Effects of task variation and communication medium on performance in small groups:

A comparison between Face-to-Face and Computer-Mediated Communication

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Paola Gonzalez

Abstract

Computer-Mediated-Communication is becoming the essential medium for human interaction in the current globalized world. Organizational support for cooperative work has been shifted from using Face-to-Face (FTF) communication in collocated groups to using Communication-Mediated-Communication (CMC) in dispersed groups. This new and growing form of communication has stimulated scholars to study the differences of group performance between FTF and CMC. Task categorization has been the methodology chosen for several empirical research studies. These studies conclude that the effectiveness of a communication medium for a given task depends on the degree to which there is a fit between the richness of information that can be transmitted via a system's technology and the information richness requirements of that task. However, there are numerous problems associated with using task categorization in such studies. One of these limitations is that categorization forces the researcher to enclose a task situation into a general predetermined category that may not describe the real nature of the activity. For instance, task categorization does not capture the dynamic interaction of groups performing tasks that involve variation. This thesis discusses the weakness and limitations of this approach and, using conclusions drawn from experimental results, propose the adoption of a more systematic approach based on the concept of Ashby's law of requisite variety.

Findings on the differences in performance of FTF groups versus CMC groups of 39 three-person groups of engineering undergraduate students revealed that the group performance was not affected by the communication medium but rather by variation in the task (low and high complexity). However, some minor differences in the high task complexity condition were found in relation to the communication media. CMC groups outperformed FTF groups in this task condition; a difference perhaps attributable to the different levels of attention to environmental uncertainty perceived in the two conditions. Physical dispersion combined with the communication technology's characteristics may have enabled the CMC groups to be more attentive to task variation (unexpected situations) than the FTF groups were. However, the general conclusion drawn is that if the requisite of variety is matched in the two experimental conditions (FTF and CMC), group performance will be most likely the same regardless physical dispersion. In other words, if the communication technology offers similar capabilities to those in FTF communication (e.g., visual, audio, and graphical synchronous capabilities) and if the factors affecting group interaction are kept constant (e.g., similar

characteristics for group members and coordination mechanisms), the performance of the FTF and CMC groups will not differ significantly. Thus, the proposed systematic approach – Ashby's law of requisite variety – would analyze the internal and external variety generated by the task situation so that a requisite of variety could be set up in the design of the task.

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The whole of science is nothing more than a refinement of everyday thinking.

Albert Einstein

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Dedication

My son, Santiago Ortegon Gonzalez. Santi, my life without you would have been boring and very simple!

My mom, Carmen Munoz. Mami, lo siento por todos los malos momentos que te di, gran parte de lo que soy ahora, te lo debo a ti!

Table of Contents

List of Figures

List of Tables

Chapter 1
INTRODUCTION

Groups are the typical building blocks of an organization; they provide companies with the mean to combine the various skills, talents and perspectives of a group of individuals to achieve organizational effectiveness (Siebdrat, Hoegl and Ernst, 2009). Therefore, reliance on groups to accomplish work tasks highlights the importance of understanding the factors that influence group task performance. Two of the key factors are: communication and task interdependence. These properties are, in turn, mutually dependent because the interaction and performance of a group, carrying out certain tasks, can be either hampered or enabled by the type of communication medium employed (Hollingshead and McGrath, 1995; Daft and Lengel, 1986; Rico and Cohen, 2005).

Moreover, with the advancement of communication technologies, groups have been able to interact and accomplish tasks from a distance, a situation that makes organizations rapidly adopt this new form of communication in order to survive in the current globalized and competitive world. Thus, several organizational tasks that used to be exclusively performed by collocated groups (groups working in the same location) are now being performed by dispersed groups (groups working from different locations) with the aid of communication technologies. However, some scholars have found that coordination across distance is more difficult than in collocated environments (Herbsleb and Grinter, 1999; Kraut and Streeter, 1995). In other words, group task performance can be affected by the type of communication media used.

These findings have originated with the proliferation of theories that attempt to predict which tasks are better performed by collocated groups rather than dispersed groups. Some of these theories are based on empirical evidence that shows, for instance, tasks that are highly interdependent need richer communication channels (Maznewski and Chudoba, 2000). Information richness theory and synchronicity theory, for example, contend that for highly interdependent tasks, collocated groups using Face-to-Face[1] (FTF) communication, would outperform dispersed groups, using Computer-

[1] FTF communication has the properties of synchronous communication

Mediated-Communication[2] (CMC) (Arunchalam, 1994; Dennis and Valacich, 1999). In these theories, interdependence of the task implies the degree to which group members will interact and depend on each other to accomplish tasks under condtions of uncertainty or equivocality. Hence, McGrath (1984) developed a typology of tasks, in which tasks were classified into four broad categories: generate, choose, negotiate and execute. The first two categories refer to uncertain tasks in which there are well-understood predetermined responses to potential problems (e.g., idea generation or brainstorming). The last two refer to equivocal tasks in which there are multiple (and possibly conflicting) interpretations of the information (e.g., negotiation) (Daft and Lengel, 1986). The previous theories have predictied that FTF groups would better perform equivocal tasks, whereas CMC groups would better perform uncertain tasks. However, these predictions have not been consistent in the literature; other scholars (Hollingshead *et al.*, 1993; Kinney and Dennis, 1994; Mennecke *et al.*, 2000) have refuted these findings with their conclusions that the relationship between communication technology and task performance is more dependent on experience with the technology and with the group membership rather than on the type of task being performed. In the light of these contradictions, we may then ask what role is played by task interdependence and the type of communication medium used in the group performance? This thesis theoretically and practically address this question.

In the first instance, the task chosen in this study, did not fall into any of the above-mentioned categories because of the dynamic characterisitcs within the task that could not be explained by the static nature of the exisitng categories; so the primer limitation was to find predictions for this study, which, in turn, revealed that the CMC field has conceptualization problems.

Consequently, the first focus for this study is to examine the shortcomings in the existing CMC literature and to question the current approaches to studying communication media impacts on performance. The second focus is to analyze the findings of experiments conducted between groups in a Face-to-Face environment (collocated gourps) and groups in a Computer-Mediated-Condition (dispersed groups) when performing a dynamic task. The dynamic properties of the task allows

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[2] CMC can provide either synchronous or asynchronous communication in the interaction

exploration of the effects of task variation and communication medium on group performance. The chosen task tests the performance of groups under conditions of low (low interdependence) and high complexity (high interdependence). The experiment was designed: 1) to approach the study of impact of communication technologies on group performance from a perspective different from that of the literature so that categorization would not be needed, and 2) to analyze and measure the performance of groups under situations of task variation. Two main considerations were taken into account during the experiment's design: first, it was essential to identify the requirements of the task and, second, find the proper communication medium to support those requirements. This approach was intended to equalize the experimental settings so that if difference was found, it would be attributed more to the physical setting than to the possible unequal communication capabilites, a situation often found in the unequal experimental comparisons in previous researches. In other words, the tools available to the groups to perform the tasks were held constant across the conditions.

Thus, the purpose of this study was not only to find the differences, if any, in the performance of groups using different types of communication media (FTF vs CMC) under low and high task variation, but also to explore the possible different patterns of interaction that can be attributed to the physical settings of the groups. This thesis is organized as follows. Chapter 2 summarizes the literature on group task performance and communication technology and concludes by identifying the theoretical limitations that impeded the generation of predictions for this study. Chapter 3 discusses the methodology and provides a detailed description of the experiment. Chapter 4 analyzes the results of the experiment. Finally, Chapter 5 discusses the main findings and summarize them in the conclusion section. At the end of this chapter, practical implications of the study and possible research directions for the future are highlighted.

Chapter 2
THEORETICAL FRAMEWORK

There is a vast amount of literature on Communication Technologies (CTs), some of which analyze the interaction of communication and technology in organizations. CTs, also known as Computer Mediated Communication (CMC), show two primary research streams: the first examines the impact of communication technology on task performance, while the other focuses on its impact on communication processes and social interaction. This chapter provides an overview of these two approaches and exposes some of their limitations that provide the theoretical basis for this study.

2.1 Task Performance

Some scholars agree that the effects of communication technologies on group performance seem to depend on the interaction of the specific group, the media employed, and the task being performed. Social presence theory (Short *et al.*, 1976), media richness theory (Trevino *et al.*, 1987; Daft and Lengel, 1986) and its extension, the task-media fit framework for information richness (Hollingshead and McGrath, 1993) have studied this interaction by mapping task types to communication media. Another approach is media synchronicity theory (Dennis and Valacich, 1999), in which, rather than studying the richness of the medium, researchers consider the synchronicity of the communication to be the critical dimension and analyze tasks under two communication processes: conveyance and convergence. This last theory thus determines the ability of the media to support these processes. The following sub-sections describe the theories in more detail.

2.1.1 Information Richness and Task Performance

Under the theory of media richness, the effectiveness of a given task's communication medium depends on the degree to which there is a fit between the richness of information that can be transmitted via the CT and the information richness requirements of that task (Daft and Lengel, 1986). Therefore, task performance will be improved when task requirements are matched to a medium's ability to convey information (Dennis and Valacich, 1999). This approach argues that some media transmit information more efficiently than others, depending on whether the information is used in situations of uncertainty (i.e., when there are well-understood predetermined responses to potential problems) or equivocality (i.e., when there are multiple – and possibly conflicting –

interpretations for the information). Therefore, the classification of organizational tasks is based mainly on the degree to which the task reflects the particular situation.

Within this concept, the most common task taxonomy used to try to predict the best choice of media for a particular situation is McGrath's typology of tasks (McGrath, 1984). McGrath proposed that most group tasks can be classified into categories that reflect four general processes: "generate," "choose," "negotiate," and "execute" (Appendix A: Figure A1). Subsequently, he and Hollingshead (1993) developed a matrix that identifies the task-media fit to information richness (Appendix A: Figure A2). Some of their empirical results indicate that tasks classified under "generate" or "choose" task categories – which reflect high uncertainty (i.e., brainstorming) – are better supported by Computer-Mediated Communication (CMC). Their explanation was that redundant paraverbal (tone of voice, inflection, voice volume) and nonverbal (eye movement, facial expression, hand gestures, and other body language) cues found in rich media, such as face-to-face and video-mediated-communication, may hinder group performance because of the probable "distraction" associated with this extra information, which is not essential for the effectiveness of the task performance. These results are supported by other studies in the area that have replicated the comparison between computer-mediated and face-to-face groups involved in brainstorming or idea-generation tasks (Rico, and Cohen, S, 2005; Chidambaram and Jones, 1993; Hollingshead and McGrath, 1993; Gallupe, et al.,1992). On the other hand, with respect to equivocal tasks, the task-media-fit matrix proposes that those tasks reflecting equivocality (i.e., negotiation tasks) are better performed by rich media such as video-mediated and face-to-face communication. The argument for this proposition was that group members require additional redundant cues to reduce the possible equivocality of the information. This finding is supported by Arunchalam (1994) but refuted by others (Hollingshead et al, 1993, Kinney and Dennis, 1994; Mennecke, *et al.*, 2000), who argue that, because work groups can adapt to any given technology over time by developing communication norms, the task-media-fit matrix on information richness may also vary over time. They contend that face-to-face groups may initially outperform computer-mediated groups on negotiation tasks, but that the difference would narrow over time as computer-mediated groups adapt their communication norms to the technology. These researchers conclude that the relationship between technology and task performance seems to be more dependent on experience with the technology and with group membership than on the type of task being performed.

2.1.2 Media Synchronicity and Task Performance

Instead of employing the term "richness" of information, Dennis and Valacich (1999) followed the basic concept[3] of medium capacity developed by information richness theorists and used it to map the dimensions of task functions, communication processes, and media characteristics under the theory of media synchronicity. Instead of media richness dimensions that owe their origins to social presence theory and presume that increased richness is also linked to increased social presence (Dennis and Valacich, 1999), media synchronicity theory uses synchronous communication as the critical dimension. Dennis and Valacich defined synchronicity as "the extent to which individuals work together on the same activity at the same time" (5). Therefore, media can facilitate synchronicity to a larger or smaller degree, as well as "support the two communication process (conveyance and convergence) across the three group functions (production, group well-being, and member support)"(5). In general terms, these authors argue that if the group is in the process of conveyance[4], synchronicity is not essential and, thus, low media synchronicity is preferred for this communication process. On the other hand, in convergence[5] processes, highly synchronous media are needed; these arguments are somewhat similar to the findings of information richness theorists. Following these similarities, Dennis and Valacich (1999) classify media according to five dimensions:

> "1) Symbol variety (capability to transmit and provide verbal, nonverbal, visual, auditory, and graphical information in various formats); 2) Parallelism (capability to enable simultaneous conversations); 3) Feedback (capability to enable rapid bidirectional communication); 4) Rehearsability (capability to enable the sender to create and edit the message carefully); and 5) Reprocess ability (capability to enable the receiver to examine and process the message again during the conversation)." (2-3)

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[3] The reason for richness differences include the medium's capacity for immediate feedback, the number of cues and channels utilized, personalization, and language variety (Daft and Lengel, 1986)

[4] "The *conveyance* of information focuses on the dissemination of a diversity of information from many sources, information not previously known to participants."(4) The goal for a group is to disseminate and obtain as possible relevant information (Dennis and Valacich, 1999)

[5] "The *convergence* on a shared meaning of this information focuses on [groups] understanding each individual's interpretation of the information, not the information itself. The goal is to agree on the meaning of the information in a current situation, which requires individuals to reach a common understanding and to mutually agree that they have achieved this understanding (or to agree that common understanding is not possible)"(4) (Dennis and Valacich, 1999)

Based on their analysis of these dimensions, Dennis and Valacich (1999) concluded that “face-to-face communication is not always the ‘richest’ medium for communication (as information richness theory does). They conclude that the “best medium or set of media depends on which of these five dimensions are most important for a given situation” (8). Therefore, in their view, attempting to choose one single medium for any task may prove less effective than choosing a medium or set of media that the group can use at different times in performing certain tasks, depending on the type of communication processes involved (conveyance or convergence).

2.1.3 Communication Structure and Task performance

Other researchers have investigated the impact of media on the communication process and have found that communicative structures (i.e., how access to visual cues affects communication outcome and dialogue structure) differ across different media (Issac, and Tang, 1994; Sellen, 1995; Rutter, 1987). Some of these scholars explored the differences in communication among face-to-face, audio-mediated, and video-mediated remote conditions in order to assess the effects of visual signals on communicative outcome and dialogue structure (Chapanis *et al*., 1972; Issac and Tang, 1994; Olson, *et al*., 1995; Williams, 1977). Some of their results showed that for problem-solving tasks, face-to-face and audio-only conditions do not differ in terms of task outcome, whereas for design tasks, face-to-face was significantly better than audio-only remote conditions. In the case of a video-mediated condition (VMC), communication achieved an intermediate level of performance that did not differ significantly from either the audio-only or the face-to-face conditions. Other studies also failed to find performance benefits of face-to-face over VMC in problem-solving tasks (Williams, 1977; Short *et al*, 1976; Chapanis, 1972), but negotiation tasks or conflict resolution showed benefits. In addition, findings from Olson *et al.* (1995) and Sellen (1995) showed that the quality of VCM (i.e., in terms of image size and resolution and of synchronicity between audio and video signals) affects user preferences. For example, high quality of video in the VCM condition was rated highly and close to face-to-face conditions and significantly better than audio-mediated conditions.

As for communication structures that measure the number and length of turns and number of pauses and interruptions in conversation, Doherty-Sneddon, *et al*. (1997), showed that visual signals in VMC improve the communication process in remote conditions; but they cannot function as face-to-face signals in substituting for the range of verbal expressions of information found in this medium. This study also found that no significant difference was discernable among the three conditions (VCM, FTF and Audio-mediated); however, when the authors looked at process and outcome together, communicative structures do differ across among the three.

2.1.4 Social Perception

With respect to exploring the social effects of mediated communication on group performance, the CMC literature started principally focusing on social cues (facial expression, direction of gaze, posture, physical distance, etc.) as an important factor that makes interactions more social. Tanis and Postmes, (2007) attempted to unravel the theories focusing on solely social cues and found two perspectives to describe this analysis: the deterministic capacity-focused approach and the constructionist approach. These authors contend that the social presence theory, the information richness approach, the cuelessness model, the reduced social cues approach and the social information processing theory, all propose that the degree of "social" cues in a communication medium is what makes a "[CT] richer because such cues help to individuate a person, thereby influencing various social processes" (Tanis and Postmes, 2003) (680). On the other hand, Walther (1992, 1996) claims that these theories have only focused on the capacity of the medium to transmit these cues instead of exploring the creativity of users to respond more imaginatively to media constraints. In response, Tannis and Postmes (2003) expand on this idea when saying that "the social effects of technology should not be understood as being determined by media characteristics (technological determinism), but as products of social and technological influences (technological constructivism)" (690).

Following this idea, the Social Identity model of Deindividuation[6] Effects (SIDE) (Reicher, *et al*., 1995; Postmes, *et al*., 1998) proposes that social cues are not the only important factor of a medium's effect on social perception. This model contends that group interaction may even benefit from the lack of personalizing cues; because there are contexts in which a group's attributes are known or can be easily inferred. Hence, lack of personal information (i.e., anonymity) could make the group more cohesive and help to form group members' perception of membership or belongings to the group. In

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[6] Deindividuation is the central assumption of the Reduced Social Cues approach and refers to a state in which people lose their individuality because group members "do not feel they stand out as individuals "and individuals act as if they are "submerged in the group" ((Festinger *et al*, ,1952) (384)

short, this approach suggests that in order to study the social effects of a communication medium, one should analyze the interaction of features of the medium (i.e., capacity) with features of the social context[7] (i.e., social identities). SIDE points out that a medium which leaves its user "cueless" does not mean the user will be "clueless" (Spears, 2002). Following this approach, several other theories consider the social/context aspects of CTs such as structuration theory, social influence theory, social information processing theory and channel expression theory. These theories emphasize that despite the use of different CTs, group members likely adapt the technology to the context of use (Tanis and Postmes, 2003). As an example, Burke and Chidambaram (1999) found that with repeated use and interaction with the CT, group members could perceive a lean CT to be as effective as a richer CT because a "lean" CT helps group members focus on the task, and thus, avoid extra information not needed for completion of the task.

2.2 Theoretical limitations of this study

The aforementioned theories' Achilles' heel is the inconsistency of research results, issue that hampers the development of useful theories in this field. This section exposes limitations in the literature that have impeded the formulation of predictions for this study.

