

Seeing is believing: communication performance under isotropic teleconferencing conditions

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Abstract

The visual component of conversational media such as videoconferencing systems communicates important non-verbal information such as facial expressions, gestures, posture and gaze. Unlike the other cues, selective gaze depends critically on the configuration of cameras and monitors. Under isotropic videoconferencing conditions people see each other in spatially consistent directions (shared video space). Isotropy is hypothesized to regulate the interactional process of conversation. Further, it is hypothesized that isotropy increases social nearness which increases persuasive force but decreases the exchange of information in group discussion tasks.

We have studied the interactional process and task outcome of two discussion tasks under isotropic and (standard) non-isotropic videoconferencing conditions relative to face-to-face conditions. The communication of unshared information was tested in a 'hidden profile' task by Stasser et al. [Journal of Experimental Social Psychology 31 (1995) 244]. Dominance and persuasive force were revealed using a prioritization game of survival items called 'Lost at the moon', featuring a dominant confederate.

The results support our hypotheses and have revealed that persuasive force (the ability to change another person's opinion) is significantly stronger under isotropic conditions (including face-to-face) than under non-isotropic conditions. In contrast, dominance (the ability to influence group solutions by dominant behavior) is similar for all conditions. Further, participants communicate almost twice as much unshared information under mediated conditions than under the face-to-face condition. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

When people meet in a shared physical space they are able to exchange enormous amounts of information carried by sound (speech), light (gaze, facial expressions, gestures, posture, physical appearance), chemicals (smell) or by direct contact (touch). In a shared physical space the communication bandwidth is only limited by our senses, not by the medium.

Modern telecommunication techniques (such as teleconferencing) allow people to meet virtually, which might eliminate the necessity to physically get together. Both auditory and visual communication can now be mediated by electronic audio and video signals across world-wide networks. The advantages of not having to travel, in terms of expenses and time-efficiency, are evident. The bandwidth of current mediated communication, however, is *limited*. Because of this limitation the richness of video

information in particular has been reduced in the spatial dimension (the size and quality of images) as well as in the temporal dimension (transmission delays and update frequencies).

Human factors researchers are challenged to understand the pros and cons of impoverished visual communication (carrying non-verbal information) during mediated interaction with respect to human behavior and task performance.

Current videoconferencing systems deal with a limited bandwidth of the video-channel by either squeezing minified images of all participants on a single monitor, or by presenting the full-sized image of only a single (speaking) participant. Further, each participant generally looks at a single monitor and is sensed by a single camera. Both options filter out natural non-verbal information such as the viewing directions (gaze) of participants relative to the others. This may seriously affect human interaction and task-performance because eye-contact often regulates the conversation by directing the supply and demand of information and by increasing the intensity of the

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conversation [2,3]. It is worthwhile, therefore, to investigate videoconferencing systems that do not filter out eye-contact and viewing direction.

We have studied the benefits of a multi-party videoconferencing system in which participants see each other in spatially consistent directions, that is, in a shared virtual space. We call this an isotropic videoconferencing system (ICOS) because the conferencing space conserves the 3D directional properties of gaze for all participants. The performance of participants during a variety of discussion tasks under isotropic videoconferencing was compared with non-isotropic videoconferencing and face-to-face conditions.

1.1. What is known about communication under teleconferencing conditions?

Non-verbal visual communication includes gaze, facial expressions, gesture and posture. Non-verbal behavior has naturally evolved, strongly suggesting that it has important functions such as regulating, completing or even substituting verbal communication. For example, selective gaze is thought to support the regulation and synchronization of conversation (e.g. taking and avoiding the floor and suggesting who should speak next [2,3]). Further, gaze is thought to provide feedback on how the listener perceives a verbal message (e.g. understanding, disinterest) or by communicating emotions (e.g. enthusiasm, anger).

Because these assumptions are intuitively convincing, one might expect researchers to have found evidence supporting these assumptions. The contrary is true, however. Research seems to show that the presence of a video channel in addition to an audio channel has no effect on the performance of tasks that are highly independent of social cues. Only when social cues become relevant (e.g. equivocal situations as conflicts and bargaining) visual communication may influence the task outcome [4,5].

Because no overwhelming effects have been found in previous studies, Sellen [6] has focussed, not on task performance, but on the interactional process of conversation (speaker turns, interruptions, etc.) as a way of assessing the effect of a conversational medium. The effect of reduced visual cues on the interactional process had been studied by others but with questionable and inconsistent results and comparing only face-to-face situations with audio-only for dyadic conversation (see [6]). Sellen used objective measures to show that under the face-to-face condition people produce significantly more interruptions and fewer formal handovers of the floor than in any mediated condition (audio-only and videoconferencing conditions). Effects of the type of videoconferencing (isotropic versus non-isotropic), however, were not significant.

These inconsistent or weak results found so far may not be surprising. The results of experimental studies on conversational task performance are likely to be very sensitive to the specific design of the videoconferencing system and to

the specific task tested. Videoconferencing systems differ a great deal with respect to video quality (size, resolution), the audio or video lag, the number of participants simultaneously visible and the configuration of cameras and monitors. Each of these aspects may influence specific aspects of the conversational process. Opposite effects may even have cancelled each other.

Clearly, experimental studies have not yet been able to support the intuitive expectations. In the following we will describe a more specific hypothesis regarding effects of videoconferencing on communication processes based on group decision experiments by McLeod et al. [7]. One of the key issues for formulating this more specific hypothesis is *social nearness* or *social presence* [4]. Social presence is regarded as a quality of a communication medium that depends on its capacity to transmit verbal and non-verbal cues as well as aspects such as the apparent distance or the ‘realness’ of the participant. In other words, social presence refers to the tangibility and proximity of other people that one perceives in a communication situation. Social nearness may be affected by a wide variety of videoconferencing aspects, for example, apparent size or stereoscopic cues [8], but also by selective gaze and eye-contact.

