermore, the overall affect change in both conditions indicated that empathy formation should be at least as strong in videoconference as in visual representation), we would be able to find support for H1 given a larger sample. On the other hand, there was no support for H3. This is highlighted by the Wilcoxon signed-rank sum test ($Z = -1.953$, $p = .051$), which signifies no significant difference between visual representation and videoconference conditions.

From the analysis on their self-report measures, visual representation plays a role in empathic communication by enhancing empathy formation as indicated by the empathy level in terms of overall affect change and effectiveness of group cohesion in transmitting emotions. In other words, the visual representation facilitates in transmitting emotions and helps remote collaborators to coordinate better as a group. The findings in our study indicate that the visual representation yields similar effects at the empathy level as the videoconference interaction. We surmise that the participants' habit of using videoconference interaction tends to perpetuate itself for remote collaboration, thus leading to the notion that H3 is not being supported in our study; this notion is probably due to the unfamiliarity of associating physiological cues to emotional patterns. In other words, the participants are largely not accustomed to any sequence of mental action to use the novel display of the visual representation to infer the emotional behavior of their remote partner. In our opinion, with longer interactions and growing familiarity with the proposed visual representation, participants should eventually yield better performance without any consciously formed purpose or anticipation of results and hence improve their rating on self-reports for empathy formation. However, whether this opinion is true is a subject for future study.

In summary, our visual representation yielded a positive affect change and higher group cohesiveness, which supports the findings by Myers (1962) that people in cohesive groups experience better emotional adjustment. Positive affect towards their remote partners has also been argued by Lott and Lott (1965) to account for their group cohesion. Our results show the participants who use the visual representation perceived their emotional experience to be more alert and less distressed, which we can relate to the claim by Lawler, Thye, and Yoon (2000) that positive emotions solidify and strengthen group cohesion. According to the affect-as-information perspective (Schwarz & Clore, 1996), positive affect will influence task performance when it seems to provide task-relevant information. For example, "people experiencing a happy mood" indicates that the task is proceeding well and people are more likely to employ novel approaches to problem solving (Gasper & Clore, 2002).

## 7.2 Implications for Using Visual Representation

Our research shows that a more empathic and interpersonal remote communication can be realized by using visual representation informed by physiological cues of a remote person. The visual representation materializes these cues as visual information. As a result, the user is able to connect with the remote person through a process of identifying and establishing an understanding for a similar emotion. We extend the interaction scenarios described in Tan, Schöning, Luyten, and Coninx (2013) by incorporating the proposed visual representation and highlight its implication to improve the empathic quality of remote collaboration.

**7.2.1 Enabling Information-Sensitive Conversation for Positive Affect and Group Cohesiveness.** The provision of visual representation can help users at a distance to form cohesive bonding with each other and strategize their communication approach toward a better emotional experience. The visual representation has the potential to communicate more of the experiential knowledge embedded in the design. More specifically, it informs the physiological cues in a simple graphical manner when someone is open for new information and ideas by being in a positive affect.

During information-sensitive conversations, such as during doctor–patient consultations, ensuring sufficient empathy makes a huge difference. In order to avoid additional mental burden on the patients, the visual representation provides clues on the emotional behavior of patients which guides a doctor to know when and how to reveal sensitive information as well as to follow up on the effects of the consultation. In a teleconferencing setup, the visual representation presents to the doctor its readings using a straightforward interface: it tells the doctor the physiological response as emotional intensities in discrete number of perspiration (sweat drops) or continuous heartbeat and respiration cycle. The doctor can subsequently steer a conversation in a natural way so that the patient will be most comfortable in receiving diagnostic results or new prognosis information.

**7.2.2 Supporting Empathic Communication Using Proposed Visual Representation.** Computer-mediated communication often compromises personal interaction via emotional cues (Riva, 2002; Tan, Schöning, Luyten, & Coninx, 2013), making empathic communication especially challenging for distributed teams. The proposed visual representations can be tailored for scenarios in which the remote person's facial view is not available. During the completion of a crucial and intensive task, for example, when a lab technician has to perform a critical task in a chemical laboratory, the remote expert can continuously monitor and determine when the lab technician is feeling distracted or stressed without seeing the technician's facial expressions in the video. Such peripheral monitoring of a remote person's physiological cues also supports team cognition by identifying appropriate opportunities to collaborate and reducing inappropriate or otherwise frustrating interruptions. Users will be able to empathize more closely with others with whom they collaborate, and, because of this, maintain strong group cohesiveness with their remote parties and improve group decision making (Zaccaro, Gualtieri, & Minionis, 1995).

### 7.3 Limitations and Future Work

During the study, we observed that the use of visual representation has an adverse effect on the mental effort when participants are first presented with such a novel display. In other words, participants are required to construct an appropriate mental mapping of the visual representation to the emotional behavior for themselves. The interpretation of the visual representation potentially introduces additional cognitive load that potentially limits the relation between the representation and the task domain that it represents. A solution in this case is to transmit only certain biofeedback as visual representation that is designed to support the task so that the user could glance at it occasionally without losing concentration.

Another limitation of our current study is a reliance on self-report assessment for subjective emotion and empathy. These have several disadvantages as self-report measures are dependent on participants giving truthful and accurate responses. Also, a self-report response does not necessarily equate to an actual emotional response. However, Shostak and Peterson (1990) argue that self-report measures increase the reliability of physiological measures and can provide sufficient validity in this context.

We envisage that visual representation can be incorporated with the avatar archetypes to give a first impression of one's intended communication and interaction style. The aim is to realize the illustrated scenario shown in Figure 1 using techniques such as realistic image synthesis (Greenberg, 1999). The users will then be able to see the "mental image" on a display, thus reducing their cognitive load. The externalization of physiological cues as visual representation is not only a valuable and efficient interface between the user and task, but also a major tool for multifaceted interpersonal interactions. Future studies should focus on relating additional visual representations and investigate the effects of having an integrated form of visual representation.

## 8 Conclusion

This paper investigated the effect of visual representation informed by physiological measurements on remote collaboration. We are specifically interested in making remote communication more empathic for collaboration on crucial and intensive tasks. By empowering users to get a better understanding of their remote collaborators, collaboration can become more efficient and more satisfying. Our user study confirmed the hypothesis that using visualization of physiological cues would significantly improve the empathy levels (in terms of group cohesion and positive affect) during remote collaboration higher than voice-only interactions and comparable to the usage of videoconference.

We evaluated pairs of participants during remote collaboration in three conditions (voice-only, videoconference, and visual representation) with self-reports for group cohesiveness and emotion change. These two measures were also used to determine how the conditions can influence empathy formation in collaborative work. We found significant differences under both measures that support our two primary hypotheses. A third hypothesis—pairs using the visual representation would have higher empathy than using videoconference for remote collaboration—was not supported.

Our results show that, during a remote collaboration session, (1) the visual representation allows users to have a higher group cohesiveness with other people than voice-only interaction, (2) the visual representation yields a significant overall increase in positive affect, and (3) the users showed a heightened alertness and less distress using the visual representation than the voice-only condition.

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