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**A Review of the Empirical
Studies of Computer Supported
Human-to-Human Communication**

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Abstract

This paper presents a review of the empirical studies of human-to-human communication which have been carried out over the last three decades. Although this review is primarily concerned with the empirical studies of computer supported human-to-human communication, a number of studies dealing with group work in non-computer-based collaborative environments, which form the basis of many of the empirical studies of the recent years in the area of CSCW, are also discussed. The concept of *person* and *task spaces* is introduced and then subsequently used to categorise the large volume of studies reported in this review. This paper also gives a comparative analysis of the findings of these studies, and draws a number of general conclusions to guide the design and evaluation of future CSCW systems.

Keywords

Communication media, conferencing, group communication, group work, groupware, human communication, person space, task space, shared workspace.

1. Introduction

Although it would seem reasonable to argue that face-to-face and electronically mediated communication would differ in many significant ways, it has not been possible to prove such an argument completely. Since the early 1970s a growing number of studies have been carried out by psychologists, sociologists, and more recently computer scientists, to compare different forms of human-to-human communication. These studies can be categorised into two main groups:

1. Those studies which have examined human-to-human communication in non-computer based environments.
2. Those studies which have examined human-to-human communication in computer supported environments.

This paper gives a detailed review of the empirical studies of the second category, which have examined the effects of “computer supported” communication tools on human-to-human communication in group-work environments. However, as many of the studies of the first category have important relevance to the topic of this paper, a brief overview of some of the earlier studies of human-to-human communication in non-computer based work environments is also given.

This paper starts with a discussion of the motivations behind the studies of human-to-human communication, followed by identifying the common characteristics of these studies. Section 4 introduces the concept of *person* and *task spaces*, which is then used in Sections 5, 6, and 7 to categorise the studies of human-to-human communication in a number of different person and task spaces. Section 8 discusses the implications of the findings from the reported studies for the design of computer supported collaborative tools. The main conclusions of this review are given in Section 9.

2. Characteristics of the studies

Apart from a few characteristics which are common to all of the studies of human-to-human communication, they cover a wide range of experimental parameters. Different researchers have compared a range of media with face-to-face communication in a number of ways. They have covered all kinds of communication modes, ranging from the usual text, audio and video-based, to very unusual forms of communication, such as speaking through a wooden screen or curtain.

The size of the groups under study have also varied from two to four or five (Chapanis, 1975; Williams, 1975; Sellen, 1992). Although in the majority of these studies the subjects have been chosen from among students (Ochsman and Chapanis, 1974; Kemp and Rutter, 1982), other groups of people such as factory workers or business managers have also been used (Mantei, 1993).

The task used by interacting groups has ranged from simple problem-solving to real-life conflict type tasks often encountered in union-management negotiations (Chapanis, 1975; Short *et al.*, 1976; Kemp and Rutter, 1982).

Many of the studies of human-to-human communication have been carried out in controlled experimental laboratory set-ups with simplified group tasks. There are also growing number of studies which have been conducted in real work environments with people working on their real life tasks.

This diversity of media, tasks, group sizes, and experimental procedures followed in different studies clearly indicates that there is a need for a better categorisation of the large volume of research in the area of human-to-human communication, so that the results of these research can be compared to generate guidelines for the usability of various communication media in different work environments. The next section introduces the concept of *person* and *task spaces*. This concept is then used as a basis for categorisation of the reported studies.

3. Person and task spaces

In face-to-face meetings the participants can usually see and hear one another. They also share the same environment and are able to see what the other participants are doing or looking at. This element of sharing the same physical environment is what Clark and Brendan (1991) have referred to as “co-presence”.

Unlike face-to-face meetings, when meetings are supported through other communication media, the participants are not usually in the same physical environment and they do not share the same workspace. This means that when people are not co-located then their meetings lack

the element of co-presence. Over the years researchers have attempted to recreate a sense of shared presence between physically separated co-workers using video and other communication links between them. However, researchers have often ignored perhaps the most important step in recreating co-presence, which is identifying what co-presence means. Buxton (1993) defines presence in terms of two spaces, person and task:

- Person space is the collective sense of co-presence between/among group participants. This includes the participants' facial expressions, voice, gaze, body language and gestures.
- Task space is the shared domain of the task being undertaken. For instance, if the task being undertaken is a design task, then a shared drawing document would be the task space.