The first limitation is associated with methodological issues. The most common approach in the literature to the study of Computer Mediated Communication (CMC) was the development of taxonomies. These taxonomies categorize tasks and media so that predictions can be made about task performance and perhaps Communication Technologies (CTs) selection. However, none of these taxonomies were helpful in the selection of predictions for this study because the task used in this study did not fall into any of those categories.

First, it is worthwhile to mention that one important benefit of using categorization in science is that it can facilitate attempts to find a common and practical ground among all the otherwise unmanageable information available in certain fields; a desired condition if there is to be useful communication

[7] For a deep understanding of this theory, refer to John C. Turner (1982) Towards a cognitive redefinition of the group. In J. C. Turner (Ed.), *Social identity and intergroup relations* (pp. 15-40). Cambridge: Cambridge University Press.

among scientists (Higgins and Safayeni, 1984). However, this state is not always reached, particularly in the social sciences. A classic example in the organizational field that illustrates the pitfall of categorization is that of Mintzberg (1971). He addressed the validity of describing manager's work under what were then the four dominant classifications: planning, organizing, coordinating and controlling. After attempting to use that classification to describe managerial work, he concluded that manager's work is so complex and dynamic that enclosing it into the above-mentioned categories would leave the context of the real activity out. According to him, "these four words [the categories] do not describe the actual work of managers at all; they describe certain vague objectives of managerial work…they are just ways of indicating what we need to explain" (2). In 1971, Minztberg called on the management science field to describe managerial work more precisely, and proposed a systematic approach based on extensively and keen observation of "real" manager's work.

More than 30 years have passed, and that call seems to be needed again, but now for the Computer Mediated Communication (CMC) field. In the aforementioned CMC literature, taxonomies have been the common approach to the study of mediated communication in organizations (Appendix B provides examples of such taxonomies). Most of them try to predict the proper fit of a communication technology to the requirements of a specific task. However, the inconsistent results in the literature make their usefulness questionable.

First, some empirical results show the disadvantages of CT in comparison with FTF communication. For instance, Information Theory contends that FTF communication (synchronous communication) can be seen as the richest medium, because it holds verbal and non-verbal cues. Thus, these cues facilitate feedback and turn taking in the communication process, which in turn, enable the transmission of shades of meaning. However, in asynchronous media (some CTs), many of the cues are erased. Interruptions, long pauses and sometimes information overload are frequent in some CTs; all situations that can hamper the flow of regular communication (Ocker, *et al*., 1999; Hollingshead and McGrath, 1995). Moreover, synchronicity theory contends that FTF groups would outperform Computer-Mediated CM groups during equivocal tasks because FTF (synchronous medium) better supports the process of convergence (Dennins and Valacich, 1999). The common experimental tasks used to test this prediction are classified as negotiating tasks, and may include cases of bargaining or, developing organizational policies, among others, in which intense discussions as well as delayed consensuses are expected to happen. On the other hand, some tasks considered as uncertain are expected to be better performed with CMC than in FTF communication. Examples of these tasks are those in the category of generating ideas; brainstorming is the classic example. Appendix C shows the common type of tasks used by the authors.

This categorization of tasks seems to enclose organizational activities in pure and general static categories (refer to the above Minztberg' example). But do not the examples of negotiation tasks (i.e., discrimination or promotion) involve intellective or decision-making process as well? To what degree can we determine when a task is intellective or decision-making in nature? Let us consider the example of a New Product Development (NPD) team, in which several experts, who may have never met before, gather to develop a new product or service for an organization. Several activities can take place in a situation like this, including generating ideas, problem solving, and decision making and negotiating. It may also be the case that not all members (experts) are located in the same room; some participants may be in remote locations communicating with the rest of the group through mediated channels (i.e., phones, computers, and video systems). How in such situations can the impact of CT on group performance be studied? Would the categorization of tasks, if possible, provide meaningful insight?

A similar issue happened when taxonomies were applied in a study of office automation. Higgins and Sayafeni (1984) point out several inherent limitations associated with the use of categorization for these types of studies. These authors argue that organizational activities cannot easily be categorized in a meaningful manner, in contrast to what several others scholars believe. The former found three implicit problems with categorization of activities: 1) With respect to human activity, similarities and differences can be found on many different dimensions, 2) The ambiguity in language creates a number of problems in generating meaningful categories, and 3) Given the static nature of categorical descriptions, task taxonomies are not informative with respect to the ongoing dynamic and interdependent activities of people in organizations.

Some questions motivated the discovery of the previous limitations: "on what bases are activities categorized? Or what aspects of two or more activities within a single category are considered to be similar to each other? and what is the process by which such similarities are detected with some degree of reliability?" (334) (Higgins & Safayeni, 1984) Human activities, as any other complex system, are made of multiple, sometimes undistinguishable dimensions. For example, a graduate student is engaged in several activities such as doing research (either for herself or for a professor as the title of research assistant), taking courses towards a degree, teaching (as part of TA's duties), playing sports (as a part of a university team), volunteering, to list a few. Thus, the graduate student' role in the university may be placed in different categories. In addition, this process of categorization uses language to describe the categories; however, these categories may correspond to many possible activities. Hence, these overlapping situations together with the need of description "always leave a residue of uncertainty about the precise nature of the activity" (334) (Higgins and Safayeni, 1984). In addition, in the Mintzberg's example, language can be seen as ambiguous because several descriptions can convey different meaning. For example, planning can be interpreted differently by a researcher than by the person who is performing the activity.

With these above-mentioned limitations, the validity of categorization is questionable. For example, would categorization of tasks, if possible, provide meaningful insight into the [NDP] situation exposed in previous paragraphs? The answer is most probably no. Categorization does not capture the dynamic and complex interactions within groups. For example, a planning activity may be interpreted as evaluating alternatives, or even as negotiating interests within a group. Categorization, in this way, is in the eye of the beholder (observer) and thus, is very subjective. In many instances, certain tasks embrace other tasks (or processes). To support this avoidance of categorization when describing dynamic activities, Kurt Lewin, in 1942, criticized traditional approaches that emphasize the "static" aspects of human behavior in his field theory[8]. He was a fervent follower of first analyzing a situation as a whole, instead of beginning with isolated elements and later attempting to organize these elements into an integrated system (Shaw and Costanzo, 1982).

Analogous to categorization of organizational tasks is the classification of media. In the CMC literature, media have been described to the extent that they support the requirements of the task (equivocal vs uncertain) with the concept of rich or poor medium, or the requirements of the process

[8] More details see: Lewin K. (1943). Defining the "Field at a Given Time." *Psychological Review.* 50: 292-310. Republished in *Resolving Social Conflicts & Field Theory in Social Science,* Washington, D.C.: American Psychological Association, 1997.

(convergence or conveyance) with the concept of asynchronous synchronous medium. Several studies have implicitly focused on only one communication technology at a time (asynchronous vs synchronous). However, today, with the advancement of CTs, media categorization has also become unclear and somewhat useless. Technologies such groupware (which allows the sharing of applications), Group Decisions Support Systems and Group Supported Co-operative Work (to support collaboration on shared tasks), provide a vast and interchangeable range of capabilities to support several tasks interdependently and simultaneously. These computer applications can support verbal, visual, auditory and graphical information in various formats as well as asynchronous and synchronous communications at the same time. Some of these computer applications support e-mail transferring, chatting and audio-video conferencing, tools that can be used interchangeable at any time during a regular meeting. Suppose, for example, that during a New Product Development (NPD) meeting, two experts have access to certain CT, One does not have a web camera in his or her computer; thus, his or her CT application are limited to only e-mail and chatting, while the other one has access to either a regular phone or to a video-computer application with a computer that supports either synchronous or asynchronous communication. In such case, what would the classification medium be with respect to the task? Would this inconsistent communication setting impact the performance of the group? If so, how?

As it can be concluded that organizational tasks as well as CTs contain a wealth of interrelated dimensions cannot easily be described using categorization and may be the cause of inconsistencies in the literature. McGrath (1994), who developed the idea of a task circumplex, referred to this inconsistency when saying that "*the problem is not that those sets of facts disagree; rather it is that they cannot be compared, because they deal with different parts of the domain and do so in different research language*"(195). This caution leads to another observation about the way CMC research has been conducted, it refers to the unequal experimental settings designed to test the researchers' propositions. Most of the experimental comparisons (FTF vs CMC) did not use similar collaborative tools in the two conditions. Let's say when testing a brainstorming task, the computer-mediated group was working isolated and given certain time to generate ideas while in the FTF group, the members were sharing their ideas simultaneously in the presence of others and having turns of talking. In the same token, the measurement of performance was more in regard with the quantity rather than with the quality of the ideas generated in the groups. Therefore, the differences in the experimental design for the both conditions would most likely lead to differences in performance. Thus, these comparisons have tested unequal situations that certainly would expose differences that may not be solely due to the properties of the task being performed but to the setting of the experimental design. Another example is a negotiation task, in which a group is expected to discuss and reach consensus on a certain issue, synchronous communication would be required to facilitate the flow of discussion. But, if the communication medium is changed to one that provides asynchronous communication, the group performance would probably be affected not by inability to perform the task, but by the impeded communication flow. Copper and Richardson (1986) in their article "Unfair Comparisons" advise organizational researchers in the use of comparisons; one of the precautions they pointed is that "each theory, factor or variable [needs to] be operationalized with equivalent fidelity and care" (182). Although, Copper and Richardson emphasized their warning when comparing and testing theories, their argument is extended to the experimental setting because if a researcher follows careful procedure equivalence, his/her findings would be more reliable.

The above-mentioned limitations were actually discovered as the author of this thesis was attempting to find parallels between the study's experimental task and the existing CMC literature. The properties of the task allowed us to carefully analyze the literature and, thus, set out another perspective to promote understanding of CMC in group performance. The task chosen for this study was the "number game", a task developed by professor Frank Safayeni of the Department of Management Sciences at the University of Waterloo. At first, the task seemed to be very simple because it consists only of having three or four people in a group add a series of random numbers; ranging from one to 19. The groups are not allowed to use pens or calculators. The groups are expected to come up with coordination mechanisms that help them accomplish the task efficiently. Thus, the task involves an intense and active interaction among group members who after sharing ideas and planning how to add the numbers more efficiently, face several other group dynamics such as decision making, problem solving, and negotiation tasks, among others. This task, then, would allow us to explore a closer dynamic as that of the organizational groups (teams), since it is less likely (not to say it is improbable) that in organizational groups, tasks would be easily categorized. For example, even if the group is first formed to generate or design a new product, process that may be located in the quadrant I: generate of McGrath's circumplex (appendix A), the group would also tackle several other tasks such as solving problems of cost materials or deciding on environmental issues for the new product; situation that may also locate the group in the quadrant II: choose of McGrath's circumplex. Therefore, if the research's intention is to measure the impact of communication technologies, in this case, the impact of computer-mediated-communication on group performance, the analysis should be based on a task that closer reflects the group's dynamics in organizations as well as on a task that facilitates the measurement of group performance.

The number game task, besides measuring group performance directly without the need of having experts to rate the group outcome, allows exploration of the response of groups in situations of high and low complexity. With this task, the above-mentioned key factors in the study of groups: communication and task interdependence would be clearly analyzed, since for the successful completion of this task, the groups need to be creative in developing collaborative adding strategies in order to score the answers as the same time to be able to share the ideas (communication) with the rest of the group members to coordinate better, process that requires close interaction among the group members (coordination).

Thus, instead of categorizing the task to determine the impact of communication technology on group performance because of the previous mentioned limitations, this study explores the effects of task variation and communication medium (FTF vs CM) on performance in small groups. Thus, it is of interest to explore the differences, if any, in performance and behaviors between groups performing an interactive task in two different settings: a Face-to-Face (FTF) environment, where all group members are in the same room, and a distributed environment, where they are located in rooms remote from one another. Specifically, I want to explore groups provided with a similar communication medium but in a different physical distribution (located vs collocated groups) will perform differently or experience different group dynamics. The fact of not being in the same room and using a communication technology to communicate may hinder or enable the group performance for this particular task, as well as to possibly show different coordination mechanisms between settings.

This approach differs from those in the existing literature because first, it identifies the essential requirements of the task, and subsequently, identifies the communication medium that supports those requirements. This approach would allow identifying any possible differences originated primordially by the physical arrangement and its properties, but do try to avoid the unequal communication capabilities found in previous researches. The number game has two basic requirements: first, the communication medium needs to facilitate discussions among group members. Synchronicity with rapid bidirectional and simultaneous communication supports this fact. Second, since the groups are expected to come up with collaborative strategies, being able to see one another would be helpful as well as simulate the FTF environment, thus avoiding a possible disadvantageous situation in the comparison. Thus with the goal of trying to equalize the experimental conditions between FTF and a distributed environment, it is equally important that the groups in the distributed condition have information similar to that available to those in the FTF condition. Hence, the communication technology needs to support all these requirements. Otherwise, the comparison would favor one condition over the other one, a situation which, would be like comparing the performance of a regular healthy runner (FTF setting) with that of a person with a physical disability (ies) (a lean CT) in a race with obstacles.

Finally, the performance will not be evaluated only whether the group gets the right answer; and how far off the groups were from the right answer. The discussion time and coordination mechanisms used, as well as the interactions among these variables will also be measured. The purpose of this study is not only to find differences, if any, between the two types of communication media, but also to explore the patterns and the extent to which all the previous variables relate to relevant outcome measures.

Chapter 3
METHODOLOGY

3.1 Task

The number game task serves as an abstraction of the types of problems dealt with in actual organizations such as decision-making, negotiation, and coordination, among others. The task consists of participants in group of three-people adding up a series of random numbers ranging from one to 19. The groups are asked to come up with different strategies for adding the numbers in the most efficient way so that high performance is reached. The numbers are shown one by one on a screen (a projection screen for the FTF condition and a computer screen for the distributed condition), and participants are not allowed to use writing materials or calculators, that is, they must rely only on their memory to get the total sums. The task consists of eight different series or runs in which the value and characteristics of the numbers vary during the task in the following way: the first two runs show 20 numbers each; the third and fourth runs display 30 numbers each; the fifth and sixth runs display 24 single-digit numbers mixed with 6 double-digit numbers; the seventh run displays 20 single-digit numbers mixed with 10 double-digit numbers; and the eighth run displays 10 double-digit numbers mixed with 19 single-digit numbers. A blank white slide was introduced after the 12th number for a surprise effect in the middle of the run. The numbers given in the task are presented in Appendix D.

The instructions given to the groups are the following:

First slide:

Welcome to the number game!

You will be shown 8 runs of series of numbers. Your job - as a group - is to come up with different strategies to add the numbers in the more efficient way.
You are not allowed to use pen, paper, and calculator and so on (Just your memory)

Second slide:

At the end of each run, your job is to report the total sum of each run of numbers. After you as a group agreed with the total sum, you say the number to Paola (the experimenter), and then she is going to tell you the accurate sum of the run.

The best group performance record has been so far 6 accurate runs out of 8 (6/8)

Can you as a group beat this record?

Third slide:

Before the runs start, you will be given an example of how the numbers are going to be displayed on the screen.
You do not need to sum up the numbers in the example. Just look at them and get familiar with the screen.

(at this point 8 more slides are shown with the numbers of the example)

Ninth slide:

Remember, your job is to report the sum of these numbers. At the end of the each run, you will see the slide "say your answer", and then you have to say the total sum to the experimenter. Following your answer, you will be given a feedback to see how accurate you were.
Before we start, you can discuss among yourselves how you are going to do this.
You have 2 minutes for discussion between each run.
You'll be told just before each run starts.

Tenth slide:

Run will start in 15 seconds!

Eleventh slide:

Run will start in 2 seconds! Ready set got!

(First numbers of the run #1 shows here and so on)

3.2 Design

3.2.1 The Study Condition

The experiment was a 2 (communication medium: FTF and CMC) x 2 (task complexity: Low and high complexity) factorial design.

For the FTF condition, the experiment was set up at the University of Waterloo's Management Sciences Uncertainty Lab (Carl Pollock Hall, Room 4366). Four cameras and two microphones were used to record the experiments, and participants were made aware of that. The room set up is shown in Figure 3-1 below:

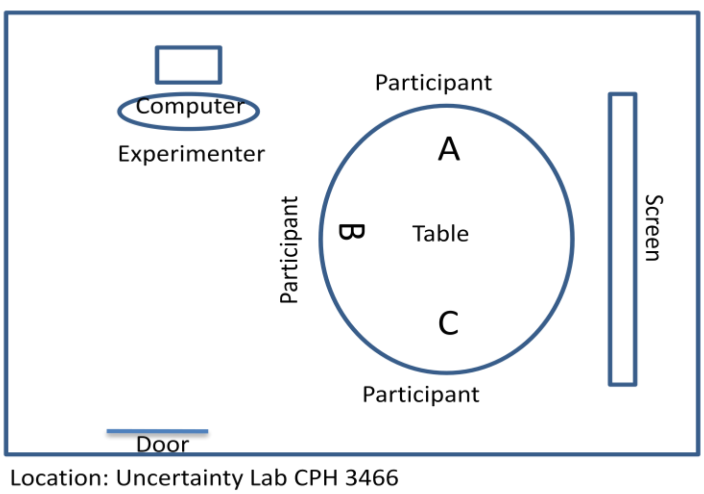

Figure 3-1 Graphical representation of the Face-to-Face condition

The group members sat in a semicircle around a round table designed with station A, B, and C; they were able to see the screen where the task was displayed. The task was displayed on a regular projection screen located on the left wall of the lab. The task was presented in 228 slides using Microsoft Office PowerPoint. The average duration time of the experiment was 35 minutes plus 15 minutes where the participants responded to a questionnaire.

For the CM condition, the experiment was set up in four different rooms located on the fourth floor of Carl Pollock Hall. The Figure 3-2 shows the physical distribution of the rooms. Each room was equipped with a 15-inch Apple MacBook Pro and a headset (technical specifications in the next section). The participants were randomly assigned to any of the three rooms and the experimenter remained in the Lab during the task. The task and instructions were displayed on the computer screen and all communication (verbal and visual) between the experimenter and group members as well as among group members was carried out through the VoIP (Voice over IP) feature of WebEx[9] meeting center. This web-based computer application service also allowed the recording of the verbal communication.