There has been an ongoing debate on the consequences of reduced social nearness. For example, the use of computer-based group decision support systems (GDSS) facilitates group interactions by providing means to exchange, store and display ideas while eliminating the need for turn taking when expressing these ideas in face-to-face meetings. As such, GDSS systems are a relatively poor communication medium yielding a strongly reduced social nearness. Interestingly, compared with conventional face-to-face meetings, GDSS stimulates participants holding dissenting opinions to challenge a majority consensus by expressing their opinions. Classical theories from social psychology and communication studies to GDSS predict that these poor (sometimes anonymous) communication media facilitate the expression of minority opinions and consequently yield higher discussion quality and discussion results [9]. However, McLeod et al. [7] argued that the same features that facilitate the expression of minority arguments may also reduce their impact. In fact, their experiments showed that in groups working on a hidden-profile investment decision task, minority opinion holders expressed their arguments more frequently under anonymous GDSS communication, but that the influence of the minority argument on private opinions and on group decisions was highest under face-to-face communication. It is widely recognized that people who express deviant opinions risk social disapproval. Creating a low-risk environment such as mediated communication conditions may facilitate the contribution of dissenting opinions. However, the higher the social presence of others, the more one is likely to pay attention to them, and the more one is likely to be influenced by them [4]. So, assuming that the variety of perspectives, information and knowledge that individual members can

bring to bear is a benefit of group decision making, poorer communication media are expected to yield more information exchange without an improvement of decision quality. In fact, the expression and influence of minority opinions are both correlated with social presence, but in opposite directions.

This leads us to the hypothesis tested in our experiments. Based on the above arguments, it may be expected that the exchange of information and opinions within groups is facilitated by social nearness, but that their influence (persuasive force) is reduced. The social nearness of ICOSs (including selective gaze) is assumed to be higher than that of non-isotropic systems, but lower than that of face-to-face communication.

Because the term social nearness is more a concept than a clear definition, direct objective measures of social nearness do not exist. However, the influence of this underlying mechanism can be derived from quantifiable measures such as information exchange, persuasive force, tension (competitive behavior) or group score (focus on group benefit).

1.2. The aim of this study

The aim of this study was to isolate the effect of shared

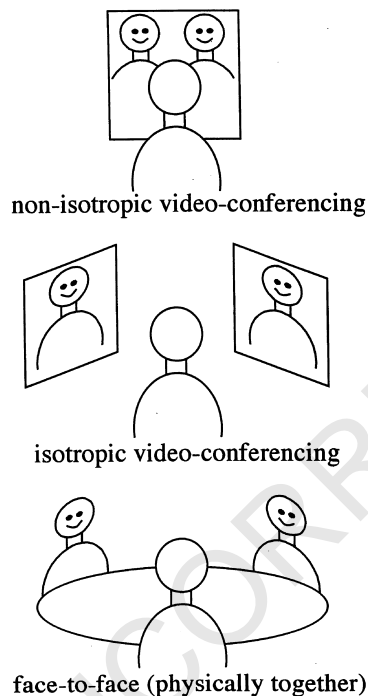


Fig. 1. A sketch of three conferencing conditions. Top: non-isotropic video-conferencing. Each participant communicates through a single camera and a single monitor with colleagues. As a result everyone looks at everyone. Middle: isotropic videoconferencing. Participants communicate through a double camera and double monitor system. Participants are now virtually placed in a triangular configuration enabling selective gaze because of the spatially consistent viewing directions. Bottom: face-to-face condition. Participants share the same physical room and see each other directly (not through video connections).

video spaces (including selective gaze) on the exchange of information and on persuasive force as compared to non-isotropic systems as well as face-to-face situations. For this purpose two mediated conditions were used that differed with respect to the configuration of monitors and cameras (isotropic/non-isotropic), but not with respect to other properties such as audio and video quality, transmission delay and console design (see Fig. 1).

The communication of information was measured in a murder mystery task called “The Case of the Fallen Businessman.” Dominance and persuasive force were revealed using a prioritization game of survival items called “Lost at the moon,” featuring a dominant confederate.

2. General method

2.1. Communication systems

To enable groups of three persons to perform tasks under videoconferencing conditions, three identical (tele)-workplaces have been designed and built. The number of three participants has been chosen since this is the minimal number of people for which selective gaze may become important (when two persons communicate it is always clear which person is addressed). The workplaces allow for two modes of use, isotropic (selective gaze) and non-isotropic communication (no selective gaze). The non-isotropic workplaces consist of a single-camera, single-monitor setup per participant, resembling traditional videoconferencing setups. For the isotropic workplaces we used a multiple-camera and multiple monitor setup per participant which allowed to selectively look at another participant (selective gaze). Otherwise, the two mediated conditions were similar with respect to the monitors and cameras used and with respect to the audio quality. For the face-to-face condition (physically together around a table), no instrumentation was required. Details can be found in the following sections.

2.1.1. Face-to-face condition (FF)

The face-to-face situation is the non-mediated situation in which people physically meet in the same room to communicate. During our face-to-face (FF) condition, three participants were placed in a quiet room at the same table. This condition supports the richest form of communication in which all aspects of verbal as well as non-verbal communication can be transmitted. The experiment leader was visibly seated at a table in the corner of the room.

2.1.2. Non-isotropic tele-communication system (NICOS)

In contrast to the face-to-face situation, the NICOS condition is a mediated condition in which sound and light are carried by an electronic connection, sensed by microphones and cameras and displayed by speakers and

monitors. Persons were physically separated and sat in different rooms (called cubicles). In these cubicles a work desk was placed consisting of a table and a cabinet used for housing a monitor, a loud-speaker and a camera.

NICOS is a picture-in-picture tele-conferencing unit in which participants observe each other on a single monitor per person which is divided in quadrants. Two quadrants were used to present the image of the other participants (top-left and top-right). The images and audio of the participants was recorded by a single camera per person with an integrated microphone, placed above the monitor. The cameras zoomed in on the head and shoulders of the participants. All signals were sent to a Quad-unit which combined the pictures in quadrants. Audio signals were combined and distributed over the loudspeakers of the monitor.

Because a single camera and a single monitor were used for each individual NICOS system, selective gaze was not possible. Hence, participants were not seen in spatially consistent directions. Hence, the system is called non-isotropic.