Ishii and his associates (Ishii *et al.*, 1992; Ishii *et al.*, 1993) use the term “interpersonal space” to refer to person space. They point out that the “interpersonal space” is different from “personal space”. Personal space refers to an individual's own space which is private and it is not shared. They also use the term “shared workspace” to refer to task space. Shared workspace seems to be a better term for describing the task space because it highlights the fact that a task space is usually shared and it is used for sharing task related information.

In many cases, such as design or problem-solving activities, the person and task spaces are separate, but there are also other situations in which both spaces are the same. For instance, in counselling or negotiation a main part of the task involves identifying the other participants' facial expressions, gaze and so on. Therefore it could be said that in such instances the task space is the person space.

During human communication and interaction process, person and task spaces are provided using different types of media. The media used for creating the person space can be face-to-face, audio, or video-based. The media used for creating the task space, on the other hand, can be very diverse, ranging from sophisticated computer-based shared workspace technology to a simple piece of paper.

Empirical studies of the human-to-human communication media can therefore be considered as studies of the effects of changing the person or task spaces. Adopting this view allows a simple, and rather useful, categorisation of the studies of human-to-human communication media into three groups:

- Those that have changed the person space while keeping the task space the same. These studies have compared different communication environments, where all of the environments had a computer supported shared workspace.
- Those that have changed the task space while keeping the person space the same. These are the studies that have examined the effects of adding a computer supported shared workspace to a single communication environment.
- Those that have varied both the task and person spaces. These are the studies that have examined the effects of adding a computer supported

shared workspace to a number of different communication environments.

4. Changes in person space

The number of the empirical studies of human-to-human communication which can be grouped together under this category is very large. There is, however, a clear distinction between the studies in which the effect of changes in person space have been evaluated in a setting where the task space has been some kind of computer-based shared workspace, and those studies in which the task space has not been computer-based, or in fact it has not been shared at all.

Although the aim of this paper is to provide a review of the empirical studies of computer supported human-to-human communication, it is important to note that the non-CSCW studies offer many valuable results regarding the importance of the role of different media in facilitating human communication. It is due to this reason that these studies are briefly described here.

4.1. Non-computer supported task space

This type of studies have generally investigated the effects of changing the person space by comparing groups of people interacting face-to-face with other groups interacting on the same task under one or more restricted modalities. These modalities have covered a range of different communication channels such as text-based, physically co-located but visually screened, and physically remote with audio-visual or just audio link.

It is interesting to note that most of these studies have often produced inconclusive or contradicting results. Weeks and Chapanis (1976) have pointed out that, in the majority of the cases, differences have been due to the type of the tasks used. There are essentially two types of tasks: cooperative and conflictive (McGrath, 1984; Hollingshead *et al.*, 1993; Mennecke and Wheeler, 1993). Cooperative tasks are those which require the communicators to agree on the process and the goal of their task, whereas conflictive tasks require the communicators to negotiate and bargain a resolution to the task in hand. This categorisation differentiates between the tasks that have to be “solved” and the tasks that have to be “resolved” (this may be resolving conflict of view-points or conflict of interests between the group members).

One of the earliest investigations of the effects of changing the person space on cooperative tasks was carried out by Chapanis and his team of researchers (Chapanis, 1971; Chapanis *et al.*, 1972; Chapanis and Overbey, 1974; Ochsman and Chapanis, 1974; Weeks *et al.*, 1974; Chapanis, 1975). Chapanis and his associates wanted to know how people communicate with each other when they exchange factual information during problem-solving tasks. To answer this question, they compared different forms of “communication modes”, made up of one or more of the “basic communication channels”, which were typewriting, handwriting, voice, video, and direct visual contact.

The most important result of these studies, which have also been reproduced by others (for a summary see Reid, 1977; Williams, 1977), was the fact that they identified a clear distinction between those communication modes involving voice, and those that did not. Teams that were able to communicate verbally were much faster than the teams that communicated through

written hard-copy material. Further, these studies demonstrated that there was virtually no difference between the communication-rich mode (essentially face-to-face mode) and any of those having an audio channel. There was also no evidence that the addition of a video channel had any significant effects on communication behaviour.

In contrast to these, studies of the effects of changing person space on conflictive type tasks have produced different findings. For instance, through a series of experiments Rutter and his team (Rutter *et al.*, 1977; Rutter and Stephenson, 1977; Rutter *et al.*, 1978; Rutter *et al.*, 1981; Rutter and Robinson, 1981; Kemp and Rutter, 1982) showed that there was a significant difference between communication behaviour of people working in face-to-face, physically co-present but visually screened, and physically remote settings. However, the results also indicated that some of the differences between these communication modes were due to physical separation and some due to visual accessibility.