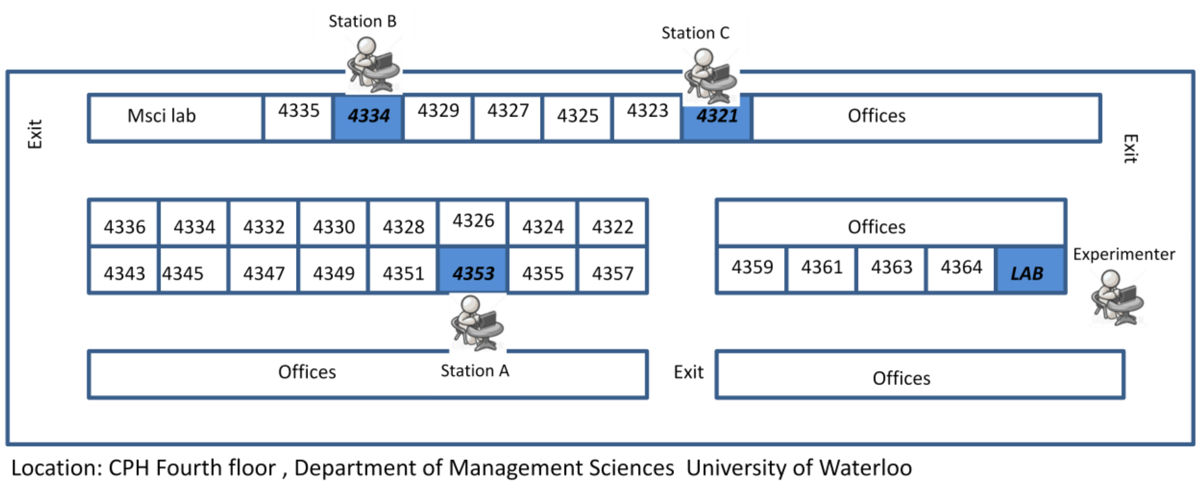

Figure 3-2 Graphical representation of the Computer-Mediated Condition

3.2.2 Communication Technology and Technical Specifications

For the Computer-Mediated-Communication condition, four identical MacBook Pro notebooks with headsets were used with the following specifications: 2.53GHz intel Core 2 Duo processor with 3 MB shared L2 cache, 2 GB of 1066 MHz DDR3 memory, hard drive of 250 GB serial ATA, built-in

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[9] "WebEx Communications Inc. is a Cisco company that provides on-demand collaboration, online meeting, web conferencing and video conferencing applications"(Iyar, S Chairman and CEO, WebEx) in internews.com Oct 7, 2005. http://www.internetnews.com/infra/article.php/3554751

airport extreme Wi-Fi wireless networking, built-in stereo speakers, built-in Isight camera, a display of 15.4 inches and operating system software of Mac OS X v10.5 Leopard. The MacBooks were connected to the University of Waterloo's wired internet connection in each room. As for communication technology, WebEX is a web-based service that supports real time desktop sharing with either phone or VoIP conferencing. Specifically, the application used was WebEx meeting center. This feature recreates face-to-face meetings with real-time data, application, voice and video sharing capabilities. For the FTF condition, the task was managed and shared by the experimenter to the participants using this computer application. The VoIP service offers synchronous communication, thus, all the participants communicated to each other simultaneously. Figure 3-3 illustrates the interface of the screen as seen by the participants while performing the task.

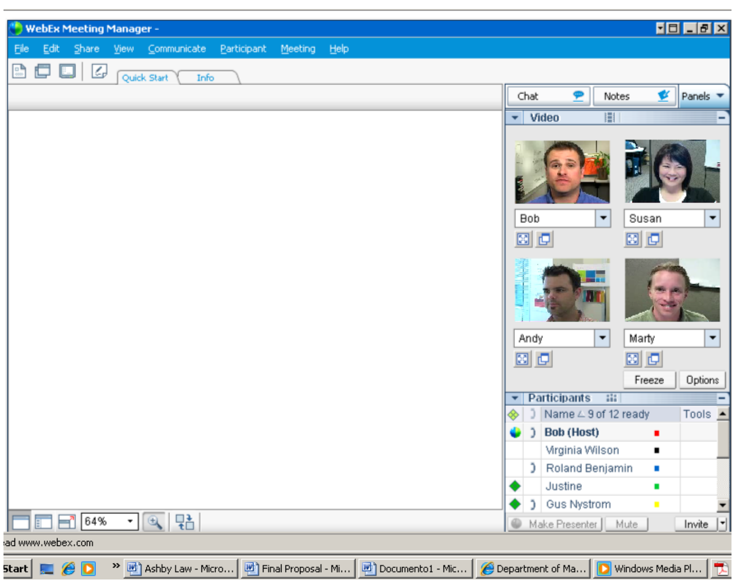

Figure 3-3 Graphical representation of the computer application interface

3.2.3 Group Size

Participants were randomly assigned in three-people groups for both conditions. Since there is limit in our capacity for information processing (Miller, 1956), the groups were supposed to distribute the workload among themselves so that performance would be increased. Therefore a group size of three would show a different and more diverse dynamic than that of dyad size. This result was confirmed by the pilot study, which also replicated the behavior of bigger group sizes (4, 5 or 6 people in a group) observed in the classroom tutorials. However, some groups decided to add the numbers individually at the beginning of the task; but later they realized that distributing the load was more efficient.

3.2.4 Participants

In this study, the participants totaled 123. 117 engineering undergraduate students, 70 enrolled in an organization theory course and 47 enrolled in an introductory economic course at the department of management sciences at UW. Participation was voluntary and students received course credit for their participation. Additionally there were 6 extra participants who were needed to fill absence participants, 3 undergraduate Management Engineering students, 2 graduate Management Sciences students and one faculty visitor.

There were four cases in which one participant registered did not show up. These students were then replaced by either the three random undergraduate students or by the pre-arranged participants.

3.3 Procedure

All participants were arranged to meet at the Uncertainty Lab at the Management Sciences Department at UW. The participants assigned to the FTF condition remained in the Lab for the entire task, whereas those assigned to the CMC condition were escorted to their assigned rooms. Prior to the task, participants were asked to introduce themselves to the rest of the group and share voluntary information about themselves (i.e., program, hobbies, nationality, etc). Those in the FTF condition did the introduction in the Lab while the CMC participants did so from their assigned rooms. Additionally, the CMC participants were briefly introduced to the computer application, WebEx, and explained what to do in case of a loss in sound or video signal. This introduction was carried out in the first station, CPH 4354, and lasted approximately 5 minutes. The participants were also made aware of the video-voice recording before the registration process and, once more, before the experiment.

Following the previous procedure, the task instructions were displayed on the screen preceding the task. The participants were asked once more if the instructions were well-understood and clarification was given if needed. After that, the first two minutes for discussion was given and the group first started to discuss the different strategies to add the numbers. Two slides alerted the group 15 seconds and two seconds before the run started; then, the first number of the run appeared on the screen. Every number was displayed solely on the screen with an approximate rate of every two seconds between each. Following the last number of the run, a slide was displayed with “Say your answer”; at this moment the group needed to come up with their total sum and report it the experimenter. There was no time limit to discuss and come up with the total sum. As soon as the group gave the answer to the experimenter, the experimenter provided the feedback with the correct answer. Therefore, the group knew immediately if they got it right or wrong as well as how off they were by the right answer. Following feedback, the second two minute-discussion time prior to the second run was given and the group decided to either adjust or maintain the previous strategy for the upcoming run. The same pattern continued for the rest of the runs (with 8 runs in total). At the end of the runs, the experimenter gave the total performance to the group saying how many they got it right as well as how off they were by the right answers. For the FTF condition, the previous procedure occurred in the same room with the experimenter running the slide show in the same room, while for the CMC condition, the experimenter was at the Lab running the slide show from her computer and sharing the task to the rest of the group. In this condition, all type of communications was done through the VoIP feature of WeBex. At the end, participants were asked to complete a questionnaire (Appendix E). In the questionnaire, the participants’ perception of their performance, satisfaction, cooperation, leadership, willingness to work with the same group, effort, stress, and for those in the CMC, satisfaction with the communication technology were of interest for this study.

Chapter 4
RESULTS

4.1 Experimental Data

The data were obtained and classified under three procedures: 1) data based on the results from the performance of the groups, 2) data based on the experimenter' observation of the recordings, and 3) data based on a post-task questionnaire.

First, the group performance results were classified in two different measurements: the performance based on right and wrong answers and the performance based on the deviation from the right answers (details in section 4.2.); these data are available in Appendix F. Also, since the task involved variation complexity along the experiment, the performance results portrays the analysis of performance excluding run #5 where the two-digit numbers appeared for the first time separately.

Second, the analysis was not only based on measuring the performance but also on investigating other factors involved in the groups' dynamics. The factors analyzed in this study were: discussion time and collaborative strategies (details in section 4.3 and 4.4).

Third, with the purpose of collecting the perception of the participants with respect to the task, the participants were asked to fill out a post-task questionnaire. Data obtained from the questionnaires allowed me to explore possible differences between the conditions regarding satisfaction, cooperation, willingness to work in the same group, effort and stress perceived by the participants. The questionnaire also asked the CMC participants about their experience with the communication technology (details in section 4.5)

4.2 Task Performance

4.2.1 Overall Performance

The following results are based on the analysis of the dependent variable "Overall Performance" in two experimental conditions: FTF condition with a sample size of n=19 groups and CMC condition with a sample size of n=20 groups. Due to some modifications of the task at the beginning of the experiments, two groups were discarded from the data in the FTF conditions and one group in the CMC conditions; two more groups from the CMC conditions were also discarded due to some technical issues.

The Overall Performance was measured in two different ways: 1) as the ratio of the number of right runs to the total number of runs and 2) as the absolute deviation from the right answer. The former is labeled as Right-Wrong Performance (RW) and is represented as one of the following data: 0 (0/8), 0.125 (1/8), 0.25 (2/8), 0.375 (3/8), 0.5 (4/8), 0.75 (6/8), 0.875 (7/8) or 1 (8/8). In this order, the closer the score was to 1 the better the performance was (data available in Appendix F: Table F.1.1, F.1.2, F.2.1, and F.2.2. The second was labeled as Deviation Performance (DP) and defined as how much, in absolute terms, the group was off by the right answer; as for example, if the right answer was 108 and the group reported 100, the deviation was 8, the same when the group had a right answer, the score reported was 0. Thus, the total performance for each group was the average of the eight runs' deviations. For this case, the closer the score was to 0 (or the smaller the number was), the better the performance was (Appendix F: Table F.3.1, F.3.2, F.4.1, and F.4.2)

Because the purpose of the study was to explore the effects of task variation and communication medium, the first analysis to check any difference in the overall performance of the groups across all the trials. For this purpose, t-tests and non-parametric test results were considered. Normality tests such as one-sample Kolmogorov-Smirnov: Goodness –of-Fit Test and Q-Q plots confirmed the normality of the performance data (Appendix G). However, to avoid possible data violation and confirm the t-tests results, non-parametric tests were also carried out for this comparative analysis[10].

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[10] The statistical analysis was done using the SPSS 16.0 package

Table 4-1 provides mean scores, standard deviations and cells for the overall groups' performance with and without run #5. T-tests results showed no statistical difference in performance for the two types of measurements (RW and DP) between FTF and CMC groups (RW $t(37)=0.226$ $p=0.823$ and DP $t(37)=1.287$ $p=0.206$, see Appendix H: Table H.1 and H.2). In addition, non-parametric test results corroborated the previous results (RW, $Z=-0.114$ $p=0.909$ and DP, $Z=-1.138$ $p=0.255$, see Table 4-2. The same analysis was carried out for the groups' performance excluding run #5 in which T-tests and non-parametric tests results showed no statistical difference either in performance for the two type of measurements between the conditions (RW $t(37)=0.124$ $p=0.902$ and DP $t(37)=0.588$ $p=0.560$ and RW, $Z=-0.171$ $p=0.864$ and DP, $Z=-0.520$ $p=0.603$)

Table 4-1 Mean scores, standard deviations for overall group performance

	Across all runs (1 to 8)			
Variable team performance	R-W Performance		Deviation Performance	
	FTF	CMC	FTF	CMC
M SD No. groups/cell	0.3487 0.262 19	0.3312 0.2194 20	7.585 4.319 19	5.975 3.471 20
	Excluding run # 5 (1,2,3,4,6,7,8)			
M SD No. groups/cell	0.3758 0.2739 19	0.3655 0.2432 20	6.3979 3.906 19	5.6710 3.8127 20

Table 4-2 Non-parametric test result for overall performance between FTF and CM groups

	Across all runs (1 to 8)		Excluding run # 5 (1,2,3,4,6,7,8)	
Non-parametric Test	R-W performance	Deviation Performance	R-W performance	Deviation Performance
Mann-Whitney U Wilcoxon W Z Asymp. Sig (2-tailed)	186 396 -0.114 0.909	149.5 359.5 -1.138 0.255	184 394 -0.171 0.864	171.5 381.5 -0.520 0.603

4.2.2 Task variation: low and high complexity performance

The structure and dynamic of the number game task allowed analyzing group performances under two task conditions: low and high complexity. Although the rate in which the numbers were displayed on the screen was kept almost constant, the characteristics of the numbers in each run introduced different dynamics in the task. Consequently, it was of interest to analyze the groups' behavior in response to the task variations. The first analysis defined Low task complexity condition (LC) as the score of the first four runs (1, 2, 3, and 4), in which only one-digit numbers were displayed, and high task complexity condition (HC) as the score of the second four runs (5, 6, 7, and 8), in which two-digit numbers and a white screen in run #8 were introduced. The second analysis excluded run#5 because it was here where the complexity changed significantly due to the first introduction of two-digit numbers; therefore, it was of interest to check further differences, if any, between the two set of performance results. Table 4-3 provides mean scores and standard deviations for the FTF and CMC groups in the task complexity conditions. The results of the MANOVA across all rungs showed no main effect of communication medium for the two types of performance measurements, for the RW performance $F(1,37) <1$, $p=0.823$ and for the DP $F(1,37)=1.65$ $p=0.206$; results that were also supported by the previous t-tests and non-parametric results. On the other hand, a main effect of task complexity variation was found, for the RW performance $F(1,37)=8.6$, $p=$**0.006** and for DP $F(1,37)=14.4$, $p=$**0.001**. As well, an interaction effect between communication medium and task complexity variation for the DP measurement $F(1,37)=5.99$, $p=$**0.019** was found(detailed results Appendix H: Table H.3)

Table 4-3 Task variation: means and standard deviation

Across all runs (1 to 8)				
Right – Wrong Performance	Task variation (Within Subjects Factor)			
Communication medium (Between Subjects Factor)	Low Task Complexity		High Task Complexity	
	M	SD	M	SD
FTF CMC	0.41 0.43	0.33 0.27	0.29 0.24	0.30 0.26
Deviation Performance				
FTF CMC	5.21 5.46	4.93 3.67	9.96 6.48	5.48 4.06
Excluding run # 5 (1,2,3,4,6,7,8)				
Right – Wrong Performance				
FTF	0.41	0.33	0.33	0.35

CMC	0.43	0.27	0.28	0.33
Deviation Performance				
FTF	5.21	4.93	7.99	5.39
CMC	5.46	3.67	5.95	5.18

Thus, the differences found in the overall groups' performance did not seem to depend on the type of communication media (FTF or CMC). However, the variation of the task from low complexity to high complexity played a significant role in the performance and in the communication medium across all runs. The results of the MANOVA excluding run #5 also showed no main effect of communication medium for the two types of performance measurements, for the RW performance $F(1,37) < 1$, $p=0.844$ and for the DP $F(1,37)=0.502$ $p=0.483$. However, these results did not show neither a task complexity effect or interaction effect between communication medium and task complexity variation as the previous MANOVA analysis did (across the all runs). The task complexity variation effect for the two types of performance measurements were, RW performance $F(1,37)=3.33$, $p=0.076$ and for DP $F(1,37)= 3.26$, $p=0.079$**.** the interaction effect result for the DP measurement was $F(1,37)=1.6$, p**=0.214** (detailed results Appendix H: Table H.3).

The analysis of interaction across all runs reveals that the task variation had an inverse and significant effect on the performance as well as on the experimental conditions for the DP measurement[11] (see Figure 4-2). As for the RW measurement, although the Figure 4-1 indicates a significant interaction effect because the lines are crossing, the interaction effect between communication medium and task complexity variation was not found $F(1,37) < 1$, $p=0.511$. For the RW and DP measurements, the groups, in general, showed significantly lower performance in high task complexity conditions. However, in the high task complexity a performance difference between FTF and CMC groups was found. For the DP, the CMC groups (M=6.48 SD=4.06) performed significantly better than FTF (M=9.96 SD=6.48); $t(37)=2.25$ $p=0.030$, see Figure 4-2 (detailed results in Appendix H: Table H.4). These results are also supported by the non-parametric test (Z=-2.025, $p=0.044$). For the RW performance, FTF groups performed slightly better than CMC groups in the high task complexity condition, but the difference was not significant $t(37)=0.573$, $p=0.570$ or in non-parametric results,

11 There was not any counterbalancing on order of the presentation of low and high complexity task.

Z=-0.488, *p*=0.625, see Table 4-4. In summary, FTF groups had a few more accurate runs than CMC groups, but the CMC groups were closer to the right answers most of the time (or less off by the right answers) than FTF groups. However, the results of the analysis excluding run #5 reveals that the task variation had an inverse but marginal effect on the performance for the DP measurement (see Figure 4-3 and Figure 4-4).