2.1.3. Isotropic tele-communication system (ICOS)

ICOS is a tele-conferencing system alternative to NICOS because ICOS offers selective gaze. ICOS consists of an individual configuration with two cameras and two monitors per person. As in NICOS, the participants were physically separated in different rooms, the cubicles. Video and audio signals of the two other participants were presented full-size on two separate monitors with integrated loudspeakers. People could not see their own picture.

The persons who participated in this three-point tele-conferencing were virtually placed in a triangular configuration. As a result the set-up approached the face-to-face situation, except that the direct view of a participant in a particular direction was replaced by an audio–video presentation in the same direction. The size of the video images presented was such that participants were virtually placed at distances of two metres relative to each other. This also allowed for displaying most of the upper-body of another participant. Consequently, not only facial expressions were visible, but also postures and arm or hand movements.

2.2. Apparatus

The workplaces for ICOS and NICOS were specially designed for these videoconferencing experiments. ICOS and NICOS are equipped with the following apparatus.

TV sets. Sony Trinitron Color TV sets, model no. KV-X2101D (diagonal: 51 cm) were used with a vertical resolution of approximately 500 visible lines. In ICOS, two TV sets were applied. Together with the user of the workplace, both TV sets were placed in a triangle. The distance between the user and the TV set was 1.25 m. In

NICOS, one TV set was applied, positioned right in front of the operator (also at a distance of 1.25 m).

Cameras. Sony Handycam Video 8 camera recorders, model no. CCD-TR330E, were used. These cameras were placed above the TVs. This position reduced the horizontal difference between viewing angle and recording angle to zero, the vertical difference was reduced as much as possible.

Video-routing. Video signals were split and routed using the Panasonic Quad Unit, model WJ-420/G. This Quad unit was applied in NICOS to combine pictures of participants on a single screen.

Data-sharing. Three Silicon Graphics Indy (R4600, Unix version 5.3) set ups were used each consisting of a computer, monitor (21 in.), keyboard and mouse. They were used to run InPerson 2.0, a data-sharing program of Silicon Graphics.

Consoles. Three consoles were built to facilitate ICOS and NICOS. These consoles were designed to be compatible with the anthropometric dimensions of the Dutch population. Small as well as tall members of this population could use the consoles in the appropriate working posture. Based on the above the height of the working desk was 750 mm above the floor. The seat height of the chairs could be adjusted between 390 and 560 mm.

For ICOS it was possible to position two TVs. These TVs were placed in a triangle with the operator behind the console to create an isotropic communication space. The height of the TVs was in conformity with the height of the operator's head. In the case of NICOS, one TV was removed and the remaining TV was placed in front of the operator. This TV showed the combined pictures of the participants.

The Indy-system was placed in front of the operator, built in the console. The operator had to look down to observe the Indy-monitor. For the other participants, it could always be seen whether a person was looking at the TV or looking down at the monitor of the Indy. The Indy-system did not cause visual obstruction when a participant had a look at the TV.

2.3. Tasks

Two communication tasks were used. These tasks had to be carried out in the FF, NICOS and ICOS conditions. Task details are described in the method sections of the individual tasks. Here we describe the motivation to choose these tasks and their global characteristics.

The Lost At The Moon task is a widely used group survival/ problem solving game in which participants have group discussions about a common strategy to survive at the moon. Participants have to rank order 15 items of equipment remaining after a crash landing at the moon. A major modification to the common setup was the introduction of a dominant confederate who argued for a particular wrong ordering of items. This task was selected for investigating

Table 1
Sequence of tasks and conditions for participants $A_n \dots I_n$ on day n (T_i denotes that this task was the i th task carried out by this participant)

Participant	Lost at the moon		Case of the Fallen Businessman	
	Mediated	Face–Face	Mediated	Face–Face
A_n		T_2	T_1	
B_n			T_1	
C_n		T_2	T_1	
D_n	T_2		T_1	
E_n	T_2		T_1	
F_n			T_1	
G_n	T_2			T_1
H_n				T_1
I_n	T_2			T_1

the effects of the different communication conditions on persuasive force by the confederate and on the quality of group solutions.

The Case of the Fallen Businessman is a murder mystery task.¹ This task was selected for measuring the influence of the three communication conditions on the sharing of unshared information during a cooperative task.

2.4. Experimental design

Design. To eliminate the undesirable transfer of knowledge about a particular task from one condition to another, we have chosen a design in which each participant carried out each task only once. As a consequence, conferencing conditions could only be compared between participants. Given these constraints, it is preferable to test each participant only once for a particular combination of task and condition. However, for reasons of efficiency, participants were tested for multiple combinations of task/condition (see Table 1).

Table 1 shows the sequence of tasks for nine participants ($A_n \dots I_n$) tested on day n . Each day only a single mediated condition was tested. On days $n = 1 \dots 5$ the mediated condition tested was non-isotropic videoconferencing. On days $n = 6 \dots 10$ the isotropic videoconferencing was tested. The face-to-face conditions were tested on all days ($n = 1 \dots 10$).

Because the Lost at the Moon task was carried out with only two participants and one confederate, each day three participants were excluded from the Lost at the Moon tasks.

After 10 days the number of participants tested was distributed as follows across tasks and conditions: 20 participants per condition tested for the Lost at the Moon task; 30 participants per condition tested for the Case of the Fallen Businessman task.

The order in which participants were tested in mediated and/or face-to-face conditions was balanced. Averaged

¹ The booklet containing the case description was kindly provided by Gerald Stasser, and was translated into Dutch.

across participants, transitions from face-to-face conditions to mediated conditions occurred as often as the reverse transitions for each mediated condition (isotropic/non-isotropic).

2.4.1. Instructions

The participants started with an instruction given by the experiment leader. During this instruction the participants were informed about different tasks and the conditions in which these tasks had to be carried out. As a part of the instruction, the working principles of ICOS or NICOS (depending on which day the experiment took place) were explained. The confederate pretended to be a normal participant, joined the instructions, filled in the questionnaires, etc.