More recent studies of human-to-human communication have tried to identify the effects of changing the visual accessibility aspect of person spaces. The interest in this type of studies have been due to the results of several other research which have shown the importance of non-verbal communication (Dittmann 1972; Viller 1991; Hiltz and Turoff 1993) in group interaction (Argyle and Cook, 1976; Short *et al.*, 1976; Argyle *et al.*, 1981). These studies have often compared video-based and face-to-face person spaces.

One of the comprehensive studies of different kinds of video-based person spaces has been carried out by Sellen (1992; 1995). She conducted a number of experiments to compare same room conversations with several types of video-based “multiparty” conversations. The aim was to see whether the availability and extent of visual cues, or the possibility of selective gaze and listening (being able to gaze or listen to one person in a meeting) were critical in group communication. The results of these studies were very similar to Chapanis’ work in that they, once again, emphasised the importance of an audio channel. They also found little evidence that the possibility of having selective gaze or selective listening had any effect on regulating conversation between the group members. These results have since been confirmed by similar studies (Slagter, 1997; Vons, 1996; Vons *et al.*, 1997), which have shown that in small group interaction with well defined roles, there is no real need for facilitating exchange of gaze direction cues. Furthermore, even when facilitating gaze is important, still video images which convey gaze direction are just as effective as providing full-motion video for regulating group communication.

However, Sellen points out that what seems to be important is not the number of cues available within a person space, but whether or not the person space is mediated by technology. She claims that there seems to be something critically different about sharing the same physical person space that needs to be studied further. This claim is also supported by Fish and Kraut (Kraut *et al.*, 1993; Fish *et al.*, 1990; Fish *et al.*, 1992; Fish *et al.*, 1993). They claim that despite the similarities between face-to-face and video mediated communication, the psychological distance between people in a video-based meeting is greater than that of those in a face-to-face situation. It might be due to this reason that when video is used to create a person space in which people can meet, this person space is more likely to be used as a task space in which task related objects are shown to others (for instance see Pagani and Mackay, 1993).

It should be noted that there are, on the other hand, empirical studies (Veinott *et al.*, 1997; Veinott *et al.*, 1999) which demonstrate that in some particular situations there is a clear advantage in adding video link to audio-based person spaces to provide the visual accessibility needed during conflictive type tasks, such as negotiation. Though once again, in some of these cases the person space plays the role of task space in which visual feedback facilitates task performance.

Although a quick review of the studies of human-to-human communication in non-computer supported collaborative work environments provides a valuable insight to the importance of audio and visual aspects of human communication, one needs to be aware of the fact that these studies have largely ignored the role of the task space, whether shared or non-shared, in collaborative work. The studies described in the next section, on the other hand, take this important factor into consideration by adopting some form of computer-based shared task space which is then used in all the different person spaces that are compared.

4.2. Computer supported task space

Advances in computer technology over the last decade have made it possible to develop groupware applications which can be used to provide various types of computer-based task spaces in which collaborative work can be carried out. Groupware has been defined as:

“Computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment.” (Ellis *et al.*, 1991)

It is often the case that when a “shared environment” is being used by physically remote people as their group task space, they also need to use supplementary media to create the person space in which their group communication can take place. The need for understanding the effectiveness of these media in supporting shared workspace collaboration has made it necessary to conduct further empirical studies of different person spaces in which, unlike the studies described earlier, the task space is computer-based and remains unchanged despite the changes made to the person space.

All the studies of the effects of changing the person space on group work carried out in computer supported shared task spaces have compared face-to-face interaction with interaction through different kinds of audio and video links. It is interesting to know that the group tasks used in these studies have always been cooperative. Perhaps this to some extent shows that performing cooperative tasks are more dependant on the availability of a shared task space than the conflictive type tasks. Also, since cooperative tasks are less sensitive to changes made to the person space, it is not surprising that these studies have produced results which indicate that there is not much difference between face-to-face, audio-based, and video-based media in supporting shared task space interaction.