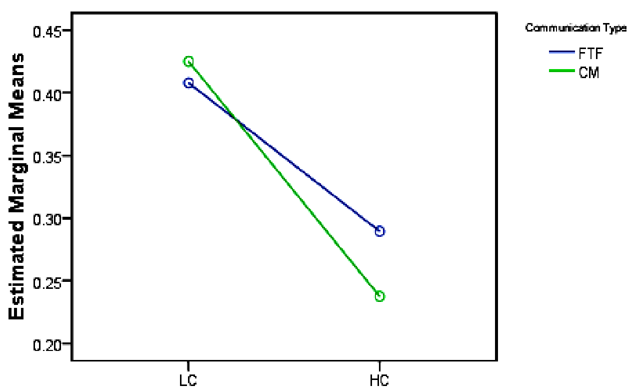

Figure 4-1 Estimated marginal means of group performance for RW across all runs

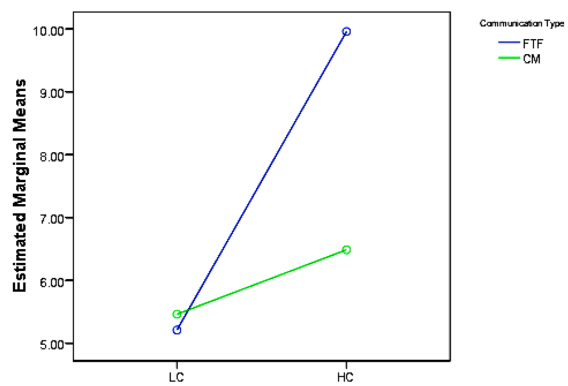

Figure 4-2 Estimated marginal means of group performance for DP across all runs

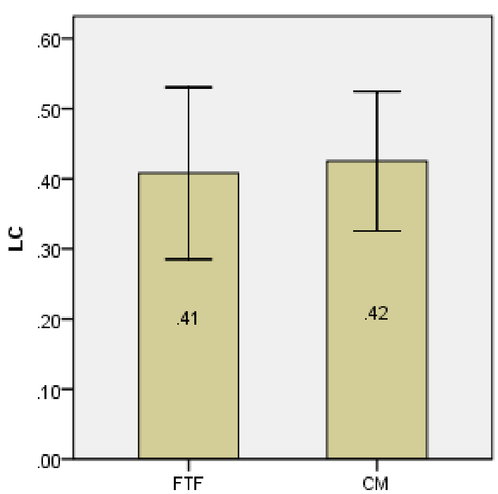

Figure 4-4 Error bar of means (95% CI of Mean) for LC in RW across all runs

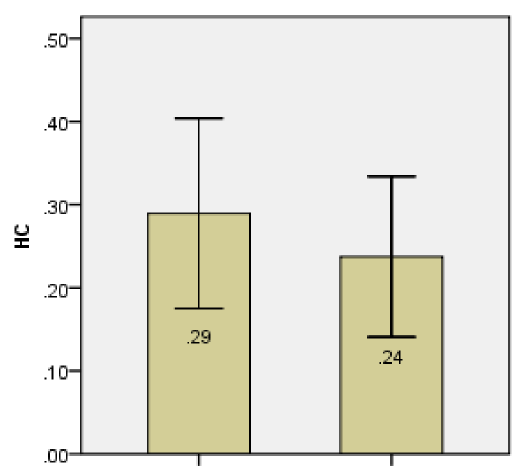

Figure 4-3 Error bar of means (95% CI of Mean) for HC in RW across all runs

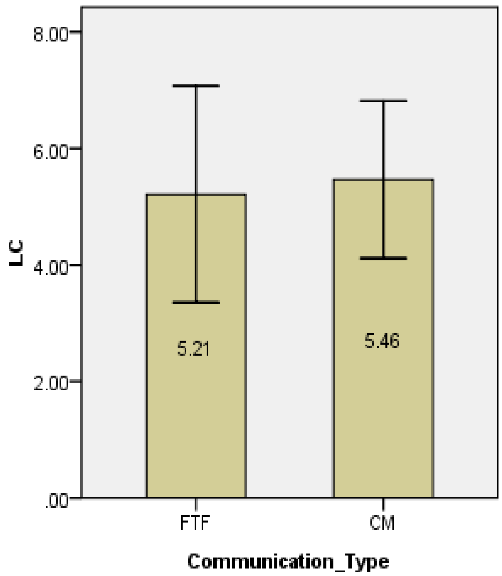

Figure 4-6 Error bar of means (95% CI of Mean) for LC in DP across all runs

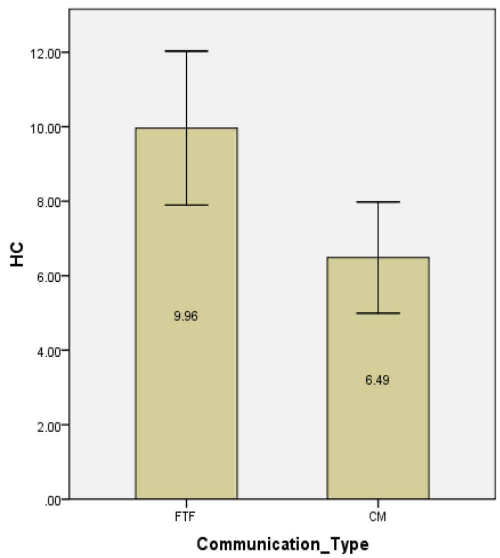

Figure 4-5 Error bar of means (95% CI of Mean) for HC in DP across all runs

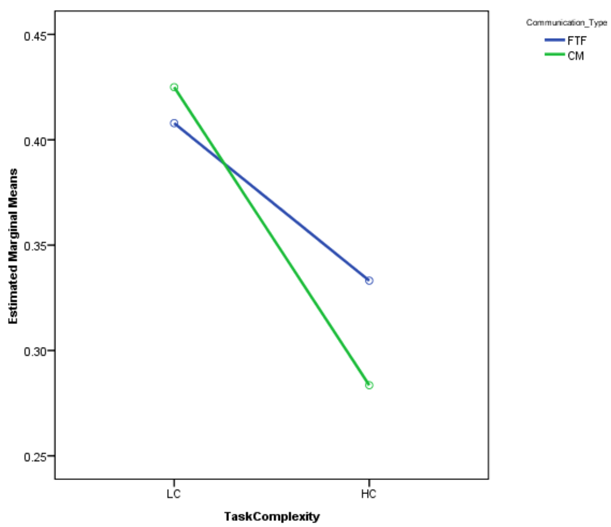

Figure 4-7 Estimated marginal means of group performance for RW without run #5

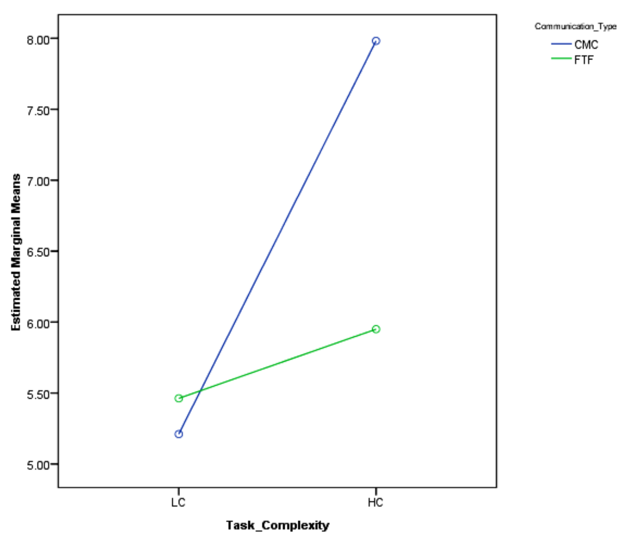

Figure 4-8 Estimated marginal means of group performance for DP without run #5

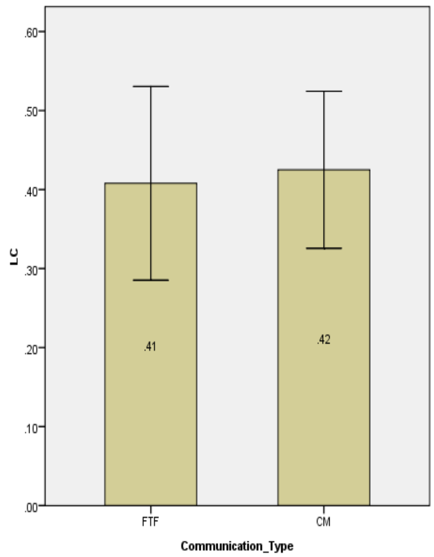

Figure 4-9 Error bar of means (95% CI of Mean) for LC in RW excluding run #5

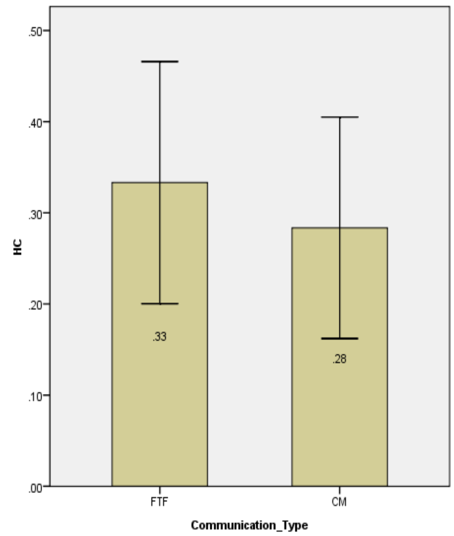

Figure 4-10 Error bar of means (95% CI of Mean) for HC in RW excluding run #5

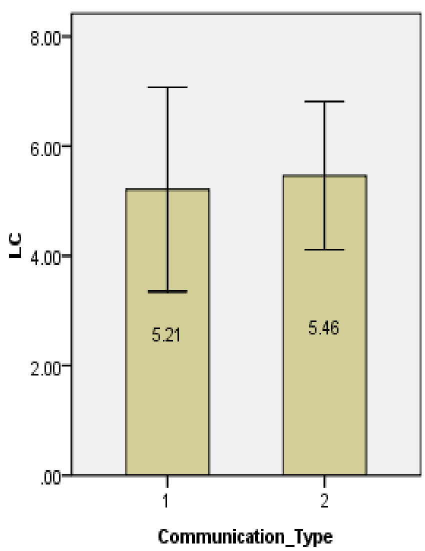

Figure 4-12 Error bar of means (95% CI of Mean) for LC in DP excluding run #5

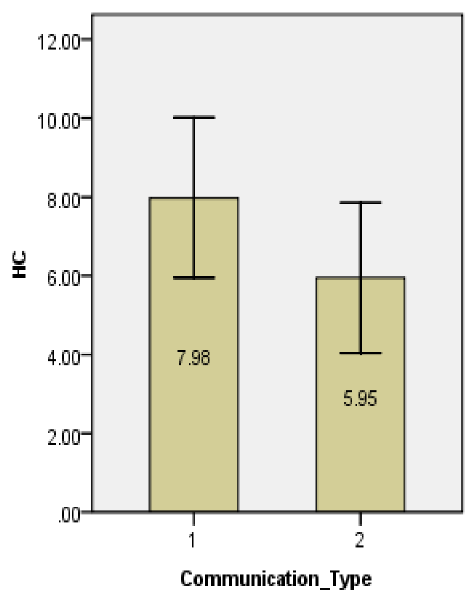

Figure 4-11 Error bar of means (95% CI of Mean) for HC in DP excluding run #5

Table 4-4 Non-parametric results of task complexity between FTF and CM groups

Non-parametric Test	R-W performance		Deviation Performance	
	LC	HC	LC	HC
Mann-Whitney U	178.5	173.5	169.5	118
Wilcoxon W	368.5	383.5	359.5	328
Z	-.333	-.488	-.577	-2.025
Asymp. Sig (2-tailed)	.739	.625	.564	.044

As for the comparison within groups, the results show that in general the groups performed better in the low task complexity than in the high task complexity condition. However, the significant differences were found for CMC groups in the RW performance measurement ($t(19)=2.77$ $p=0.012$), and for the FTF groups for the DP measurement ($t(18)=-3.54$ $p=0.002$) (detailed results in Appendix H: Table H.5). These results were equally supported by the non-parametric test (Wilcoxon Signed test) within groups, for the RW performance measurement, the CMC groups ($Z=-2.456$ $p=0.014$), and for the DP measurement, the FTF groups ($Z=-2.717$ $p=0.007$), see Table 4-5. This result also show that CMC groups had less correct runs in the high task complexity situation than FTF groups, but CMC did not significantly deviate from the right answers as often FTF groups did.

Table 4-5 Non-parametric result of task complexity variation within FTF and CM groups

	Across all runs (1 to 8)			
	Right – Wrong Performance		Deviation Performance	
HC – LC	FTF	CMC	FTF	CMC
Z Asymp Sig (2-tailed)	-1.393[a] 0.164	-2.456[a] 0.014	-2.717[a] 0.007	-0.980[a] 0.327
	Excluding run # 5 (1,2,3,4,6,7,8)			
Z Asymp Sig (2-tailed)	-0.626 0.531[a]	-1.770 0.077[a]	-1.791 0.073[a]	0.093 0.926[a]

Based on positive ranks

On the other hand, no significant differences were found in the pair-comparison results when excluding run #5. Only marginal differences were found in the case of CMC groups in the RW ($t(19)=1.82$ $p=0.083$), and for the FTF groups for the DP measurement ($t(18)=-1.798$ $p=0.089$) (detailed results in Appendix H: Table H.5). These results were equally supported by the non-parametric test (Wilcoxon Signed test) within groups, for the RW performance measurement, the CMC groups (Z=-1.770 p=0.077), and for the DP measurement, the FTF groups (Z=-1.791 p=0.073).

In addition, the graphical representation Figure 4-13 and Figure 4-14 supports the previous statistical results, and shows the differences in performance between FTF and CM groups (average of all groups in each run) during the 8 runs of the experiment. Figure 4-13 displays the performance based on the Right-Wrong performance, and Figure 4-14 displays the absolute deviation performance that supports the statistical difference found between FTF and CM groups in the high task complexity; the difference mainly due to the run #5 where two-digit numbers were introduced. On this run, FTF groups deviated significantly more from the right answer than CMC groups did, difference that was supported statistically by the previous results.

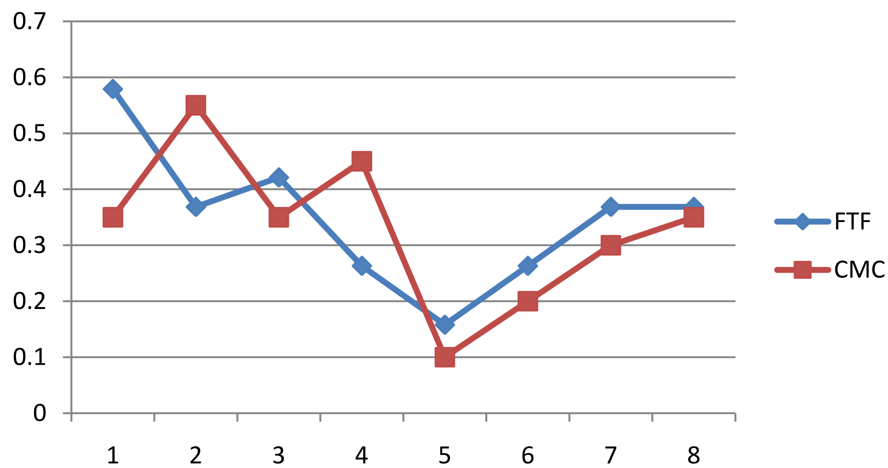

Figure 4-13 Comparison of the RW performance between FTF and CM groups (0 to 1) for all runs

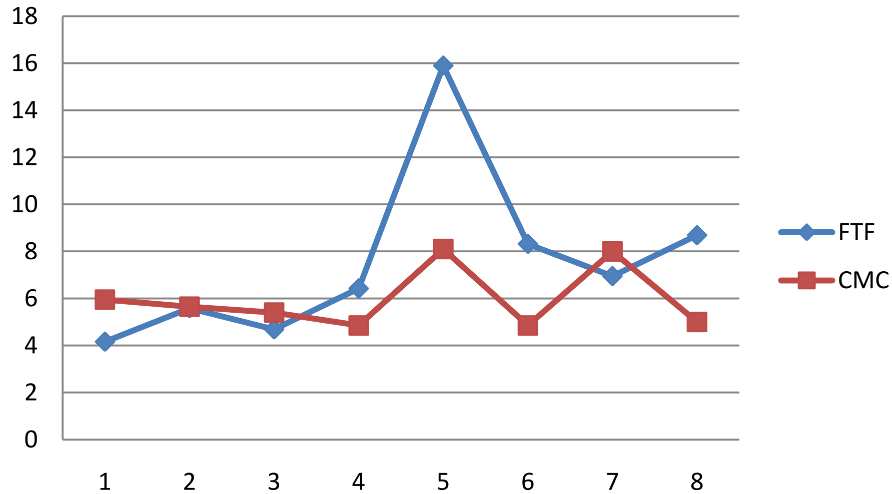

Figure 4-14 Comparison of the DP between FTF and CM groups (the closest to 0 the better) for all runs

In addition, the Figure 4-15 and Figure 4-16 display the graphical representation of the performance of the groups for each run excluding run #5 (where the main difference was found mostly for the DP measurement). A learning effect is observed in the performance of the high task complexity for the RW measurement. For the DP measurement, although the run #5 was removed (the biggest difference between FTF and CMC groups) there are still two marginal differences between the conditions in the high task complexity (run #6 and run #8), where CMC groups perform marginally better than FTF groups. From Figure 4-16 it is observed that the FTF groups were more deviated from the correct answers along the experiment than the CMC groups which had a more constant deviation performance along the task.

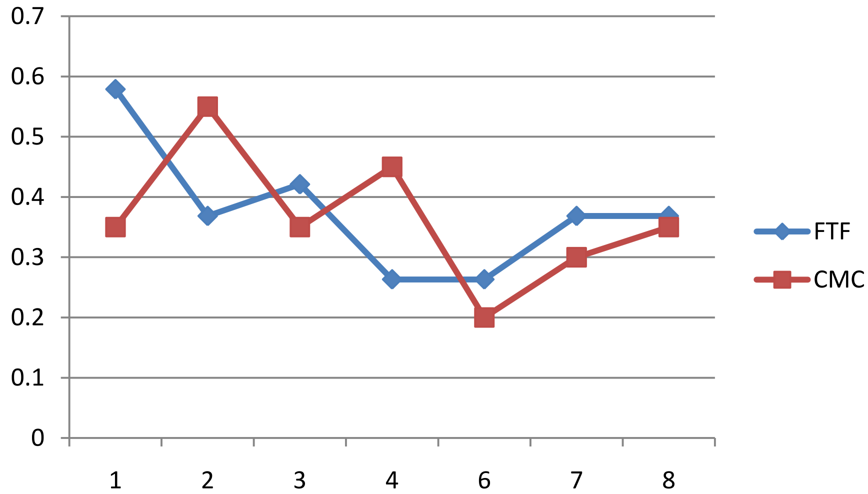

Figure 4-15 Comparison of the RW performance between FTF and CM groups (0 to 1) without run #5

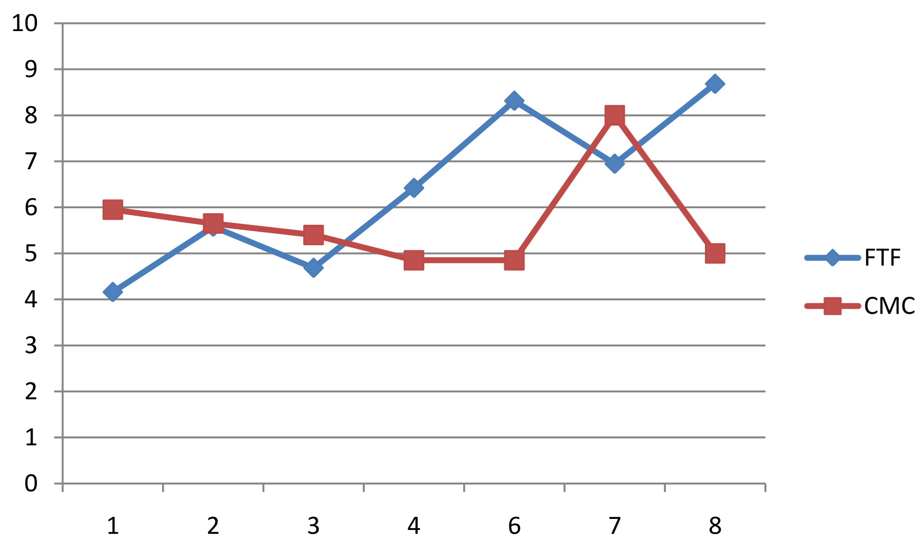

Figure 4-16 Comparison of the DP between FTF and CM groups (the closest to 0 the better) without run #5

4.3 Discussion time

From the literature, it was difficult to predict what condition will show greater discussion time. For one side, there are the followers of Information richness theory who predict that physical proximity or "social presence", the case of the FTF groups, would stimulate the discussion among the group members. However, the followers of the Social Identity model of Deindividuation, arguing that the social cues are not the only important factor in the interaction, may predict that the discussion time in the CMC may be greater than in the FTF condition, because since the group members have less social constraints (no physical contact, not being observed, etc) they are more willing to participate in discussions. For this study the discussion time was defined as the total time the groups talked during each of the two-minute discussion time before each run. However, the results of this experiment regarding with discussion time show no difference between the two conditions.