2.4.2. Data collection

During the experiments, all dependent variables were measured as specified in the task descriptions. The Netherlands Personality Questionnaire was filled out during a pause or introduction of the participants before carrying out any task. Video recordings were made of all tasks carried out in the mediated conditions and the first five days of the face-to-face situations.

2.5. Analysis

Each task was carried out only once for a single communication condition. Thus, we can compare results only between subjects, not within subjects. For each dependent variable of each task, we carried out an ANOVA analysis with a single independent variable (the communication condition). This variable (face-to-face, mediated isotropic or mediated non-isotropic) had two degrees of freedom. We have calculated the F-values for the main effect of communication condition. The number of degrees of freedom for the ANOVA analysis depended on the number of participants or groups involved in the analysis. Moreover, the degrees of freedom varied because values that differed more than three standard deviations from the average for a particular condition were considered outliers and were left out of the analysis. Further, we carried out Tukey significance tests for revealing possible significance of differences between conditions. Because of the exploratory nature of this research we will consider effects significant at 90% confidence levels.

2.6. Participants

The group of participants consisted of 80 students (40 male, 40 female). None of the participants was familiar with the tasks. Participants that had to carry out tasks in the same group did not know each other. Groups were composed of mixtures of the two sexes (randomly assigned). Participants were paid \$40 for their participation.

Table 2

Expert solution as given by the Crew Equipment Research Section of the NASA Manned Spacecraft Center at Houston, Texas [10]

Rank order	Item	Explanation
15	Box of matches	Useless since there is no oxygen on the moon
4	Food concentrates	Satisfies basic energy requirements
6	50 ft of nylon rope	Useful in scaling cliffs, tying injured together, etc.
8	Parachute silk	Protection from sun's rays
13	Portable heating unit	Only useful if on the dark side of the moon
11	Two.45 caliber pistols	Possible source of self-propulsion
12	1 case dehydrated pet milk	Duplicates food concentrate in bulkier form
1	2 hundred-pound tanks of oxygen	Absolute necessity for life support
3	Stellar map (of the moon's constellation)	Most important means of determining position and directions
9	Life raft	CO ₂ bottle possible propulsion device
14	Magnetic compass	Virtually useless since magnetic field on the moon isn't polarized
2	5 gallons of water	Absolute necessity to sustain life
10	Signal flares	Possible distress signal once close enough to mother ship to be seen
7	First aid kit containing injection needles	Injection needles fitted to suit aperture quite useful
5	Solar-powered FM receiver-transmitter	Only useful if line-of-sight transmission is possible with limited transmission range

3. Effects of persuasive force

3.1. Method

3.1.1. Description

The participants had to think of themselves as crew members of a spaceship which was originally scheduled to rendezvous with a mother ship on the lighted surface of the moon. Due to mechanical difficulties the spaceship had been forced to crash land at an unknown distance from the mother ship. It was further indicated that with the exception of 15 items all equipment was damaged during the crash landing. The available equipment had to be evaluated with respect to its importance for ensuring survival during the crew's cross-country trek to reach the mother ship.

Participants were asked to rank in order the 15 items for survival in terms of their relative value and utility for survival. An expert solution was known [10] (see Table 2) serving as a base line for the quality of the solutions of participants before and after a group discussion.

Lost At The Moon was carried out in teams of three participants. To control processes such as dominance and persuasive force one of the participants was an confederate (always the same male confederate) who played a dominant participant. This confederate promoted a seriously wrong solution inducing strong equivocality (conflicting opinions). The fact that a confederate took part in the experiment was not known to the other participants.

3.1.2. Procedure

At the start of the Lost at the Moon task, participants were separated and had to rank the 15 items in order of their personal preference. This first individual solution was followed by a group discussion (approximately 30 min) in which the three participants had to generate a group solution. During the discussion participants were entirely

free to exchange arguments and preferences. The predefined initial ranking of the confederate (see Table 3) which he defended during the group discussion was the same for all trials and conditions. Also the arguments put forward by the confederate were the same for all conditions.

After the group solution was determined participants were separated and asked to write down their (second) individual solution, possibly influenced by the group discussion.

3.1.3. Dependent variables

The Lost At The Moon task was carried out under the three communication conditions and the following dependent variables were measured:

- quality of pre-solution: the quality of the individual solution *before* the group discussion;
- quality of group solution: the quality of the group solutions after discussion;
- quality of post-solution: the quality of the individual solutions after the group discussion;
- interactional behavior: the number of handovers of the floor, number and durations of overlaps of speech during discussions (taken from Ref. [6]). The measurements of these variables were recorded by the experiment leader, assisted by software.
- personality: The Netherlands Personality Questionnaire [11] was used to measure the personality of participants.

Furthermore, participants answered the following questionnaire on a 1...5 point scale:

- Did you have eye contact with other participants (never...regularly)?
- Was it clear which person wanted a response from another person (not...very)?

Table 3
The confederate’s predefined prioritization of the item list

Confederate	Item	Explanation
3	Box of matches	Needed to observe the compass on the dark side of the moon
14	Food concentrates	Unable to eat through helmet
13	50 ft of nylon rope	On the moon everybody is weightless
12	Parachute silk	Too thin to carry stuff, too thin to keep the astronauts warm
4	Portable heating unit	Can be connected to the suits on the cold and dark side of the moon
6	Two.45 caliber pistols	Possible sound-signals for rescue
5	1 case dehydrated pet milk	Contains all possible food supplements
7	2 hundred-pound tanks of oxygen	There is enough oxygen in the suits
8	Stellar map (of the moon’s constellation)	Stellar map only contains information of the light side of the moon.
15	Life raft	There’s no water on the moon
2	Magnetic compass	Useful to reach mother ship
9	5 gallons of water	It’s better to take milk instead of water since milk contains more food supplements
1	Signal flares	The most important thing is to be localized by the mother ship.
11	First aid kit containing injection needles	Useless
10	Solar-powered FM receiver-transmitter	Does not work at the dark side of the moon

- Were you able to determine the gaze direction of other persons (never...always)?
- How easy was it to interrupt other persons (very...not)?
- Was it easy to perceive the facial expressions of the other persons (very...not)?