For instance early studies of the use of simple shared task spaces in different person spaces, such as those carried out by Smith *et al.* (1991), Minneman and Bly (1991), and Gale (1990; 1991) showed that the content and quality of the outputs of groups working on cooperative tasks in different person spaces were the same. The results of these studies also indicated that there was no significant difference in the time taken to complete the tasks in different

environments. These results have been substantiated by more recent studies which have evaluated the use of more sophisticated computer supported shared task spaces in different communication environments (Masoodian *et al.*, 1994; Masoodian and Apperley, 1995a; Masoodian and Apperley, 1995b; Masoodian *et al.*, 1995; Apperley and Masoodian, 1995; Masoodian 1996; Masoodian and Apperley, 1996; Olson *et al.*, 1995).

Despite the fact that the above mentioned studies show that the task outcome and performance of groups working on cooperative tasks are not significantly affected by the changes made to the person space used to support the shared task space, the participants' subjective view of the face-to-face interaction remains more positive than video-based or audio-based interaction. In many of these studies subjects rate face-to-face communication to be slightly more "natural" than mediated forms of human-to-human communication.

A comparison of these findings with those described in the previous section suggest that, regardless of whether or not the task space is computer supported, cooperative tasks are not affected by changes made to the person space. There is also some evidence that when there is a computer supported shared task space available then the differences between various types of person spaces become even less important (Masoodian 1996). It seems that small group interaction remains satisfactory and productive whenever there is a shared workspace plus an audio communication channel available, even when the visual communication channel is reduced or eliminated altogether.

5. Changes in task space

The empirical studies discussed in the previous section demonstrate that conflictive type tasks are sensitive to changes made to the person space in which the group interaction and communication takes place. This is perhaps due to the fact that for this type of group tasks the person space is also the task space, hence changing the person space is in fact like changing the task space, which in turn affects the outcome of the group task. For cooperative tasks on the other hand, task space is separate from the person space, and as a result changing the person space does not generally affect the outcome of the cooperative tasks. Therefore, it is reasonable to suggest that perhaps varying the task space will have more significance on the performance and outcome of cooperative tasks than changing the person space.

One of the ways of changing the group task space is by providing a computer supported shared workspace (groupware) in which group work can be carried out. The addition of a groupware is considered to be a change in the task space because it modifies the space in which the remote collaborators perform their task. The lack of groupware, on the other hand, means that there is either no shared task space (such as in audio-based meetings), or that the shared task space is not computer-based (such as in face-to-face meetings). Although there are mainly three types of person spaces that are commonly used (audio-based, video-based, and face-to-face), only audio-based and face-to-face communication modes have been examined in the studies of the changes to the task space.

An extensive study of the implications of adding a computer-based shared task space to an audio-only person space has been carried out by Whittaker *et al.* (1993). This research showed that shared task spaces are most useful for tasks that have a strong graphical component. In such cases providing visual information about the group task is much more important than providing information about the participants' facial expressions or eye-gaze.

Furthermore in remote collaborative work, shared task spaces offer an obvious advantage of providing a permanent record of what has been done and what needs to be done, making them very valuable for complex group tasks.

A similar experiment by Hughes *et al.* (1993) confirmed that a combination of an audio-based person space plus a shared task space is generally sufficient for supporting satisfactory collaboration. Hughes *et al.* also concluded that a key requirement for computer supported shared workspaces is the provision of necessary and sufficient information to maintain cooperation through mutual awareness, and to allow continuous repair of the awareness.

There are also a few studies which show that providing a computer-based task space even improves collaborative work carried out in a face-to-face person space. Although currently decision support systems (Poole *et al.*, 1988; Nunamaker *et al.*, 1991; Mantei, 1993) are being utilised more than shared workspaces for supporting face-to-face meetings, the potential effectiveness of shared workspaces for enhancing group work is also being realised. Therefore, it is not surprising that a number of researchers are exploring the use of a range of computer technology in supporting such meetings.

One such study was carried out by Olson *et al.* (1992; 1993) to explore the effects of using a shared editor on the collaborative design process. The results of this study demonstrated that the subjects easily learned to utilise the shared task space for organising their work, and consequently produced designs that were of a higher quality than the ones produced by the unsupported groups. However, the subjects who used the editor were less satisfied with the design process, and they explored a fewer number of ideas.

Hymes and Olson (1992) discuss another study which compared the results of a brainstorming task performed in three different environments. The groups, who worked in a face-to-face person space, either used a shared editor or they entered their ideas into a single-user editor. The output from these groups were compared with the output from the same number of individuals working alone (referred to as “nominal groups”, see Valacich *et al.*, 1994). This study showed that groups working face-to-face with the shared group editor generated more ideas than the ones working face-to-face without the shared editor. The nominal groups also produced more ideas than the groups working face-to-face without the shared group editor. There was, on the other hand, no difference between the nominal groups and the groups working face-to-face with a shared editor, in terms of the number of ideas generated. This result indicates a clear advantage in using the shared group editor in a face-to-face brainstorming environment.