For this case, the maximum discussion time would be 16 minutes if the group covered all the discussion times for the eight runs. The discussion time measured the time group members talked regardless whether or not it was task discussion oriented. For this analysis, the sample size of the CMC conditions was reduced to 13 groups because 7 group-recordings were deleted from WeBex when the subscription was canceled. Therefore, the discussion time data were 19 FTF groups and 13 CM groups.

Table 4-6 provides mean scores, standard deviation for the groups' discussion time for the two measurements: the average time (Total time/No. of groups), the total time (total sum of the times) and the total time for conditions in LC and HC of the task. T-test results showed no significant difference in the previous measurements, see Table 4-7 (detailed table in Appendix H: Table H.6).

Table 4-6 Mean scores, standard deviations for discussion time

Discussion Time	Average Time AV		Total Time TT		Low Complexity TT		High Complexity TT	
	FTF	CMC	FTF	CMC	FTF	CM	FTF	CM
M	1.0735	1.0649	8.4826	8.3654	4.43	4.60	4.1579	3.9108
SD	0.34257	0.32734	2.722	2.5544	1.481	1.367	1.615	1.687
No. groups	19	13	19	13	19	13	19	13

Table 4-7 T-test result of comparison of decision time between FTF and CMC groups

Description (Equal variances)	t	Sig. (2-tailed)
Average time	0.071	0.944
Total time	0.123	0.903
Low task complexity	-0.350	0.729
High task complexity	0.417	0.679

4.4 Coordination Mechanisms

4.4.1 Descriptive and quantitative analysis of the collaborative strategies

One of the most important characteristics of this task was the level of coordination required by the group members to perform the task. The task required the group members to create strategies to sum up the numbers more efficiently. During the above-mentioned discussion time, the group members shared their knowledge and formed strategies in order to achieve the desired outcomes. Some groups started to add the numbers individually but later realized the need of a collaborative strategy to perform better. The participants realized that the group's success would depend greatly on the degree of cooperation and coordination between the group members. For data analysis' purpose, the strategies were classified as follows:

- *3rd number*: Since the group size was three participants assigned with location *A, B, C* for both conditions, this strategy was the most common. Each member was assigned a number to add every third number. For example if the run had 20 numbers the assignation was: *A* added the 1st , 4th , 7th , 10th , 13th , 16th , 19th , *B* added 2nd , 5th , 8th , 11th , 14th , 17th and 20th, and *C* added the rest. At the end each member gave the respective sums and, then, the subtotals were added to give the final total. Some groups kept the same strategy but rotated the starting point, and this was considered as a change in strategy (strategy changes will be discussed in section 4.4.2).
- *Bunch 2/3/5/8/10*: This strategy followed the same pattern as the 3rd number but instead of adding every 3rd number, each member added the numbers in bunch of two, three, five, eight, or 10 consecutive numbers first and the rotation followed the same pattern as the *3rd number* strategy; for example if a group decided to add a bunch of 5 consecutive numbers, the pattern was: *A* added 1st , 2nd , 3rd , 4th , 5th , *B* added 6th , 7th , 8th , 9th , 10th and *C* added 11th , 12th , 13th , 14th , 15th and so on.

• *2 to 1:* For this strategy, two members distributed the adding between them following a strategy (e.g., every 2nd number, single/double digits, even/odds, etc) and the third member (most of the time, the most skillful in adding) added all numbers as a checkup option.

• *Single/double*: Under this strategy are those groups that distributed their adding between single digits and double digits, such for example: if the group followed strategy 2 to 1, two members distributed the adding, one adding all the single digits and other adding double digits.

• *Odds/evens*: Similar to the previous strategy but in this case instead of single/double, the group distributed the adding between one adding all even and other adding all odds.

• *Innovative*: There was the case of some other uncommon strategies that were described as innovative. An example of one innovative strategy was: The members distributed the adding by having a member in station *A* adding numbers ending in 0,1,4,9, a member in station *B* adding numbers ending in 2, 5, 8 and a member in station *C* adding numbers ending in 3, 6, 7. The group's argument for this classification was that "there was a chance that the counting will be simplified due to 1 plus 9 is 10 (station *A*), 8 plus 2 is 10 (station *B*) and 3 plus 7 is 10 (station *C*)."

The frequency of occurrence of each strategy was counted and compared in each condition. The Figure 4-17 Type of strategy and frequency comparison between FTF and CMC condition displays the frequency and compares the two conditions.

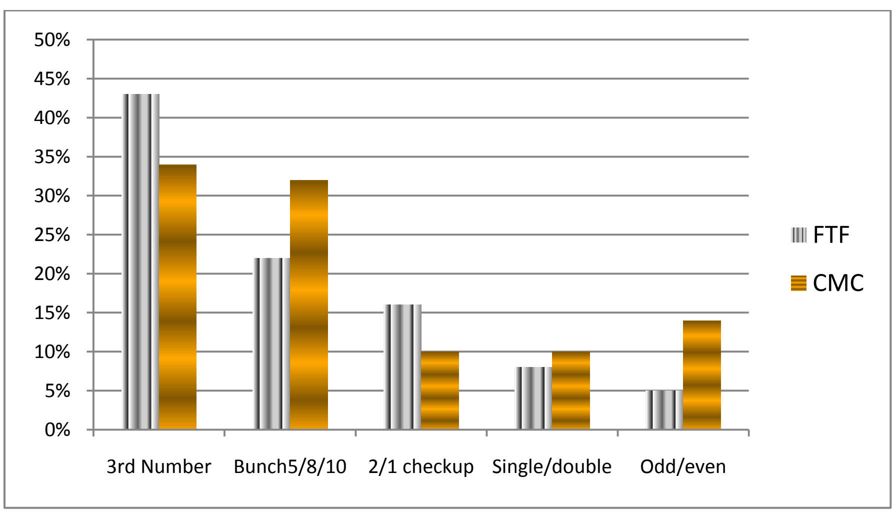

Figure 4-17 Type of strategy and frequency comparison between FTF and CMC condition

The Figure 4-17 shows that FTF groups used the 3rd number and 2/1 strategies more often than CMC groups. However, the CMC groups used more strategies than FTF groups. Although, the 3rd number strategy was the most common strategy for the two conditions, CMC groups used this strategy in combination with more specific strategies (e.g., single/double or odd/even).

For the innovative strategies, six out of 20 were presented in the CMC condition while two out of 19 in the FTF condition. A detailed description of the innovative strategies can be seen in appendix H. Another observation was turn taking. The groups used different types of signaling to pass or receiving the turn of adding to or from the next person. This signaling was classified as follows:

- *Voice*: This signaling includes any voice utterances that the group members used to pass the turn. As for example, some groups said the last number they added aloud as a signal, other said the word "next". This was the most common signaling happened in both conditions.
- *Raise hand*: For some groups, saying the number or the word next was distracted, instead they raised their hands, not as sign of passing the turn but as receiving the turn of adding. This signaling only happened in the FTF condition
- *Tapping*: These groups tap on the table with their hands as a sign of passing the turn. This signaling only happened in the FTF condition.
- *Flash hand on the screen:* There was one group in the CM condition that flashed their hands on the web cam as a sign of passing the turn.

The following tables show the frequency of the different signals that the groups used as turn taking or passing during the experiment:

Table 4-8 Signal types in the FTF condition

Signal type	No. of groups
Say loud (i.e. number or next)	8
Raise Hand	2
Tap or make sound on the table	7

Table 4-9 Signal types in the CMC condition

Signal type	No. of groups
Say loud (i.e. number or next)	10
Raise Hand	0
Tap or make sound on the table	0
Flash hand on the screen	1

In addition to classifying the strategies, the number of strategy changes per group during the task was also measured as an indicator of group adjustment to performance. For example, one group changed strategies six times during the task, while another kept the same strategy for the entire task. Strategy change was defined as complete change of strategy, for example, from adding the numbers individually to switching to a 3rd number strategy, or defined as a small change when, for example, it was a rotation turning change or a turn signal change. The mean of strategy changes for the FTF groups (M=2.26 SD=2.07) was very similar to the mean of strategy changes for the CMC groups (M=2.5385 SD=1.45), this was supported by a t-test that showed no significant difference between the two conditions with a p-value=0.662.

4.4.2 Correlation analysis: Strategy changes performance

Since the strategy changes was used as an indicator of group adjustment to performance, a correlation analysis indicated the type of relation between the performance and the strategy changes for the two studied conditions (FTF and CMC). The Table 4-10 shows two main significant correlations both happened in the FTF condition. The negative correlations explain that the more number of strategy changes were used, the worst the performance was observed. The correlation shows a negative sign for the RW measurement because this indicator is measured as a ratio that falls between zero to one, hence, the closer the performance was to one the better the performance was. Yet, for the DP measurement in which the correlations have positive sign, results that also show the same pattern as before; the more strategy changes the group had, the less effective the group performance was. However, the results showed that this relationship was stronger in the FTF condition than in the CMC condition.

Another observation was for the low task complexity condition in which the strongest correlations happened. This result may be attributed to the group adjustment to the task.

Table 4-10 Correlation for strategy changes and overall performance in FTF and CM groups

	FTF/RWP	FTF/DP	CMC/RWP	CMC/DP
Pearson Correlation *r*	-0.637	0.630	-0.431	0.169
Sig. (1-tailed)	0.002	0.002	0.071	0.291
No. of groups	19	19	13	13

Table 4-11 Correlation for strategy changes in task variation in FTF and CM groups

	R-W FTF		R-W CM		DP FTF		DP CM	
	LC	HC	LC	HC	LC	HC	LC	HC
Pearson Correlation r	-.542	-.472	-.641	-.041	.460	.360	.051	.000
Sig. (2-tailed)	.017	.042	.018	.893	.047	.130	.868	.998
No. of groups	19	19	13	13	19	19	13	13

4.5 Questionnaire response

Appendix H: H.7 summarizes the mean responses of the 5-point Likert-type questions in the questionnaire (Q1: *Were you satisfied with the overall performance of your group*? Q6: *I feel that all the strategies and conclusions were mainly made by cooperation,* Q7*: I feel I put effort in performing the experiment*, Q8: *I feel my performance got better as the experiment went along,* Q9*: I feel the group performance got better as the experiment went along* and Q10: *I felt stress performing this task*). Non-parametric test (Mann-Whitney test) analysis of the questionnaire responses between the two conditions revealed no significant difference between the perception of FTF and CMC participants. (see Appendix H: H8).

For the questions Q4 ("*If you were to perform the same task or different task, would you prefer to be in a different or similar group experiment*?") and Q5 ("*Was there one person who you would call "leader" in your group?*"), a chi-square test of independence was carried out and showed no relation between the preference of working in the same group (X^2(1,117)= 0.137, p=0.711) and presence of leader (X^2(1,117)= 0.362, p=0.547) with the communication medium (see Appendix H: Table H.10 and H.12). Moreover, in the two conditions, FTF and CMC groups, the majority of groups preferred working in the same group again. But, with respect to the presence of a leader in the group, the results were somewhat tight between and within the conditions; in the FTF groups, 52.2% felt the presence of a leader in the group whereas 47.8% did in the CMC groups,. (See Appendix H: Table H.11).

Only CMC participants answered Q11, Q12, Q13, Q15 and Q16 questions since these questions were related to the communication technology. The results in Table 4-12 show that even though more than 90% of the participants in the CMC condition were unfamiliar with WeBex, the participants felt comfortable with the computer application. In addition, 60 % of the participants thought that seeing their group members on the screen helped them perform better and, thus, the majority of the participants did not think that the performance would have been better in FTF condition.

Table 4-12 Results of the participants' perception about WeBex, CM groups only

Question Description	Yes	No	Other
11. Were you familiar with WeBeX interface?	1.7%	93.3%	
12. Would you use WEBEX again for a similar experiment?	89.3%	7.1%	
13. Seeing your group members on the screen helped you perform better	60%	38.3%	
15. Video screen size in the interface were: Right (yes) Small (no)	33.3%	66.7%	
16. Your group would have performed better in a FTF environment	30%	66.7%	3.3%

Chapter 5
DISCUSSION AND CONCLUSIONS

5.1 Discussion and Suggestion

This chapter presents the observations from the aforementioned results. The observations are based on the task performance effectiveness. This indicator is not taken as a single variable; instead, it is determined by terms of two performance measurements (Right-Wrong Performance and Deviation Performance), discussion time, and collaborative strategies.

The main goal of the study was to find any differences in the performance between and within the two communication types of communication media (FTF and CMC), dealing with task variation. The empirical evidence from this study revealed how the performance of the groups was not affected by the communication medium but rather by the variation of the task (low and high complexity). However, the empirical evidence also showed that the performance of the groups was not affected either by the communication medium or by the variation of the task when removing run #5 from the analysis. The results showed no significant effect on the overall performance between FTF and CMC groups based on the two types of measurements (RW and DP). This finding cannot be easily compared with the existing CMC literature. First, the literature shows inconsistent results, so it was difficult to make predictions about this study; second, the characteristics of the task used in this study differed substantially from those used in the literature. Media and task categorization are the common approach in the literature, but this study did not follow this trend because of the limitations of categorization discussed earlier in this study (see section 2.2). However, it is worth exploring how the results of this study would have been discussed if they had been complied with the literature. The next example shows how the results would be interpreted if that would have been the case:

Assume that the number game was categorized, based on theory of information richness (Daft and Lengel, 1996), as either an uncertain or equivocal task. For one side, the theory would classify the task as an uncertain one because the task goal was to find right answers to specific problems (i.e., to find the right sum for the runs). Thus, the prediction I, in presence of an uncertain task, would be that CMC groups outperform FTF groups. This argument is based on the assumption that redundant paraverbal and nonverbal cues found in a rich medium (FTF), may hamper group performance because of the possible "distraction" in communication; cues that may not be essential for the performance of the task (Rico and Cohen, 2005; Chidambaram and Jones, 1993; McGrath and Hollingshead, 1993; Gallupe et al, 1992). Although, the characteristics of the number game task deviate from the tasks used in the computer mediated literature (i.e., brainstorming, choosing the best alternative without task variation); the prediction I supports some of the study results, because for the DP score, CMC groups outperformed FTF groups in the high task complexity. This finding would perhaps be attributed to less distraction in the CMC groups. The following situation supports the previous assumption of less distraction.

Five groups in the CMC condition opted for muting the microphones in order to avoid possible distractions. In the questionnaires, some participants blamed their low performance on the counting distraction originated by other group members, as illustrated by the following comments:

"..Do it in your head, don't count them aloud.." (FTF)
"..If we give the signal, it may be distracting.." (FTF)
"..I'll mute the mic because I tend to whisper to myself when I calculate.." (CMC)
"..I think it's better to be alone since there's less distraction when you're concentrating on adding numbers..." (CMC)

The CMC groups indeed performed significantly better under high task complexity condition (run #5, 6, 7 and 8) based on the DP score. This statistical difference can also be explained by Figure 4-14, which shows the main gap in performance between the two conditions in run # 5 when the two-digit numbers were introduced. From this result, it can be inferred that, although all groups were aware of the appearance of two-digit numbers from the instructions at the beginning of the task, CMC groups responded more efficiently to this type of task variation and were less deviated from the right answers than the FTF groups. In other words, CMC groups were less "surprised" in run # 5 than FTF groups were. However, the results of the study also show that in low task complexity conditions for the RW and DP performance scores, no difference in performance was found between FTF and CMC groups. However, this outcome may contradict prediction I, if the number game were classified only as an uncertain task, CMC groups would outperform FTF groups during the whole completion of task, and not only in the high task complexity condition.

On the other hand, the theory would also classify the number game task as an equivocal task since the groups were exposed to variability and surprising situations (i.e., two-digit numbers, and a blank screen in run # 8) when performing the task. Thus, this complexity would cause some confusion and conflict within the group. In some cases, conflict originated when a group member wanted to change the strategy constantly to deal with the variation of the task, but others wanted to keep it constant. Although, the ultimate goal of the number game was to find the accurate sum for the runs, the task also involved a number of activities necessary to accomplish the task efficiently, for example: decision making, negotiation, strategy formulation, individual memory, and individual strategy adding, to list a few. These dynamic and interchangeable activities would then make the task be classified as equivocal. Thus, the prediction II would be that FTF is a suitable medium to reduce equivocality in the task (McGrath and Hollingshead, 1993; Arunchalam, 1991) and that FTF groups would perform better than CMC groups. The results of this study did not follow prediction II. FTF groups did not perform better than CMC groups.