The quality (Q) of a solution (prioritized list) (L_i) is defined as the Spearman coefficient r_S of the rank correlation with the expert solution called E (see Table 2):

$$Q = r_S = 1 - \frac{6 \sum_{i=1}^n (L_i - E_i)^2}{n(n^2 - 1)}$$

where L_i denotes the ranking of item i and n is the length of

Table 4
Results Lost at the Moon

Communication condition	Q_1	Q_g	Q_g	$(Q_2 - Q_1)$	$(Q_2 - Q_g)$	$(Q_2 - Q_1) \otimes (Q_g - Q_1)$	# Hand-overs	# Overlaps	Dur. overlaps (s)
Face-to-face	0.65	0.10	0.23	- 0.40	0.11	$r = 0.73$	172	6.4	2.7
Isotropic	0.54	0.07	0.24	- 0.28	0.17	$r = 0.85$	162	15.6	3.3
Non-isotropic	0.63	0.09	0.41	- 0.22	0.32	$r = 0.37$	167	7.5	3.7

the item list. The Spearman correlation coefficient can vary between -1 and 1 .

Using this quality measure we have calculated the quality of the confederate’s predefined non-optimal item list. This quality $r_S = -0.56$ can be considered the bottom-line of the negative influence of the confederate on the group solution.

3.2. Results

3.2.1. Quality of solutions

The quality of a solution is defined as the Spearman’s coefficient r_S of the rank correlation with the expert solution (see Table 2). We have calculated the quality of individual pre- and post-solutions (*before* and *after* the group discussions) and the quality of the group solutions.

3.2.1.1. Quality of individual pre-solutions. First we have calculated the average quality Q_1 of individual pre-solutions across participants per communication condition. There are no a priori reasons to expect a difference between conditions in the average quality of individual pre-solutions because no communication between participants had taken place at that time. The average quality of the pre-solution serves as a base-line to discuss the changes in quality induced by the group discussion. The average values of the quality of the individual pre-solutions are presented in Table 4 (see also Fig. 2). The ANOVA analysis shows significant effects ($F(2, 52) = 5.06, P < 0.01$) of condition on Q_1 .

As expected, face-to-face and non-isotropic conditions show no significant differences. However, the isotropic video-condition differs slightly but significantly ($P < 0.05$) from the other conditions. We have no reasonable explanation for this unexpected deviation other than bad luck.

3.2.1.2. Quality of group solutions after the group discussion. Individual solutions and arguments were discussed during the group discussion leading to a group solution of which the quality (Q_g) was calculated for the ten groups per condition. The average values of the quality of group solutions are presented in Table 4 (see also Fig. 2). The ANOVA analysis shows no significant effects ($F(2, 24) = 0.05, P = 0.95$) of condition on Q_g . The quality of group solutions does not differ significantly between conditions but was much lower (0.09 on average) than the initial individual solutions (0.61). This can be taken as a measure for the *dominance* of the confederate, that is,

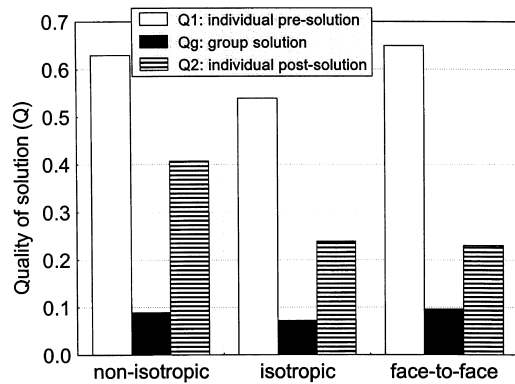


Fig. 2. Average quality of individual pre- and post-solutions, and the group solutions.

the amount of negative influence the confederate can have during the discussion on the solution of the group.

3.2.1.3. Quality of individual post-solutions. To see if participants had really been convinced by the arguments of the confederate that led to a decrease of the group solution, we measured the individual solutions again after the group solution was determined (the post-solution, Q_2). The average quality of the individual post-solutions are presented in Table 4 (see also Fig. 2). The ANOVA analysis shows significant effects ($F(2, 54) = 3.60$, $P < 0.05$) of condition on Q_2 . The average quality of individual post-solutions under non-isotropic video-conditions differs significantly from the face-to-face condition ($P < 0.05$). The difference with the mediated isotropic condition approaches significance ($P < 0.10$). In the non-isotropic condition participants appear least convinced of the arguments of the confederate that led to a decrease of the group solution. Such recovery can be taken as a measure of believe in the arguments of the confederate (persuasive force). It appears that the persuasive force is less strong under non-isotropic conditions than under isotropic conditions.

3.2.1.4. Difference between the quality of individual post- and pre-solutions. We cannot exclude the possibility that the significant difference of quality of the post-solution Q_2 between non-isotropic and isotropic conditions was caused by the already significant lower quality of pre-solution Q_1 under isotropic conditions. Therefore, we have calculated the average values of $(Q_2 - Q_1)$ across participants for each condition (see Table 4). The ANOVA analysis shows that the effect of condition approaches significance ($F(2, 51) = 2.58$, $P < 0.10$). The difference between $(Q_2 - Q_1)$ under non-isotropic mediated conditions and face-to-face conditions approaches significance ($P < 0.10$), just as found for Q_2 . The quality under non-isotropic conditions, however, is not significantly better. This means that the effect of a lower initial quality Q_1 under isotropic conditions on Q_2 cannot be excluded.

3.2.1.5. Difference between the quality of post- and group solutions. The recovery from the quality-decreasing group discussion as measured by the individual post-solutions can also be measured directly by taking the difference between the quality of the individual post-solutions and the quality of the group solution ($Q_2 - Q_g$, see Table 4). Significant effects of condition are found ($F(2, 50) = 7.31$, $P < 0.01$). The difference between the quality of group and post-solutions under non-isotropic video-conditions differs significantly from the face-to-face condition ($P < 0.01$) as well as the isotropic condition ($P < 0.05$). This is consistent with the findings for Q_2 .