These studies, though few in number, demonstrate that despite the fact that communication in face-to-face person spaces has often been considered to be an optimal form of interaction, there is a lot to be gained by adding a computer supported shared task space to this type of communication environment. As Hollan and Stornetta (1992) point out, there are various problems even with face-to-face interaction which can to be solved by the use of groupware technology.

Despite the fact that there are no studies of changes to the task space in video-based person spaces, based on the research described in this section, it can be claimed that the addition of a

computer supported task space to any kind of person space has positive effects on group task performed in such an environment. This, in turn, further supports the observation made earlier, that in situations where the task space is more important than the person space then the addition of computer supported task space reduces the effect of changing the person space on cooperative tasks even further.

6. Changes in task and person spaces

There are several empirical research which have varied both the person and task spaces under investigation. These studies have mainly compared face-to-face communication with different forms of “mediated communication”. The aim of these, often long-term, studies have been to show whether face-to-face person spaces can be substituted by a combination of other kinds of person and task spaces created using audio, video, and computer technology.

In one such study, Tang and Isaacs (1993) observed a team of five software designers who were distributed across three locations for fourteen weeks. The result of this study, which compared several combinations of video, audio, and computer links, indicated that people found a video channel useful for mediating interpersonal interaction. Tang and Isaacs claimed that because video allowed a greater mutual understanding between users, it would improve the quality of the collaborative work in the long term. Despite this, Tang and Isaacs pointed out that desktop conferencing is unlikely to replace face-to-face or video conference room meetings completely. Further analysis of the data from this experiment (Isaacs and Tang, 1993; Isaacs and Tang, 1994) identified a number of advantages in using video conferencing over just audio conferencing, as well as identifying several disadvantages of video conferencing over the face-to-face meetings.

Another long-term study which was conducted by Galegher and Kraut (1990) compared face-to-face, audio plus computer-mediated, and computer-mediated interaction environments. The results of this research demonstrated that the computer-mediated groups had to work harder, communicate for longer periods of time, and had more difficulties in coordinating their work than the groups who worked in the face-to-face environment. Also, although all the groups produced outputs of the same quality, the subjects working in the computer-mediated environments were less satisfied with their products, were less committed to their group members, and felt less intellectual benefit was gained from working with other people. A subsequent study by Galegher and Kraut (1992), which confirmed these findings, showed that given the choice the subjects selected the face-to-face person space even when it was not really required for the task they were performing.

Once again these long-term studies, as well as other short-term studies such as the one reported by Adrianson and Hjelmquist (1991), verify that often for some unknown reasons people subjectively prefer working in face-to-face person space to working in other mediated person and task spaces, usually even without the quality and outcome of their performance being affected by such changes.

7. Discussion of the implications

The empirical studies reviewed in this paper are very diverse in terms of those aspects of group communication which they have investigated. This diversity has in turn led to findings which are often difficult to generalise. In fact, the findings of these studies may sometimes seem contradictory to one another. However, if one makes an assumption that all these studies

are in fact about the investigation of human-to-human communication in different person spaces, then one can find three factors that have important effects on the outcome of these experiments. These factors are:

1. Task space: whether it is computer supported or not
2. Group task: whether it is cooperative or conflictive
3. Group size: whether it is large or small

Based on this assumption it is possible to draw a number of general conclusions from these studies, which can be used to guide the design of the future CSCW systems. These conclusions are discussed below.

7.1. Task space

In face-to-face meetings both forms of human-to-human communication, that is verbal and visual, can be carried out without the need for any kind of technology. Meetings between physically remote people, on the other, require the use of a number of different media through which people can communicate with one another verbally or visually. These media are usually text-based, audio-based, or video-based. Textual and audio communications are generally used for verbal interaction, whereas communication through video is usually visual.

Despite the similarities between the use of audio and text-based media for verbal communication, a number of studies reported in this paper clearly indicate that an audio channel is much more effective for verbal communication than a textual channel. Also when the findings of the non-CSCW studies are compared with the findings of the CSCW-based studies, it is possible to claim that audio-based communication is more effective than text-based communication regardless of the type of task space used. This is perhaps due to the fact that the channels used by humans to focus on the audio-based verbal communication (ears) are different from the ones used to focus on the task space (eyes). Although humans can use the audio channel to communicate verbally while they are working on a task, it is impossible for them to carry on working while they are communicating textually.