The previous example illustrates how empirical evidence can be interpreted differently based on categorization. This kind of interpretation may be one of the reasons for the inconsistency of the results in the literature and, thus, the cause of lack of good generalizations so that predictions can be made regardless of the type of task. It is ambiguous to determine whether a task, or in this case the number game task, could be classified as an uncertain or equivocal, intellective or judgmental task (McGrath's categorization). This type of categorization does not explain the degree to which a task can be placed in a specific category. In the former example, it was not clear how to determine or to measure the amount of either uncertainty or equivocality within the task so that predictions for the study could have been made.

Furthermore, the results of this study also show that there was no difference in the discussion time between the two conditions and that CMC groups developed slightly more types of strategies than FTF groups. These results may also contradict earlier research based on the theory of social presence (Trevino et al, 1987; Daft and Lengel, 1986; Short et al, 1976). Since this theory considers FTF as the “richest” medium because it enables the transmission of additional redundant cues to reduce the possible equivocality of the information, then it may have been assumed that FTF groups would come up with more variety and respond more efficiently than CMC groups. The results of the study showed the contrary.

Another possible reason for these conflicting and overlapping results can be attributed to the unequal comparisons presented in most of the CMC literature. Some studies compared FTF groups (synchronous medium) with CM groups in an asynchronous mode (e.g; e-mail, groupware, even chatting) when the task indeed required synchronous communication. (Rico and Cohen, 2005; Hollingshead et al., 1993). In this case, the likelihood of finding differences between the two conditions is high, because the comparison is unequal. Thus, an asynchronous medium would hamper the performance of these types of tasks. Consequently, the approach should not be based on establishing which condition would be more efficient than the other, when comparing unequal communication media, but on understanding what the requirements of the task are and to what extent the communication technology addresses these requirements.

Contemporary communication technologies (CTs) simulate FTF communication very closely, so somehow all the “paralinguistic” signals can be transmitted. New CTs offer synchronous audio, text, and video that enables simultaneous communication without delay in the communication, as well as the possibility of sharing instantaneous visual and graphical information (e.g; desktop sharing). Hence, the question would instead be “What makes a FTF communication so unique that it could not be replaced by a CT?” Possible positive explanations may rely on the possibility of exerting greater social expectations in a FTF environment, but on the other hand, these expectations can also hamper the performance of the group due to social distractions. Answering this question is beyond the scope of this study.

Consequently, it seems that the comparisons may not be sufficient for the explanation of what really happens in groups interacting with CTs. Let us recall the comment of the most cited researchers in the area of CMC: “The problem is not that those sets of facts disagree; rather it is that they cannot be compared, because they deal with different parts of the domain and do so in different research language.” (McGrath and Hollingshead, 1994).

In order to unravel this limitation, McGrath and Hollingshead (1994) proposed a conceptual framework for studying the impact of technology on groups (Appendix I). The authors suggest that the study of the impact of technology in groups depends on several factors such as: the time and space distribution of the group's work, the nature and qualities of the tasks, the degree to which various characteristics of the group's work are prestructured and on various characteristics of the group, its members, and its context. It can be said that there has been a call to study this phenomenon from a systematic approach. McGrath and Hollingshead encourage researchers to ask proper research questions that allow exploring the impact of CMC on group performance more systematically. The authors point out that the concern, should deal, for example, with the set of conditions under which certain technology yield better performance results than other does. In other words, the question can be re-phrased as: what needs to be redesign in the technology so that it could meet the requirements of the task?

With the aim of answering the last question and overcome the above-mentioned limitations, I suggest looking at the possible effects of communication technologies on groups' performance by focusing on the requirements of the task that need to be supported by the communication technology. Specifically, I propose to use the construct of Ashby's law of requisite variety (Ashby, 1956) from the field of cybernetics as a possible framework for studying groups interacting with communication technologies, thereby analyzing the requirements of the task in a dynamic environment. In order to further aid the understanding of this theory, a summary of Ashby's law of requisite variety is provided in Appendix J.

It is useful to begin this approach of Ashby's laws considering the relationship of the existing concepts in the CMC literature and the constructs presented by Ashby. Specifically, the relationship between Ashby's law of requisite variety and the CMC literature on the fit between media and tasks will be considered. The CMC literature considers the tasks in terms of a number of basic dimensions. The most prominent approach has to do with information processing and communication media in organizations. The task requirements are then based on the information richness conceptualization, the media synchronicity theory and the group development. The theory of media richness (Daft et al., 1979, 1984, 1986 and 1987) categorizes tasks as uncertain and equivocal (former example). It proposes that the fit between media and tasks depends on the ability or richness of the media to convey the information requirements of the task. The theory of media synchronicity (Dennis and Valacich, 1999; Munzer and Holmer, 2009) instead uses synchronous communication as the critical dimension to find the best fit between media and, in this case, the communication process. This theory examines the ability of the media capabilities (immediacy of feedback, symbol variety, parallelism, reprocessability, and rehearsability) to support two communication processes (conveyance and convergence) across the three group functions (production, group well-being, and member support). The TIP (Time, Interaction and Performance) theory (McGrath, 1990) hypothesizes that depending on the task variation (i.e., increased task difficulty), features of the group (i.e new group members), or features of the situation (i.e change in time limits) in which the group may face a more complex situation, the group will need to find the suitable communication medium that fits the requirement of the task requirements. Although, the theories agree on the idea that technology or communication media should accommodate the requirements of the tasks, they do not explain how the requirements of the tasks in a dynamic environment could be identified and analyzed. To this limitation, Ashby's law of requisite variety explains the situation in variety terms.

In Ashby's terms, it can be said that the requirements of the task, in combination with the group attributes, would be as the number of possible states during the task performance that a group needs to deal with in response to the requirements of the task and to the possible perturbations from the communication media. To clarify the previous statement, Ashby used the concept of variety to define the set of possible outcomes within some defined situation (Ashby, 1956); this variety can also be seen as the number of possible states in the environment that can affect an organization or a specific situation, what is also known as environmental uncertainty (Scala *et al*, 2004). In the number game task, for instance, several sources of variety or uncertainty could potentially have affected the group performance, such it was the case of: the use of one-digit vs. two-digit numbers, individual memory errors and adding mistakes, the white screen in the last run, distraction, competition, and communication technology, among others. Most of these sources of variety came from the structure of the task, but others from the experimental condition, as for example, the distraction and the communication technology (the distraction originated by the FTF environment and the technical issues originated in the communication technology). Furthermore, Ashby states that ideal organizations as any other ideal dynamic system are those that better regulate the uncertainty or variety in the environment. In general terms, the amount of regulation that can be achieved by the system so that it can reach a desired state (in this case, good performance), was explained by Ashby's law of requisite of variety with the following statement: "only variety in the regulator can force down the variety due to the disturbance; only variety can destroy or absorb variety" (26) (Scala *et al*, 2004).

In this task, the variety in the regulator was determined by the different coordination mechanisms originated by the group interaction. The group needed to find the optimal requisite of variety to deal with the possible internal and external perturbations. Thus, the groups needed to find the best coordination mechanisms that could handle the disturbances originated by the task and the environment. In other words, the groups needed to identify the best variety in the regulator (coordination mechanisms) in order to force down the variety in the environment. The variety (disturbances) in the environment can be seen as internal or external, for example in this task, the internal disturbances were those originated by the group members (memory and adding errors, possible dislikeness in group, different level of attentions, etc) and external disturbance were those originated by the task (single vs double digits and white screen) and the communication medium (technological issues, familiarity with the technology, etc). The groups needed to find the best variety in the regulator to absorb the internal and external variety so that a desired outcome would be achieved. For example, in the case of the CMC groups, if the communication technology is the factor affecting the group performance, the reason is that there is a missing requisite of variety in the design of the technology; hence, the solution might be to find what is exactly missing in the communication technology so that it can be re-designed, and thus fulfill the requisite of variety needed by the system or situation.

For the number game task, the mechanisms of coordination or the collaborative strategies developed by the groups acted as the regulator of the system. Although, most of the strategies were common for the two conditions, the CMC groups tended to perform the task with more variety in the distribution of the adding than the FTF groups did (see Figure 4-17). For instance, CMC groups used more specific distribution of the adding such odds, even, single, double than the FTF groups. Furthermore, the occurrence of "innovative strategies" was higher in CMC groups (6 out of 19) than FTF groups (3 out of 19). With respect to the turn taking, FTF groups used more different turn signals than CMC groups. To this point, it can be said that although the physical setting may have constrained the CMC groups for the creation of different turn taking signals, the setting did not hinder the final performance; instead, it may have stimulated the variety of strategies. Similarity for the FTF groups, who despite having more diverse turn taking signals, did not outperform the CMC groups. On the contrary, FTF groups showed lower performance in the high task complexity condition for the DP score. Thus, it can be speculated that CMC groups made use of the communication technology to regulate the source of variation: some groups muted their microphones to handle the distraction caused by other group members when adding the numbers loudly. In addition, the newness of the communication technology (93.3% of the group members in the CM conditions were not familiar with the WebEx) may have made CMC groups more aware of any environmental uncertainty, situation that perhaps explains the better performance of the CMC groups in the high task complexity condition. In Ashby's terms, CMC groups followed the principle of: only variety (more coordination mechanisms and muting microphones) can destroy variety (task complexity, communication technology and, distributed setting). CMC groups' tendency to deal with the task variation was to generate more innovative strategies but keep the strategy constant along the task. The correlation results (Table 4-11) show that CMC groups changed the strategy more often in the low task complexity condition than in the high task complexity. The results show how the mutual adjustment happened in the beginning of the task, and then the groups found a suitable (optimal) strategy for the rest of the task. A possible explanation is that CMC participants performed the task in a more self-sufficient way because they were isolated from the rest of the group; thereby stimulating the generation of more creative ideas.

Yet, FTF groups' tendency to deal with the variety was slightly different. They were more prompted to change the strategy during the task. A conjecture to this result is that since the group members were in the same group, they could see each other in a broader spectrum than CMC groups could. Thus, possible adding errors were more easily attributed to people. In FTF groups, the changes in strategy were more related to changes in turning or distribution of the task load, than to a radical change of strategy. For example, if the counting was first assigned in order *A*, *B*, *C*, a change was counted if the group shifted the order to *B*, *A*, *D*, or if the distribution of adding was first, every ten numbers, a change was counted if the group decided to either increase or decrease the task-load distribution. A particular situation happened more often in FTF groups than CMC groups: Sometimes fewer loads were given to one member of the group, or even the strategy *2 to1* check-up was more common in FTF groups. A possible reason for this situation is that when a group member looked somehow confused or making more errors in the adding, the rest of the group may have thought that the error came originally from her or him, instead of their strategy itself, and thus the rest of the group gave that person less numbers to add. Perhaps, the extra information available for FTF groups made them behave in that way; while for CMC groups who had less information available (they had small 4×4 cm^2 screens on the interface), were more concerned with getting familiar with the strategy and adjusting the strategy to people, rather than people to the strategy. Thus, the likelihood of the errors be attributed to people was smaller for CMC groups. Perhaps, for the FTF groups, the constant changes of strategies during the task were the reason of the lower performance in high task complexity condition for the DP score. The correlation results (Table 4-10) show that changes in strategy correlates negatively with performance; strong correlations occurred in FTF groups.

Regarding the previous example, it can be concluded that since the comparison between FTF and CMC groups was kept almost equal, in regard with the attributes of the communication (both conditions had synchronous communication), the different physical distribution of the groups yielded the above-mentioned differences found. For instance, CMC groups were collocated while FTF groups were in the same room; and, thus, CMC groups had less information available than FTF groups did. The task was shown in a bigger screen in the FTF condition and the group members could see each other in a greater extent than CMC groups could. However, these differences did not seem to be very significant when performing this task because the overall performance of the groups in the two conditions was not greatly affected by these differences. Therefore, in Ashby's law of requisite variety's terms, these results could be explained in the following way: First, since the characteristics of the task and the group members were equal in the two conditions, the overall performance between the two conditions was the same because the requisite of variety was matched. Second, since the physical context and communication medium were different so were the disturbances originated by the context (FTF and CMC); this situation made the groups, in each condition, responds differently to the variation of the task. This difference was seen in the groups' performance in the high task complexity condition as well as in the strategies used by the groups in each condition.

In this order, the law of requisite variety suggests, primordially, understanding what the requirements of the task are so that the major factors interacting in the situation can be captured; then, the best or proper setting to perform the task efficiently could be designed. For example, if the task would instead require adding only 10 numbers without time limit, synchronous communication would not be needed, and thus perhaps redundant. In such situation, the groups would not even feel the need of developing collaborative strategies because just one person could handle the variety of the task. In this case, the task has less variety, and thus a different requisite of variety (e.g., less people and asynchronous media would perhaps be enough) is needed to handle it.

Another important feature of this conceptualization of Ashby's law of requisite variety is that both human and non-human elements (i.e., technology) are treated in attuned terms. Here, the important concept is to understand the task in more detail and to understand what people are really doing, so that the variety can be identified. After identifying this variety, the communication medium given and the group attributes should have the requisite of variety needed to handle the variety of the system.

In summary, instead of using task and media categorization, which has brought, unnecessary variety to the CMC literature; the concept of Ashby's law of requisite variety would be concerned only on the amount of variety in the system or task, encompassing in this way all the possible factors acting in the situation. This theory would analyze the internal and external variety generated by the task, so that a requisite of variety could be set up in the design of the task situation. In this sense, Ashby's law provides a systematic approach, even in language, to understand and explain a dynamic situation. It says how the variety is generated by the system, and how the group could handle it.

However, as almost every theory does, the law of requisite variety has some shortcomings. In the first place, the broad coverage of the theory with its simple but powerful model (Disturbances, regulator, outcomes and environment) allows the application of the theory in many fields in science; therefore, the effective usage of this concept depends on how well the researcher understands the situation. For instance, one of the biggest limitations that the law has is the measurement of variety. In the beginning, Ashby based his theory on information theory, and then measured the variety in the system with bits of information in a logarithmic form (quantified in terms of the – average – number of binary digits required to count a given number the alternatives); hence, when it comes to measure the variety in an organizational context with the human element involved, different interpretations come into place. Some scholars have used different measurements of variety to assess the organizational effectiveness, as for example: designed scales to measure the Perceived Environmental Uncertainty (PEU) and the Rational Strategic Decision Making (RSDM) as the measurement of uncertainty in the organization (Lewis and Stewart, 2003), or network of task dependencies to measure the coordination or interaction among the interdependent components of the system using the echo technique[12] (Scale, J. *et al*., 2006). As for measuring the impact of technology in a system, the last approach (echo technique) would be more revealing, because, the effectiveness of the communication technology can be assessed by asking the people's perceptions of the usefulness of the technology in relation with the task being performed. However, people's perceptions should not be only based on the communication technology, but also on the helpfulness or unhelpfulness actions found when performing the task. The last statement accounts to the several sources of variety that a dynamic system can generate. In this sense, a mismatch variety cannot be generated only by the communication technology used, but also by the unhelpful behaviors of other members of the group. In the number game task example, if all the requirements of the task, such as communication medium and coordination mechanisms were propering set for the performance of the task, but the characteristic of the group members were not, the group performance would be still affected. Let us say that in one condition, one participant for each group was told to not be helpful when performing the task; the group performance would then be affected by the missing requisite of variety in the group interaction, rather than by the communication technology.

5.2 Conclusions

There are four main conclusions that can be drawn from this study:

First, the task chosen for this study and the experimental results drew attention to several limitations in the existing CMC literature. The theories found in the literature were not helpful to come up with predictions for this study. The dynamic characteristics of the task and the equalized experimental

[12] The echo technique measures how a particular situation is perceived by its members. This technique consists of asking open questions about their jobs, so that it can be identified other individuals or groups each subject interacts with. This open-ended interview was developed by Bavelas (Bavelas, 1942).

conditions used in this study did not follow the trend of the existing literature, but allowed discovering some of its shortcomings. The results based on the proposed framework exposed two possible main explanations for the limitations in the CMC literature:

I) the requisite of variety in the experimental comparisons between conditions in which most of the literature based their hypothesis was not the same. Thus, it was evident that these mismatch comparisons would bring differences in performance between conditions; generally speaking, it was like comparing apples to oranges.

II) The categorization approach did not capture the dynamic interaction of groups when performing a particular task. In short, the existing CMC literature shows limitations in conceptualization, since it is not clear how to categorize the tasks.

Second, although the results showed some minor differences in the condition of high complexity, there was no significant difference in the overall group performance between FTF and CMC conditions. A possible explanation for the differences found in the DP measurement is due to the lack of attention of the groups to environmental uncertainty. The groups located in the same room probably did not attend to surprises as much as the groups who were distributed in different rooms did. This finding may be related to the internal variety (i.e., distraction) associated with the type of interaction. Whereas these are assumptions, the overall results (experimental and questionnaire data) showed no significant differences based on the communication medium, and the groups tended to behave alike in response to the conditions of the task.

Third, although few participants in the CMC condition felt that they could have performed better if they had been in the FTF condition, the majority of participants felt quite comfortable performing the task with computers regardless of their unfamiliarity with the interface. This outcome can be attributed to the attributes of the participants who participated in the study. They were undergraduate engineering students who use computers as part of their daily interaction. In addition, the participants' experience with communication technologies made them propose improvements in the design of the computer application, WebEx, to help in the performance of the task. The technical and interface suggestions were: bigger screen videos, different arrangement of the screens, and a turn signal feature when a person talks.

Fourth, as a general conclusion of this study, it can be said that the whole research area of computer mediated communication has not been useful in providing good and proven theories that can be applied to any situation or task given. Therefore, I proposed the adoption of a more comprehensive approach, to study the impact of communication technologies on group performance, based on the concept of Ashby's law of requisite variety. With this concept, any dynamic situation can be explained regardless the varying conditions of it. Thus, as solid theories are, the law of requisite variety can be applied to any situation; "good theories should have two main properties: generality because they can be tested in any place with any specie, and parsimony in the sense they involve the least number of concepts to explain models (Safayeni, 2008). Consequently, I propose to analyze a task situation in the following spectrum:

1) Understand the requirements of the task situation in terms of the variety it brings;
2) Look for the coordination mechanisms that the group or individual needs to have in order to handle the variety; and
3) Identify the technology available to the group so that the variety can be handled (the technology for this particular o future studies means the communication technology or medium in which the group sends the communication messages).