3.2.1.6. Correlation between the change of Q_2 relative to Q_1 and the change of Q_2 relative to Q_g . It is of interest to further scrutinize the data and to consider not only the differences between averages of different conditions but to also consider correlations between individual performances and group performances within conditions. For example, does the difference between the qualities of the two individual solutions ($Q_2 - Q_1$) correlate with the difference ($Q_g - Q_1$) between the qualities of the group and the individual solution. In other words, does sensitivity to dominance as measured by $Q_g - Q_1$ have predictive power for persuasive force as measured by $Q_2 - Q_1$ at an individual level? Therefore we have calculated the correlation levels for each communication condition (see Table 4). We calculated the correlation of $(Q_2 - Q_1)$ with $(Q_g - Q_1)$ which is denoted as $(Q_2 - Q_1) \otimes (Q_g - Q_1)$. Correlation coefficients of $(Q_2 - Q_1) \otimes (Q_g - Q_1)$ are significantly lower ($P < 0.05$, two-sided significance test for the difference between correlation coefficients, $n = 20$) under non-isotropic conditions than under other conditions. This suggests that the confederate's dominance resulting in a decrease of the quality of the group solution has considerably less impact on the individual post-solution under non-isotropic conditions. The arguments of the confederate seem less convincing under non-isotropic video conditions. This is consistent with the observation that the average quality of individual post-solutions is less affected by the group discussion under non-isotropic conditions than under other conferencing conditions.

3.2.2. Interactional behavior

So far, we have reported on the quality of solutions (task outcome) resulting from the group discussions. Here we focus on the interactional process during group discussions in terms of interruption behavior. We have calculated the following measures (see Table 4) for each condition:

- Number of handovers of the floor: the number of times that a speaker gives the floor to another speaker.
- Number of overlaps: the number of times that a participant started speaking though the previous speaker had not yet finished.
- Average duration of overlap (in s).

897 None of the measures differed significantly between
898 conferencing conditions.

900 3.2.3. Questionnaire

901 The following questions showed significantly different
902 scores (on a five point scale) for the between conferencing
903 conditions. The effect of condition on questions not
904 mentioned were not significant.

905
906 3.2.3.1. *Were you able to determine the gaze direction of*
907 *other persons (never...always)?* As expected, the
908 appreciation of being able to determine each others
909 viewing direction under isotropic conditions (4.93
910 averaged across face-to-face and mediated isotropic) was
911 significantly higher ($P < 0.05$) than for the non-isotropic
912 condition (2.67).

913
914 3.2.3.2. *Did you have eye-contact with other participants*
915 *(never...regularly)?* This question reveals the subjectively
916 rated frequency of eye-contact during the group discussion.
917 The average ratings are 4.2 for the face-to-face condition,
918 3.9 for the isotropic condition and 2.9 for the non-isotropic
919 condition. The subjective rating of the frequency of
920 eye-contact is significantly lower ($P < 0.05$) under the
921 non-isotropic video condition than under the face-to-face
922 condition. This may explain the observation of less
923 believe in the arguments of the confederate in the
924 non-isotropic condition assuming that persuasive force is
925 facilitated by eye-contact.

926 3.3. Discussion

927
928 We have found convincing evidence that non-isotropic
929 and isotropic videoconferencing conditions score *differently*
930 with respect to *persuasive force* (the confederate's
931 arguments are less convincing under non-isotropic
932 conditions) but similarly with respect to *dominance*.
933 Further, performance under isotropic conditions does not
934 significantly differ from performance under face-to-face
935 conditions.

936 The frequency of floor changes can be taken as a measure
937 for involvement, interactivity and spontaneity. Further, the
938 average duration of overlap is seen as a measure of the ease
939 of regulating the conversation [6]. Hence, the results show
940 that spontaneity, interactivity and regulation are similar in
941 mediated and face-to-face conditions.

942 This result is contrary to observations by Sellen [6].
943 Sellen used objective measures to show that under the
944 face-to-face condition people produce significantly more
945 interruptions (overlaps) and fewer formal handovers of the
946 floor than in any other mediated condition (audio-only and
947 videoconferencing conditions). A possible explanation may
948 be that interruptions in our ICOS and NICOS conditions are
949 not discouraged by transfer delays which are generally a
950 major cause of difficulties with interrupting or with handing
951 over the floor to other speakers.

952 The results of the questionnaire indicate that the isotropic

mediated condition was appreciated more than the non-
isotropic condition with respect to regulating the conversa-
tion with non-verbal behavior (eye-contact, selective gaze).
At the same time, the persuasive force of the confederate
appears to be higher under the isotropic condition (see Table
4). It is likely that selective gaze and persuasive force are
correlated.

962 4. The effect of unshared information

963 4.1. Method

964 4.1.1. Description

965 The Case of the Fallen Businessman is based on the
966 experiments of Stasser et al. [1]. Participants have to read
967 a series of interviews from a homicide investigation. These
968 interviews are contained in a booklet that also includes other
969 material such as maps of the city and the site of crime, a note
970 ostensibly written by one of the suspects, and a newspaper
971 article summarizing background information. The
972 participants' task is to choose which of the three male
973 suspects (Eddie, Billy, or Mickey) was most likely to be
974 guilty. The interview contains 24 clues that incriminate or
975 exonerate particular suspects. Specifically, there were six
976 incriminating clues for each suspect, but there were also
977 three clues that exonerate suspect Billy and three clues
978 that exonerate suspect Mickey. The total set of 24 clues is
979 designed such that suspects Billy and Mickey can be ruled
980 out as viable suspects. Moreover, the full set of clues
981 supports the conclusion that suspect Eddie had a motive
982 as well as an opportunity to commit the crime and
983 had attempted to frame suspect Billy. The 24 clues are
984 distributed over the participants such that 15 clues
985 were shared and nine clues were unshared. Of the 15
986 shared clues, three incriminate Eddie, six incriminate
987 Billy and six incriminate Mickey. The nine remaining
988 clues are critical for identifying suspect Eddie as the
989 guilty party. These critical clues are unshared and
990 distributed: one participant receives three clues that
991 incriminate suspect Eddie, one participant receives
992 three clues that exonerate suspect Mickey, and one
993 participant receives three clues that exonerate suspect
994 Billy. The Case of the Fallen Businessman has been
995 set up such that it is difficult to analyze the case even
996 when all information is available.