Furthermore, while verbal communication relies on an audio channel, visual communication relies on a visual channel. This means that in cases such as a counselling session where the task and person spaces are the same, a person can communicate while concentrating on the task space as well. However, when the task and person spaces become separate the focus of attention has to be divided between them.

In a CSCW environment the primary focus of attention is the shared task space (computer screen). The results of many of the reported studies indicate that the addition of video to an audio communication channel has very little effect on the outcome of the experiments. The reason for this is that the availability of the audio communication allows the subjects to concentrate on their shared task space without diverting their attention to communicate visually with one another.

Therefore it can be concluded that the choice of communication media to support shared workspace collaboration is very much dependent on the type of task being undertaken by the group. If the task requires special attention to the task space, and the task space is separate

from the person space, then an audio-based communication channel is sufficient for supporting a computer-based shared workspace. These are usually tasks that have a strong graphical component (Whittaker *et al.*, 1993).

On the other hand, if the person space is more important than the task space, or when the task and person spaces are the same, then more effort should be given to facilitating visual communication. This is generally the case with conflictive type tasks, such as union and management negotiations. However, such tasks are not usually performed in a computer-based shared workspace environment.

There are also cases where both the task and person spaces are important for achieving the group task (such as teaching calligraphy, where being able to see the movements of the hand is important). In such cases it is best to integrate the task and person spaces to provide a seamless medium (Ishii and Kobayashi, 1992) in which the users can switch their attention smoothly between the two spaces. Ishii and his colleagues (Ishii, 1990; Ishii and Kobayashi, 1992; Ishii *et al.*, 1992; Ishii *et al.*, 1993; Ishii and Ohkubo, 1993) have designed a number of systems which combine video and computer technologies to provide a seamless medium of communication. Buxton (1993) also reports on a number of other systems which integrate the person and task spaces, among these are the two systems by Tang and Minneman (1990; 1991a; 1991b) called VideoDraw and VideoWhiteboard.

7.2. Group task

As was mentioned earlier, in many cases the observed variations between the communication media in the studies described in this paper are largely dependent on the group task type. It is, therefore, reasonable to say that the task type is the most important factor which affects group work in different person spaces. Broadly speaking, cooperative tasks are not sensitive to the changes in the person space (so long as there is audio connectivity) while conflictive tasks are.

In conflictive tasks the interpersonal relationship between the participants is particularly important. This means that the extent to which the participants impress, like, trust, or dominate one another is likely to have effects on the group work (Williams, 1977). Therefore, any changes to the person space which affects the relationship between the participants will affect the group work as well. However, it is often likely that the changes to the person space will have little effect on the task outcome, and the main effects will be reflected in the process by which the outcome is achieved (McCarthy and Monk, 1994).

Williams (1977), Short *et al.* (1976), and McGrath (1984) discuss a number of ways in which the changes to the person space may affect the group work. One of the most interesting explanation has been given by Rutter and Robinson (1981). They argue that the differences between communication media, which are the basis of different person spaces, arise not so much from the loss of visual cues, but rather from the loss of social cues. This loss of social cues in turn affects the content and style of the conversation between group members within a particular person space.

The types of task performed in CSCW environments are generally cooperative. These are the tasks that are least sensitive to the variations in the visual characteristics of person spaces.

Although audio plays an important role in cooperative group interaction, the addition of visual channels to an audio channel seems to have very little effect on the task outcome or group communication.

The result of some of the experiments discussed in this paper indicate that the availability of a shared computer supported task space in a collaborative work environment reduces the sensitivity of the cooperative type tasks to the changes in the person space even further. In such environments the task space is more important than the person space (the space through which the interpersonal relationships are established). This simply means that if the computer-based shared task space is supported by an audio channel, visual communication will not be required.

On the other hand, if it is necessary to facilitate the interpersonal relationship between the group members, video and other types of visual channels could be added to the audio link. There are also several ways in which the computer software used to provide the shared task spaces could be enhanced to allow better support for the group members' interpersonal relationships or awareness of one another's presence or task related activities.

7.3. Group size

The number of people in a group has also important consequences for group work and communication. As the group size increases the range of abilities and skills available to the group increases as well (Shaw, 1981). Changing the group size also changes the number of people who take part in the actual processing and manipulation of the information. The advantages of increasing the group size, and therefore increasing the human resources of the group, are obvious for a variety of tasks such as problem-solving, but there are also other tasks for which a smaller group size is more advantageous.