Explicitly, the observer should first identify whether a group or individual in a dynamic situation is expected to perform and handle the variety in the situation. Second, the observer should determine if the group or individual as well as the tools to perform the task have the requisite of variety to handle the variety of the situation. With this analysis, predictions can be easily made using simpler but rich theoretical conceptualization. For instance, in this study, if the situation had been approached in that manner, it would have been expected that the FTF and CM groups would perform more or less the same because they had similar requisites of variety. Yet, what happened in previous researches in which mismatch situations in the requisite of variety of the system were found, and therefore some conditions were seen more favorable than others

5.3 Other recommendations and future research

As with other experimental research with human subjects, the biggest limitation in this study was the sample size. For this study the number of groups analyzed was 19 for the FTF condition and 20 for the CMC condition; a sample size which was not appropriate perhaps to apply parametric tests because of the possible errors associated with the level of significance (Type I and II errors). Despite that, two-tailed t-tests were carried out for all comparisons in order to test any significant difference. Normality plots were created to check normality of the data, and some data showed more compliance to the normal distribution than others; hence, non-parametric tests were also used to corroborate the results. Therefore, the sample size for this type of studies should be preferably greater than 25 in each condition so that the results would comply more with statistical assumptions, and perhaps be more revealing. However, if the requisite of variety is matched in the two conditions, an increase in the sample size would most likely show the same results.

As for the discussion time between the runs, a two minute-discussion may not have been sufficient time to disclose any possible difference in the amount of conversational time. For that reason, the discussion time should be extended, and a more detailed analysis should be carried out not only in relation to the total discussion time, but also in the type of messages sent. For example, it is worth exploring if there is any difference in communication behaviors (i.e., seeking or clarifying behaviors in the communications) between the two conditions, even with a matched requisite of variety of the system is set up. Also, this study neither measured nor analyzed the time it took to the group to come up with the final answers. This time was not limited in the experiment, and there were some groups that took longer than others to agree with the final answer.

In addition, the dynamic characteristics of the number game task make the task a very useful tool for studying the behavior of individuals or groups under conditions of uncertainty, situation which is not easy to test in lab experiments. Some modifications to the task would enable exploring the performance of groups under other conditions. For instance, variation of group size would show how and to what extent crowdedness affects group performance, variation in the information given in the set of instructions could also affect performance, and perhaps the coordination mechanisms would be also affected by the information available at the beginning of the task.

This study proposed a more comprehensive approach to tackle the research in the computer mediated communication. However, further theoretical and practical research is required to assess the proposed framework's appropriateness in the field. A possible model to follow is the approach developed by

Scala *et al.*, (2006) in their application of cybernetics to manufacturing flexibility. They represented the general task structure of an organization as a network composed of nodes (tasks) and connections representing communication and coordination. With this type of approach, contrary to the categorization of tasks, the analysis of task requirements and its relation with the communication technologies existing could be approached using information flow analysis and the echo method. First, identifying the properties of the information needed between nodes (i.e., between departments) as well as the properties of the existing communication medium to transfer this information. Second, interviewing the people who intervene in the situation in order to identify mismatches in the requisite of variety in the system; the mismatch could be measured based on the helpful/unhelpful behaviors either from other departments (or group members) or from the disturbances generated by the technology. With this analysis, recommendations can be drawn for either improving the design of the communication technology or changing the task structure.

Finally, this study revealed that variety does not come only from the task structure or the type of communication medium, but also from people (i.e., distractions, adding errors). For this reason, further research is required with respect to the possible internal variety generated by social interaction. Nowadays, the advanced communication technologies facilitate several social and work interactions that were previously only accomplished by FTF communication; and the use of computer mediated communication is becoming very popular day by day. Thus, it would be interesting to determine what type of tasks would indeed better perform using FTF communication rather than using CMC communication; in a question form: What kind of attributes does FTF communications possess which makes this communication medium irreplaceable by a computer mediated interaction? Future research could perhaps examine the differences in social expectations between a distributed environment and FTF setting in a specific situation. For instance, the effects of amplifying or decreasing the visual information of the person through the communication technology on performance can be explored; when and to what extend groups members need to see each other when performing certain task.

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APPENDICES

Appendix A McGrath’s Task Categorization

Figure A1.   McGrath’s Task Circumplex (1984)

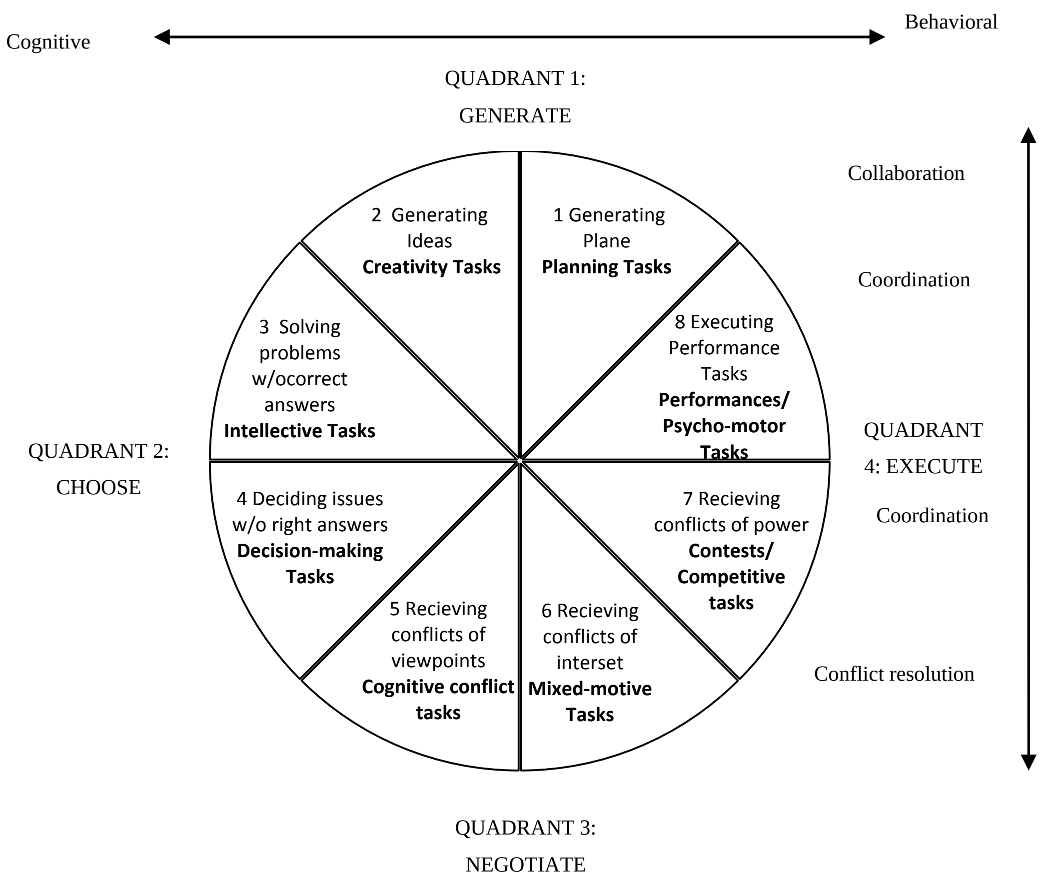


Figure A2. Task-Media Fit on Information Richness (1993)

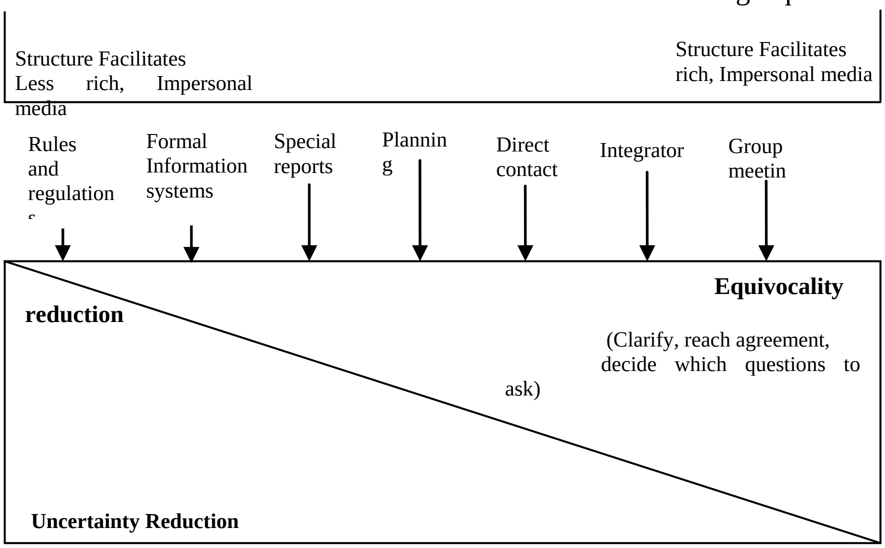
Task Type(s)	Computer Systems	Audio Systems	Video Systems	Face-to-Face Communications
Generating ideas and plans	Good Fit	Marginal Fit Medium too rich	Poor Fit Medium too rich	Poor Fit Medium too rich
Choosing correct answer: intellective tasks	Marginal Fit Medium too constrained	Good Fit	Good Fit	Poor Fit Medium too rich
Choosing preferred answer: judgment tasks	Poor Fit Medium too constrained	Good Fit	Good Fit	Marginal Fit Medium too rich
Negotiating conflicts of interests	Poor Fit Medium too constrained	Poor Fit Medium too constrained	Marginal Fit Medium too constrained	Good Fit

Increasing potential richness required

Increasing potential richness of information transmitted

Appendix B Other categorization of tasks

Figure B1. Information Role of Structural Characteristics for Reducing Equivocality or Uncertainty (1)



Source: Daft and Lengel . Organizational Information Requirements, media richness and structural design. Management Science . Vol 32. No. 5. May 1986

Figure B2. Relationship of Department Technology with Structure and Information Required for Task accomplishment (2)

ANALYZABILITY	Low — VARIETY	VARIETY — High
Unanalyzable	1. Unanalyzable, Low Variety (craft technology) Structure: a. Rich media to resolve unanalyzable issues b. Small amount of information Examples: Occasional face-to-face and scheduled meetings, planning, telephone	2. Unanalyzable, High Variety (Non-routine Technology) Structure: a. Rich media to resolve unanalyzable issues b. Large amount of information to handle exceptions Examples: Frequent face-to-face and group meetings, unscheduled meetings, special studies and reports.
Analyzable	3. Analyzable, Low Variety (Routine technology) Structure: a. media of low richness b. Small amount of information Examples: Rules, standard procedures, standard information system reports, memos, bulletins.	4. Analyzable, high Variety (engineering technology) Structure: a. media of low richness b. large amount of information to handle frequent exceptions Examples: Quantitative data bases, plans, schedules, ical reports, a few meetings.

Figure B3. Relative Trait Salience of Selected Media (3)

	Feedback	Symbol Variety	Parallelism	Rehearsability	Reprocessability
Face-to-Face	high	Low-high	low	low	Low
Video conference	Medium-high	Low-high	low	low	Low
Telephone	medium	low	low	low	Low
Written e-mail	low	Low-medium	high	high	High
Voice mail	low	low	low	Low-medium	High
Electronic mail	Low-medium	Low-high	medium	high	High
Electronic Phone ("chat")	medium	Low-medium	medium	Low-medium	Low-medium
Asynchronous group ware	low	Low-high	high	high	High
Synchronous group ware	Low-medium	Low-high	high	Medium-high	high

Sources:

(1) and (2) Daft and Lengel. (1999) *Organizational Information Requirements, media richness and structural design*. Management Science , Vol 32, No. 5.

(2) Dennis, A. and Valacich, J. (1999). Rethinking Media Richness: Towards a Theory of Media Synchronicity. 32nd Hawaii International Conference on System Sciences, (pp. 1-10).

Appendix C Type of experimental tasks used in the literature

- Hollngshead, A., McGrath, J. and O'connor, K. (1993)

Illini Guides (Intellective task)
Group product: Six multiple-choice questions with distractions
Scoring: Percentage correct of questions and distractors

Moromark (Intellective)
Group product: Up to eight solutions
Scoring: Points awarded for elements of correct answers

Northwest (Decision Making)
Group product: Dichotomous choices with rationale
Scoring: persuasiveness of rationale

Secretary (Generate)
Group product: Generate series of possible plans
Scoring: Number of plans and creativity of each

Discrimination (Negotiation)
Group product: Series of dichotomous choices
Scoring: Point for each choice based on outcomes

Promotion (Negotiation)
Group product: Series of dichotomous choices
Scoring: Point for each choice based on outcomes

- Blasio, P and Milani, L. (2007)

Task: "The subjects were presented with two options regarding a project to restructure their university refectory and they were asked to choose one of them. The task, of the choice-dilemma type, was formulated by us in such a way as to entail a taking a decision between two alternatives. The first,low risk option, (Option A), contemplated the minor enlargement of the university refectory with a partial reduction in inconvenience (queues and crowding), balanced against an unvaried cost of the meal ticket. The second, high-risk option, (Option B), offered the advantage of a considerable expansion of the refectory, which would completely eliminate the inconvenience caused by overcrowding, balanced against uncertainty about the cost of the meal ticket, which could rise considerably in price, in the event that the refectory was not full every day, and could be reduced in the event that the refectory was fully used."

Scoring: Likert-scale of preference was given to the participants to choose the best offer.

- Chidambaram, L. and Jones, B. (1993)

Task: (Decision making tasks with no a priori right or wrong answer)

A firm background is given. The company is Palo Verde Vintners Inc. (PVVVI), a large California-based wine maker with significant international operations. The participants are given with two tasks: 1) PVVI has had a problem with its image in the European markets and participants are asked to redeem the shattered image of the firm and 2) PVVI has a limited line of white, red, and rose wines, and participants are asked to create new products depending on the capacity of the firm.

Scoring: Media perceptions were evaluated by a post-session questionnaire and group performance was measured using three different constructs: quality of decision, quality of the process used to arrive at the decision, and the number of alternatives examined. Experts judged these measurements.

Münzer, S and Holmer, T (2009)

Task 1: (Conveyance)

"The chosen hidden profile task was a murder mystery originally developed by Cruz, Henningsen, and Smith (1999), and adapted and translated into German by Piontkowski, Böing-Messing, Hartmann, Keil, and Laus (2003). The case involved choosing the most likely suspect out of four suspects. Ten pieces of information existed about each suspect (a total of 40 pieces of information), of which four were common and six were unique (i.e., known to only one participant). Each participant received a total of 20 pieces of information (i.e., all 12 common pieces of information and 8 unique pieces of information in addition; two unique pieces of information of each suspect). The common information incriminated three out of four suspects and vindicated one particular suspect. However, the unique information, taken together, incriminated this particular suspect, which was the optimal choice, and vindicated the other three suspects.

Task 2: (Convergance)

" The logic of using a secondary task is based on the assumption that a primary task and a secondary task will compete, in principle, for an attentional or processing resource. If two tasks are performed concurrently, and if the primary task is fulfilled with priority in order to fulfill a higher order goal, then the secondary task should provide a measure of the spare capacity not required by the primary task. If decreased performance is thus found in a secondary task in a particular experimental condition compared to another condition, then this finding is interpreted as higher mental effort required for the primary task in that condition". The secondary task adopted in this study was developed after a description provided in Brünken, Plass, and Leutner (2003). It required the visual monitoring of a separate window on the computer screen showing the capital letter "A" positioned at the top-middle part of the screen. The letter began as black, but after a time interval randomly varying between 5 and 10 seconds, changed to red. The participant could press any one of several marked keys to indicate notice of this color change. After reaction, a new trial with a black letter was started. If a participant did not react to the task for 5,000 ms., then the trial was considered a "missed trial," and a new trial started. In addition, a brief acoustic alarm signal (like a telephone ring) delivered via headphones at a comfortable volume reminded the participant to direct attention also to the secondary task after a missed trial. The secondary task program recorded reaction times as well as missed trials.

Scoring:

Free recall test. A test form was prepared in which participants were asked to list all the incriminating and all the vindicating pieces of information for each suspect that they could remember. In addition, participants were asked to indicate which of the four suspects was selected as the murderer by their group.

Questionnaire. The questionnaire contained questions about the difficulty to solve the task using a chat tool as well as questions about experience with computer use and computer-mediated communication.

Appendix D Numbers displayed in the "number game task"

Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8
1	3	9	4	9	9	8	3
5	9	8	2	1	2	3	4
9	7	7	6	8	6	11	12
3	5	2	4	12	11	7	1
8	9	9	9	9	9	1	7
3	8	8	8	19	18	16	15
7	5	5	2	1	6	7	6
2	1	9	4	5	8	9	3
8	9	4	6	1	1	10	13
7	3	2	3	7	4	3	2
5	8	8	8	2	3	13	14
6	5	5	1	6	4	4	9
4	4	4	8	7	5	13	White screen
5	7	7	6	11	12	9	4
3	3	5	8	7	5	8	6
8	2	2	2	2	7	2	4
7	5	9	1	17	11	15	19
5	8	7	4	8	4	2	6
4	7	5	7	7	16	3	3
8	9	9	9	9	5	1	8
		3	8	13	16	10	10
		7	3	6	3	6	1
		2	5	9	2	17	18
		8	8	4	5	4	6
		4	7	6	3	3	5
		6	3	12	12	14	14
		8	9	8	3	6	6
		1	2	5	6	1	3
		4	4	7	7	17	17
		6	3	2	5	3	2
Total 108	Total 117	Total 173	Total 154	Total 220	Total 208	Total 226	Total 221

Appendix E Pos-task questionnaire

Date:________________________ Name: _________________________ Station : ________

Age: ____ Gender: Male: ___ Female:___

Program you are enrolled in: ____

Is English your first language: yes ____No ____ if not which one is: ______________________

1. Were you satisfied with the overall performance of your group?

   1 2 3 4 5

   |-----|-----|-----|-----|

   Low Satisfied — Medium Satisfied — High Satisfied

   Explain:

   ____

   ____

2. What strategies did your group use and how successful were they?

   ____

   ____

   ____

   ____

3. If you were to perform the same task again in a group, what strategy would you recommend?

   ____

   ____

   ____

4. If you were to perform the same or different task, would you prefer to be in a different or similar group experiment?, please explain

   ____

5. Was there one person who you would call "leader" in your group?

Yes___ No____ If yes, please circle the person location or station A B or C

6. I feel that all the strategies and conclusions were mainly made by cooperation

1 2 3 4 5

Low Cooperation — Medium Cooperation — High Cooperation

7. I feel I put effort in performing the experiment

1 2 3 4 5

Low Effort — Medium Effort — High Effort

8. I feel my performance got better as the experiment went along

1 2 3 4 5

Low Performance — Medium Performance — High Performance

9. I feel the group performance got better as the experiment went along

1 2 3 4 5

Low Performance — Medium Performance — High Performance

10. I felt stress performing this task

1 2 3 4 5

Low Stress — Medium Stress — High Stress

Please respond the following questions ONLY if you use computers to perform the task

11. Were you familiar with WEBEX interface?
Yes ____ No______

From where: ____

12. If you were going to be in another similar experiment, would you choose WEBEX again?
Yes ____ No ______

Why: ____

13. Do you feel that seeing your group members on the screen help you perform better?
Yes_____ No ______

Explain: ____

____

14. Do you feel that video screens in the interface were? (please circle)
Small Just Right Big

15. Do you feel your group would have performed better if all of you were face to face?
Yes____ No ______

Explain: ____

____

____

16. Do you have any suggestion for the design of the interface, so it will help you perform better

This type of task?