997 4.1.2. Procedure

998 First, participants individually read and reviewed the
999 booklets in about 20 min. The individual booklets contained
1000 shared information (available to each participant) and
1001 unshared information (available only to a single
1002 participant). However, none of the participants knew
1003 which information was shared and which information was
1004 unshared. The participants then indicated (judged) which
1005 suspect they thought was most likely to be guilty on an
1006
1007
1008

Table 5
Results Case of the Fallen Businessman

Communication condition	Communicated unshared items	Eye-contact?	Viewing direction?
Face-to-face	0.68	3.7	3.9
Isotropic	1.28	4.3	4.4
Non-isotropic	1.15	3.1	3.0

individual private questionnaire. After this individual judgement, a discussion took place in which the participants discussed the case together. All communication conditions were tested for this task. After a maximum of 45 min, the participants had to decide as a group which suspect was most likely to be guilty.

4.1.3. Dependent variables

The following dependent variables were measured for the “The Case of the Fallen Businessman” task:

- Individual judgements: judgements before the group discussion (Eddie, Billy or Mickey);
- Group judgements: judgements after the group discussion (Eddie, Billy or Mickey);
- Information sharing: the number of unshared clues communicated during the group discussion (an unshared clue that was mentioned one or more times during the discussion contributed one point to ‘the amount of information sharing’, clues that were not mentioned contributed zero points);
- Completion time: the duration of the group decision;
- Questionnaire: see the Method section of Lost at the Moon.

4.2. Results

4.2.1. Quality of judgements

First, we have calculated the percentage of correct individual judgements (based on the booklets, before the group discussion) of who was ‘guilty’. This percentage varied between 36 and 43% (across 30 participants per condition). A Kruskal–Wallis test (a non-parametric one-way analysis of variance) showed that the differences between conditions were not significant ($P = 0.95$). Second, we have calculated the percentage of correct group judgements (after the group discussions). This percentage varied between 40 and 60% (across 10 groups of three participants per condition). Again differences between conditions were not significant ($P = 0.60$), just as were the completion times of the group discussions.

4.2.2. Communicated unshared items

During the experiments we scored the frequency with which unshared items were communicated during the group discussion. When an unshared item was communicated one or more times it was labelled ‘1’. When it was not mentioned it was labelled ‘0’. Note that an item that was

mentioned more than one time contributes only 1 point, identical to an item that was mentioned only once. In fact, we have scored the amount of *non-redundant* information that was communicated (see Table 5 or Fig. 3).

An ANOVA shows a clear trend for the effect of condition on the communication of unshared items ($F(2, 25) = 3.15$, $P = 0.06$). A post-hoc Tukey test shows that under isotropic conferencing conditions participants communicate more unshared information ($P = 0.06$) than under face-to-face conditions (almost twice as much). A similar effect is observed for the non-isotropic condition, but is not significant.

4.2.3. Questionnaire

The actual amount of information shared with other participants may depend on the ease of regulating the conversation (e.g. eye-contact, selective gaze). The following questions of our questionnaire that ‘probe’ this issue resulted in significantly different ratings between conditions (see Table 5). The rating results for the question “Did you have eye-contact with other participants?” and “Were you able to determine the gaze direction of other persons?” show similar effects. Eye-contact and selective gaze were rated highest for the isotropic video condition, even higher than for the face-to-face condition. Lowest ratings were found for the non-isotropic video condition. The non-isotropic condition differed significantly ($P < 0.05$) from the isotropic video condition in both cases.

4.3. Discussion

Our results prove that participants communicate significantly more unshared information under mediated isotropic communication than under face-to-face

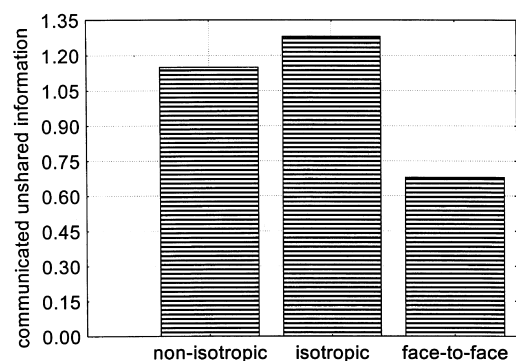


Fig. 3. Average communicated unshared information.

conditions. Further, the data strongly suggest a similar increase of information sharing under the non-isotropic condition. However, the increase in information exchange does not lead to an increase of the number of correct judgments. Clearly, these effects support our hypothesis.

Interestingly, the increase of information exchange is seen in conditions for which the ease of regulating the conversation (by eye contact and selective gaze) is lowest. This seems counterintuitive because the exchange of information often requires finding the right moment for interruptions which is easier if selective gaze can be used. A possible explanation is suggested by the findings by Williams [12] and Van der Velden [13] who reported that poor communication conditions appear to induce more task-oriented and formal cooperative behavior. This effect may compensate or even overrule the effect of reduced non-verbal cues for regulations such as eye-contact and selective gaze.

5. General discussion

Based on the findings of McLeod et al. [7], we hypothesized that mediated communication conditions would increase the exchange of information, but decrease persuasive force. More specifically, these effects were expected to be correlated with social nearness and social nearness was expected to be higher in isotropic conditions (highest in face-to-face conditions). Consequently, information exchange was hypothesized to be highest with non-isotropic videoconferencing, and lowest in face-to-face situations. The reverse order was expected for persuasive force.

The effects of communication conditions on information exchange and persuasive force are consistent with this hypothesis. Persuasive force was highest in isotropic communication conditions. In fact, the isotropic mediated condition was as good as the face-to-face conditions. Further a clear trend was observed that the exchange of information was higher under mediated conditions, although no influence was found of isotropy within mediated conditions.