Besides the limitations that the task type puts on the maximum group size, the choice of a particular task space can also introduce further limitations. For instance, even though it is possible to involve a large group of people in a computer supported brainstorming task (Gallupe *et al.*, 1992), it is very difficult to have a large number of people working on a design problem in a computer-based shared workspace. Computer supported shared workspaces have several limitations when they are used to provide the group task space for large number of users. For example, when there are more than a few people using a shared workspace the speed of the software degrades, the group's coordination activities become very difficult, the number of the activities on the screen at a given time becomes too many to understand or predict by the users, and sharing the common artefacts becomes difficult. Therefore, small groups are best suited for the type of cooperative work performed in a computer-based shared workspace. The optimum number of people for such groups seems to be about five (defined as small groups by Slater, 1958). In terms of the structure of the conversations however, there are essentially only three types of group conversations, dyadic, three-people, and larger than three-people.

The majority of the empirical studies reported here have been based on groups of two people. Some of these studies indicate that the effects of person space on the interaction process between two people working on cooperative tasks is not significant, regardless of whether the group work is carried out in a computer-based shared task space or not. There are also studies (Masoodian and Apperley, 1996; Masoodian, 1996; Olson *et al.*, 1995) which show that

making changes to the person space has no significant effects on interaction process between groups of three people.

This paper has also discussed a number of studies involving groups of more than three people. As the majority of these studies are based on conflictive type tasks, they cannot be used to extend the results of the experiments on cooperative tasks for groups of larger than three. Nevertheless, based on some of the observations made during the experiments by Masoodian (Masoodian and Apperley, 1996; Masoodian, 1996), it seems unlikely that variations to the person space will have significant effects of the process of group interaction between four or five people, though further studies are required to examine this observation in detail.

Therefore, there seems to be enough evidence to claim that changes made to the person space is not likely to affect the interaction process between small groups of people working on cooperative tasks in computer supported shared workspaces. On the other hand, if computer-based shared workspaces are going to be used by larger groups, then their design should be improved to facilitate better group interaction. The next section discusses some of the ways of improving currently available CSCW systems.

8. Improving CSCW systems

Over the years researchers have generally focused on the person space in which group work takes place. They have in particular paid a lot of attention to the importance of visual communication and the use of video as a communication medium for creating person spaces which support visual accessibility between remote collaborators. Unfortunately this has often been at the expense of ignoring the role of task space in supporting group interaction, and the type of improvements which can be made to computer supported shared task spaces used in remote collaborative work.

It is obvious from the review of the empirical studies reported here that an audio-based person space supported by a computer mediated shared task space is a suitable environment for cooperative work involving small groups. This is of course largely dependent on the capabilities of the computer-based shared task space used in such an environment. Currently available groupware which can be used to provide shared task spaces are by no means capable of supporting all aspects of cooperative work.

Cooperative activities are often very complex to analyse and understand, mainly because they are dependant on a large number of inter-related factors. Unfortunately many of these factors are poorly understood, or ignored by designers of the groupware applications. More recently though, researchers and designers are attempting to identify some of these factors, so that they can be supported by computer-based shared task spaces. One of these factors currently under investigation by several researchers is called group awareness. Dourish and Bellotti (1992) define group awareness as:

“An understanding of the activities of others, which provides a context for your own activity. This context is used to ensure that individual contributions are relevant to the group’s activity as a whole, and to evaluate individual actions with respect to group goals and progress. The

information, then allows groups to manage the process of collaborative working.”

Dourish and Bellotti then define context as consisting of both the objects of the collaboration, as well as the way in which these objects are produced. This kind of awareness information is important in coordinating group activities regardless of the group task domain.

Group awareness can be categorised into at least two kinds, informal awareness, and workspace (task space) awareness (Gutwin *et al.*, 1996a; Vertegaal, 1999; Vertegaal *et al.*, 1997). Informal awareness means knowing which group members are around, whether they are available or not, or what sort of activities they are engaged in. Workspace awareness on the other hand, means knowing where in the workspace each group participant is working, what each person is doing, or what sort of changes each person is making to the task space.