In both tasks tested, a significant effect was found of conditions on the self-rated frequency of eye-contact and the self-rated ease of determining gaze direction. Appreciation of both aspects was lowest under the mediated non-isotropic condition and equally higher for both isotropic conditions (mediated isotropic and face-to-face). As such it is tempting to explain the effects on persuasive force as well as on information exchange in terms of the quality of eye-contact and selective gaze and thus by isotropy.

If however, isotropy is the explaining factor, the information exchange in isotropic mediated conditions is expected to be as low as in the face-to-face condition, which was not found. With respect to information exchange it is likely that additional factors play a role in lowering the thresholds for

expressing opinions and exchanging information such as a poor (visual) representation of other participants, inducing more task-oriented and formal cooperative behavior [12,13].

If social nearness is the underlying mechanism of the observed effects it should include factors such as the accessibility of other participants through eye-contact or selective gaze as well as factors such as the quality of the visual perception of the other participants which is determined by spatial and temporal resolution and their apparent size. The specific dependencies of social presence or telepresence on such factors have been studied independently in follow-up experiments and will be reported separately.

5.1. Predictive power of the findings

The variety of tasks and communication conditions tested is only a subsample of the rich world of communication tasks and communication systems that will be of interest when new applications are developed in the near future. Therefore, when trying to generalize our findings, the limitations of the range of variables tested have to be taken into account. We will discuss a few limitations in the following.

5.2. Only discussion tasks were tested

The tasks tested were selected on their potential to induce differences in conversational behavior and task-outcome under the different communication conditions. The tasks were characterized by a high level of equivocality and task-outcome will strongly depend on non-verbal information [4,5,12,14]. Tasks that a priori did not rely on non-verbal information (video communication) were not selected. Generally only discussion tasks were considered in which non-verbal information was influential for conveying information (arguments). For formal, objective and relatively emotionless exchanges of information one may find only insignificant effects of communication conditions; calling each other by phone would be sufficiently effective for such tasks.

5.3. Persuasive force was tested based on acted behavior

The results of the Lost at the Moon task proved that persuasive force is influenced by isotropy under mediated conditions. For this purpose we have ‘exposed’ participants to a standardized dominant behavior by an confederate using pre-defined item lists and arguments. This way it became possible to objectively compare persuasive force between conditions. The obvious disadvantage of this method is that the results cannot be generalized beyond the typical dominant communication behavior of the single confederate tested. It would be of interest to study a natural variety of dominant participants, perhaps revealing a correlation between measures of dominance of individual

participants and the similarity of their individual solutions with the group solution.

5.4. Tested groups were small (three participants)

We have tested group tasks in which three participants discussed arguments to reach a group decision. Three participants is the smallest group for which gaze direction can play a role in regulating conversational behavior. Moreover, the number of cameras and monitors needed to realize isotropic conditions grows rapidly with the number (n) of participants and equals $n(n - 1)$, unless techniques are used to derive one view from a set of others [15]. However, it would be valuable to examine the role of gaze direction for larger groups in which the regulation of conversation becomes increasingly important.

5.5. Participants did not know each other

The participants tested in our experiments had not met each other before. Consequently, participants had no a priori information about the social context or characters of fellow group members. The process of forming a group during the experiments started from scratch. This is unlike group work (meetings, discussions) of colleagues having a shared history of working together. Future research may reveal possible effects of mutual familiarity of participants.

5.6. Is it good or bad?

Whether we should label changes in task-outcome or conversational behavior due to mediated conditions as positive or negative depends entirely on what task-outcome is appreciated by the participants. For example, the increased individual resistance of listeners to non-valid arguments under non-isotropic mediated conditions may not always be appreciated by a speaker if the success of his mission relies partly on non-verbal behavior. He may favour isotropic conditions. In general, the specifications of videoconferencing set-ups should be built on a thorough analysis of tasks and human communication processes. Evaluation of our findings will depend strongly on the intention of the users of mediated communication systems.

5.7. Differences in image quality

Under mediated conditions, the resolution of the image of a person perceived is inherently lower than under face-to-face conditions: the number of pixels with which a face can be represented is finite. The spatial resolution of the image in our experiments was approximately 2.5 arcmin, clearly beyond the acuity (1 arcmin) of the human eye. Although participants subjectively reported to have no problems with recognizing facial expressions, we cannot exclude a better transfer of non-verbal visual information with higher image resolutions.

The resolution with which a face was represented in our experiments was approximately similar for non-isotropic

and isotropic conditions. Also, the subtended angle of a person's face was similar under both mediated conditions and similar to the subtended angle under face-to-face conditions. Therefore, we do not believe that differences in image quality can be responsible for the differences in performances as observed in our experiments.

5.8. Future research

Because of the observed differences of communication behavior and task-outcome between conferencing conditions, one may eventually want to choose for isotropic conferencing set-ups when, for example, persuasive force is critical. However, it should be noted that isotropic set-ups go with higher expenses because more desk-space, cameras, monitors and bandwidth are required. Therefore, the added value for specific operational tasks should be evaluated before such a choice is made. For some tasks it may even be worthwhile to see if audio-only systems (no non-verbal information) may suffice.

We have isolated the role of isotropy and have not yet focussed, for example, on the optimal sizes, resolutions and update-frequencies of the images presented nor on the added value of coloured images. All these properties determine the required bandwidth and are interesting variables to study in future experiments. Further, a very important variable is the delay between the actions of a person at one end of the line and the audio-visual representation of that person at the other end (transmission delay). Such transmission delays can seriously disturb interruption behavior and therefore the speed of communication, the quality of task-outcome and the user's appreciation of the medium. The role of image properties and of transmission delay are interesting topics for future research.

A final aspect that we have not studied is the evolution in time of conversational behavior when participants are exposed to videoconferencing conditions for considerable longer time spans, say days, than the length of our experimental sessions. It cannot be excluded that the user's appreciation of a system and also the user's objective task performance changes over time while getting familiar with the system. During longer exposures and more regular use of videoconferencing facilities, users may adapt their conversational behavior to both the limitations and the opportunities of the system, eventually yielding other behavior than observed in our experiments. Aspects like team-building and group participation under different communication conditions should be studied in future research.

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