Informal awareness between physically co-located people is typically achieved by meeting people in a shared physical environment. This may happen by meeting someone at the hallway, or hearing people talking in the common work area, and so on. Video has often been used to provide a means of informal awareness for physically remote co-workers. There are a large number of systems available today (Root, 1988; Heath and Luff, 1991; Dourish and Bly, 1992; Fish *et al.*, 1992; Dourish 1993) which either use real-time full motion video links, or regularly updated still-frame video images, to create a sense of informal awareness between group members.

Despite their effectiveness in creating informal awareness, video-based systems are generally costly in terms of their special video equipment and the communication bandwidth required. A more cost effective way of achieving the informal awareness is through extending the groupware programs used to provide the group shared workspace, or designing groupware whose only purpose is to facilitate informal awareness. Peepholes (Greenberg, 1996), TELEFREEK (Cockburn, 1993), and Piazza (Isaacs *et al.*, 1996) are among some of the useful prototype groupware designed for informal awareness, and which achieve this awareness through the task space itself. There are also various systems (Nakanishi *et al.*, 1996) which provide shared virtual environments or spaces (Benford *et al.*, 1996) supporting informal awareness during casual meetings.

Compared to informal awareness, workspace awareness seems to be much more important in achieving the group task outcome. There are a number of activities which people perform around shared workspaces. Tang (1991) identifies some of these activities to be drawing, listing (writing), or hand gesturing. Although drawing and writing activities are generally supported by most groupware systems, many of the group awareness activities such as gesturing are not.

As with informal awareness, video has also been used to provide workspace awareness. This has been achieved by integrating task and person spaces. However, this is once again a costly solution which has a number of limitations. For instance, many of the systems that use this technique are only useful for dyadic group work. A better way of achieving workspace awareness is through extending the groupware.

Recent work by one group of researchers (Gutwin *et al.*, 1995; Gutwin and Greenberg, 1996; Gutwin *et al.*, 1996b; Gutwin and Greenberg, 1998a) has shown a number of extensions which can be made to increase the ability of groupware in supporting workspace awareness. Empirical studies by these researchers (Gutwin and Roseman, 1996; Gutwin and Greenberg, 1998b) have indicated that these extensions are useful in providing workspace awareness in collaborative work environment.

As a final point, it should also be mentioned that even when it is necessary to use video for facilitating visual communication or group awareness, it should be kept in mind that many of the currently available video conferencing tools are not effective in achieving these requirements. There are, however, a number of technologies being developed which attempt to solve some of the existing problems with video conferencing tools (Vertegaal, 1999; Vertegaal, 1998; Vertegaal *et al.*, 1998; Vertegaal *et al.*, 1997)

9. Conclusions

This paper has categorised the empirical studies of computer supported human-to-human communication, based on the notion of person and task spaces. This review has demonstrated the diversity of existing studies in terms of their experimental characteristics, as well as their findings. Unfortunately this diversity has often made it difficult to draw general conclusions which would hold true across a range of group sizes, tasks, or collaborative work environments. This review, however, shows that using the concept of person and task spaces it is possible to generalise some of the findings of the existing research to guide the design of future CSCW systems.

These studies have clearly indicated that the task space plays an important role in effectiveness of computer supported collaborative work. This type of work, which is often cooperative and involves small group of people, depends heavily on the type of interaction that takes place in a shared workspace.

In a face-to-face cooperative work setting, the shared workspace can be anything, ranging from a whiteboard, piece of paper, or workbench, to a sophisticated computer display unit. In this type of setting, the person space supporting the communication between the collaborative partners consists of both audio and visual channels. The audio channel is used for human-to-human communication, while the visual channel is used for viewing the shared task space as well as the person space, often with rapid switching between viewing the person and task spaces.

In a physically remote cooperative work setting, on the other hand, the shared task space has to be created using either a computer-based groupware or a video link between the collaborative participants. The person space has to be created using audio or video medium (or perhaps textual medium, to a limited degree). In this kind of setting audio still remains important as a communication channel which provides the person space. However, unlike the face-to-face situation, the effectiveness of video for supporting the visual aspect of person space is reduced greatly, as the visual channel is generally used to concentrate on the task space.

This means that a combination of audio-based person space and a computer, or video-based task space is generally sufficient for supporting cooperative tasks between small groups of physically remote people. Computer supported task spaces are more suitable than the video-based task spaces, unless it is necessary to share view of interaction with real-world objects which cannot be done in standard groupware products.

Therefore, it is suggested that rather than attempting to integrate video and other means of communication with audio to support remote shared workspace cooperative work, industry should be devoting more attention to improving groupware technology which is used to provide the shared task space facility for remote collaborative work.

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