____

____

____

Appendix F Detailed data results of group performance

Table F.1.1 Total RW in the FTF Condition

FTF	Runs/ Accuracy (1= Right answer 0= wrong answer)							
Groups	1	2	3	4	5	6	7	8
1	1	1	1	1	1	0	0	0
2	1	0	0	0	0	0	1	1
3	1	0	0	0	0	0	1	0
4	0	0	1	1	1	1	1	1
5	0	0	1	1	0	0	0	0
6	1	0	0	0	0	0	0	1
7	1	1	1	0	0	0	0	0
8	1	1	1	0	0	1	0	1
9	0	0	1	0	0	0	0	0
10	1	1	0	1	0	1	0	0
11	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	1	0	1	0	1	1	1	0
15	1	1	1	1	0	1	1	1
16	0	0	0	0	0	0	0	0
17	1	0	0	0	0	0	0	0
18	1	1	0	0	0	0	1	0
19	0	1	0	0	0	0	1	1
TOTAL	11	7	8	5	3	5	7	7

Table F.1.2 Group RW data in the FTF condition

Groups	Performance (1)	Low (2) Complexity	High (3) Complexity	High (4) Complexity
1	0.625	1	0.25	0.33
2	0.375	0.25	0.5	0.33
3	0.25	0.25	0.25	0.33
4	0.75	0.5	1	1.00
5	0.25	0.5	0	0.00
6	0.25	0.25	0.25	0.00
7	0.375	0.75	0	0.00

8	0.625	0.75	0.5	0.33
9	0.125	0.25	0	0.00
10	0.5	0.75	0.25	0.33
11	0.125	0	0.25	0.00
12	0	0	0	0.00
13	0	0	0	0.00
14	0.625	0.5	0.75	1.00
15	0.875	1	0.75	0.67
16	0	0	0	0.00
17	0.125	0.25	0	0.00
18	0.375	0.5	0.25	0.33
19	0.375	0.25	0.5	0.33

(1) Performance = No. Right runs / Total No. Runs (i.e. 3/8 = 0.375)
(2) Low Complexity = Performance for runs 1,2,3,4 (i.e. 2/4 = 0.5)
(3) High Complexity = Performance for runs 5,6,7,8
(4) High Complexity = Performance for runs 5,6,7

F.2 Video-Computer-Mediated Condition

Table F.2.1 Total RW data in the CMC condition

CMC	Runs/ Accuracy (1= Right answer 0= wrong answer)							
Groups	1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	0
2	0	0	1	1	0	0	0	0
3	0	0	0	1	0	0	0	0
4	1	1	1	0	0	1	1	0
5	0	0	0	1	0	0	1	1
6	1	1	0	0	0	0	0	0
7	0	0	1	1	0	0	0	1
8	1	1	1	1	0	0	1	1
9	1	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0
11	0	1	0	1	1	1	0	1
12	1	1	0	0	0	0	0	0
13	0	1	1	1	0	0	0	0
14	0	0	0	0	0	0	0	1
15	0	1	0	0	0	0	0	0
16	1	1	0	0	0	0	0	0
17	0	1	0	0	0	1	1	0

18	1	0	1	1	0	1	1	1
19	0	1	1	0	1	0	0	0
20	0	1	0	1	0	0	1	0
TOTAL	7	11	7	9	2	4	6	7

Table F.2.2 Group RW data in the CMC condition

CMC Groups	Performance (1)	Low (2) Complexity	High (3) Complexity	High (4) Complexity
1	0.00	0.00	0.00	0.00
2	0.25	0.50	0.00	0.00
3	0.13	0.25	0.00	0.00
4	0.63	0.75	0.50	0.67
5	0.38	0.25	0.50	0.33
6	0.25	0.50	0.00	0.00
7	0.38	0.50	0.25	0.00
8	0.75	1.00	0.50	0.33
9	0.25	0.25	0.25	0.00
10	0.00	0.00	0.00	0.00
11	0.63	0.50	0.75	0.67
12	0.25	0.50	0.00	0.00
13	0.38	0.75	0.00	0.00
14	0.13	0.00	0.25	0.00
15	0.13	0.25	0.00	0.00
16	0.25	0.50	0.00	0.00
17	0.38	0.25	0.50	0.67
18	0.75	0.75	0.75	0.67
19	0.38	0.50	0.25	0.33
20	0.38	0.50	0.25	0.33

(1) Performance = No. Right runs / Total No. Runs (i.e. 3/8 = 0.375)
(2) Low Complexity = Performance for runs 1,2,3,4 (i.e. 2/4 = 0.5)
(3) High Complexity = Performance for runs 5,6,7,8
(4) High Complexity = Performance for runs 5,6,7

F.4 DATA FROM ABSOLUTE DEVIATION CLASSIFICATION

Table F.4.1 Total DP in the FTF Condition

FTF	Runs/ Deviation Performance (The smaller the number the better performance)*							
Groups	1	2	3	4	5	6	7	8
1	0	0	0	0	0	11	28	1
2	0	1	9	1	7	2	0	0
3	0	16	12	8	9	2	0	20
4	10	4	0	0	0	0	0	0
5	14	17	0	0	18	1	11	4
6	0	1	3	7	19	24	2	0
7	0	0	0	6	11	4	4	4
8	0	0	0	2	10	0	8	0
9	1	1	0	2	3	20	10	13
10	0	0	10	0	20	0	25	4
11	4	20	28	6	18	18	4	0
12	19	7	15	5	23	15	20	25
13	2	11	5	10	37	20	2	10
14	0	10	0	33	0	0	0	24
15	0	0	0	0	11	0	0	10
16	28	14	2	18	48	7	2	7
17	0	4	3	10	18	1	16	36
18	0	0	1	5	20	9	0	7
19	1	0	1	9	30	24	0	0
TOTAL	79	106	89	122	302	158	132	165

*Performance is defined as the absolute numerical deviation from the right answer

Table F.4.2 Group DP data in the FTF condition

FTF Groups	Performance (1)	Low (2) Complexity	High (3) Complexity	High (4) Complexity
1	5	0	10	13.00
2	2.5	2.75	2.25	3.00
3	8.375	9	7.75	3.67
4	1.75	3.5	0	0.00
5	8.125	7.75	8.5	10.00
6	7	2.75	11.25	15.00
7	3.625	1.5	5.75	6.33
8	2.5	0.5	4.5	6.00
9	6.25	1	11.5	11.00
10	7.375	2.5	12.25	15.00
11	12.25	14.5	10	13.33
12	16.125	11.5	20.75	19.33
13	12.125	7	17.25	19.67
14	8.375	10.75	6	0.00
15	2.625	0	5.25	3.67
16	15.75	15.5	16	19.00
17	11	4.25	17.75	11.67
18	5.25	1.5	9	9.67
19	8.125	2.75	13.5	18.00

(1) Performance = The sum of total absolute numerical deviation of the runs
(2) Low Complexity = The sum of total absolute numerical deviation for runs 1,2,3,4
(3) High Complexity = The sum of total absolute numerical deviation for runs 5,6,7,8
(4) High Complexity = The sum of total absolute numerical deviation for runs 5,6,7

F.5 VIDEO-COMPUTER-MEDIATED CONDITION

Table F.5.1 Total DP in the CMC Condition

CMC	Runs/ Deviation Performance (The smaller the number the better performance)*							
Groups	1	2	3	4	5	6	7	8
1	16	11	1	5	37	1	10	13
2	3	37	0	0	2	4	26	20
3	20	5	16	0	3	22	11	2
4	0	0	0	9	20	0	0	3
5	4	15	12	0	21	1	0	0
6	0	0	12	17	6	1	20	10
7	2	10	0	0	3	1	1	0
8	0	0	0	0	20	3	0	0
9	0	1	2	7	5	1	5	0
10	4	30	8	1	9	15	6	2
11	19	0	1	0	0	0	21	0
12	0	0	15	10	5	2	6	10
13	20	0	0	0	1	6	6	25
14	1	2	6	2	2	23	20	0
15	23	0	19	9	10	11	9	4
16	0	0	4	22	5	2	18	1
17	4	0	10	3	10	0	0	1
18	0	2	0	0	2	0	0	0
19	1	0	0	12	0	3	1	1
20	2	0	2	0	1	1	0	8

*Performance is defined as the absolute numerical deviation from the right answer

Table F.5.2 Total DP data in the CMC condtion

CMC Groups	Performance (1)	Low (2) Complexity	High (3) Complexity	High (4) Complexity
1	11.75	8.25	15.25	16.00
2	11.5	10	13	10.67
3	9.875	10.25	9.5	12.00
4	4	2.25	5.75	6.67
5	6.625	7.75	5.5	7.33
6	8.25	7.25	9.25	9.00
7	2.125	3	1.25	1.67
8	2.875	0	5.75	7.67
9	2.625	2.5	2.75	3.67
10	9.375	10.75	8	10.00
11	5.125	5	5.25	7.00
12	6	6.25	5.75	4.33
13	7.25	5	9.5	4.33
14	7	2.75	11.25	15.00
15	10.625	12.75	8.5	10.00
16	6.5	6.5	6.5	8.33
17	3.5	4.25	2.75	3.33
18	0.5	0.5	0.5	0.67
19	2.25	3.25	1.25	1.33
20	1.75	1	2.5	0.67

(5) Performance = The sum of total absolute numerical deviation of the runs
(6) Low Complexity = The sum of total absolute numerical deviation for runs 1,2,3,4
(7) High Complexity = The sum of total absolute numerical deviation for runs 5,6,7,8
(8) High Complexity = The sum of total absolute numerical deviation for runs 5,6,7

Appendix G Results of normality test of the performance data

1) One-sample Kolmogorov-Smirnov: Goodness-of-Fit Test and P-P plots for RW performance

One-Sample Kolmogorov-Smirnov Test

		OPftf	OPcm
N		19	20
Normal Parameters[a]	Mean	.3487	.3312
	Std. Deviation	.26213	.21943
Most Extreme Differences	Absolute	.144	.221
	Positive	.144	.221
	Negative	-.117	-.110
Kolmogorov-Smirnov Z		.629	.988
Asymp. Sig. (2-tailed)*		**.824**	**.283**

a. Test distribution is Normal.

*The OP may be assumed to come from a normal distribution with the given mean and standard deviaton

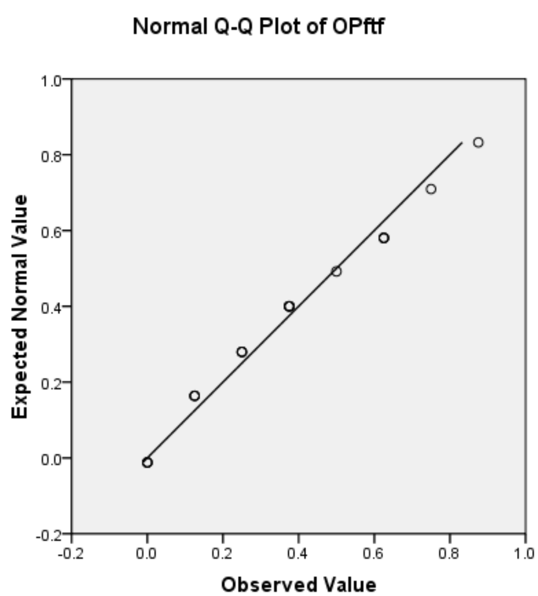


Figure G-1: Normal Q-Q plot of RW performance of FTF groups

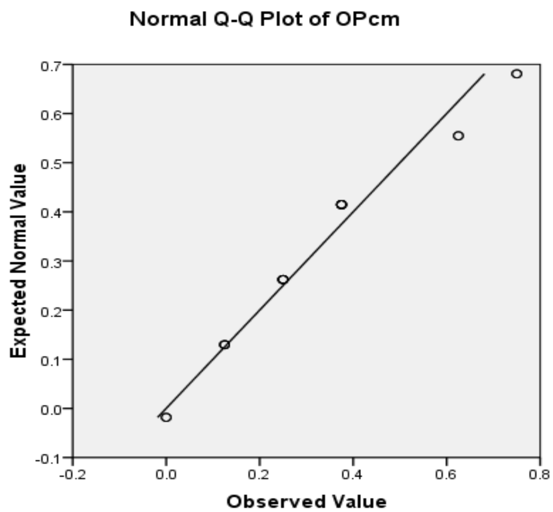


Figure G-2: Normal Q-Q plot of RW performance of CM groups

2) One-Sample Kolmogorov-Smirnov: Goodness –of-Fit Test and P-P plots for Deviation performance

One-Sample Kolmogorov-Smirnov Test

		OPftf	OPcm
N		19	20
Normal Parameters[a]	Mean	7.5855	5.9750
	Std. Deviation	4.31930	3.47112
Most Extreme Differences	Absolute	.164	.115
	Positive	.164	.115
	Negative	-.088	-.086
Kolmogorov-Smirnov Z		.716	.516
Asymp. Sig. (2-tailed)*		***.684***	***.953***

a. Test distribution is Normal.

*The OP may be assumed to come from a normal distribution with the given mean and standard

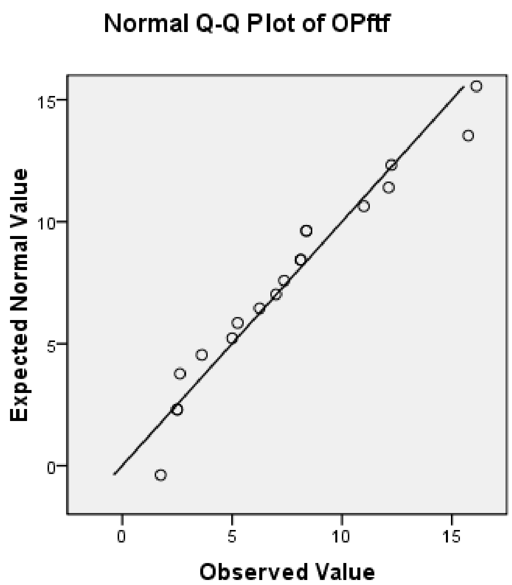


Figure G-3: Normal Q-Q plot of Deviation performance of FTF groups

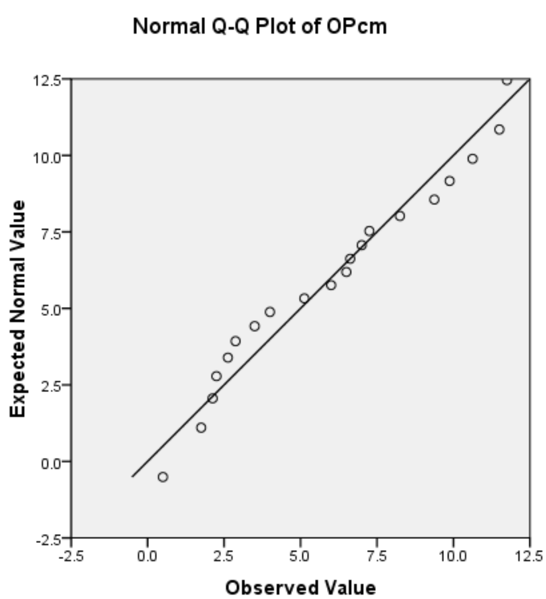


Figure X: Normal Q-Q plot of RW performance of CM groups

Appendix H Statistical test results

Table H.1 T-test result for comparison of overall RW performance between FTF and CM groups

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
meancat	Equal variances assumed	.921	.343	.226	37	.823	.01743	.07726	-.13910	.17397
	Equal variances not assumed			.225	35.175	.824	.01743	.07761	-.14010	.17497

Table H.2 T-test for comparison of overall deviation performance between FTF and CM groups

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
meancat	Equal variances assumed	.429	.517	1.287	37	.206	1.61053E0	1.25159E0	-9.25445E-1	4.14650E0
	Equal variances not assumed			1.280	3.454E1	.209	1.61053E0	1.25871E0	-9.45994E-1	4.16705E0

Table H.3. Task complexity performance: Repeated measures analysis of variance

Source of variation	Sum of Squares		DF		F		Sig. of F	
Right – Wrong Performance	All runs	Excl. #5	All runs	Excl. #5	All runs	Excl. #5	All runs	Excl. #5
Between Subjects Effects								
Within Cells	4.3	10.2	37	37				
Communication medium	0.006	0.005	1	1	< 1	<1	0.823	0.844
Within-Subjects Effect								
Within cells	1.9	2.53	37	37				
Task Complexity	0.45	0.228	1	1	8.6	3.3	**0.006***	0.076
Comm.Type x Task Comp	0.023	0.022	1	1	< 1	<1	0.511	0.577
Deviation Performance								

Between Subjects Effects								
Within Cells	1129.4	1138.42	37	37				
Communication medium	50.5	15.44	1	1	1.65	0.502	0.206	0.483
Within-Subjects Effect								
Within cells	417.4	587.25	37	37				
Task Complexity	162.4	51.74	1	1	14.40	3.26	**0.001***	0.079
Comm.Medium x Task Comp	67.6	25.42	1	1	5.99	1.6	**0.019***	0.214

Table H.4. T-test for comparison of task complexity (LC vs HC) between FTF and CM groups

	Levene's Test		T-test for Equality of Means						
	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% confidence interval of the difference	
								Lower	Upper
R-W LC	1.192	.282	-.179	37	.859	-.017	.095	-.210	.176
R-W HC	.221	.641	.573	37	.570	.052	.090	-.132	.235
DP LC	2.46	.125	-.182	37	.857	-.251	1.38	-3.06	2.56
DP HC	1.32	.257	2.25	37	**.030***	3.473	1.54	.356	6.59

Table H.5 T-test for comparison of task complexity variation (LC vs HC) within FTF and CM groups

				95% CI of the difference				
Paired LC - HC	Mean	SD	SEM	Lower	Upper	t	df	Sig (2-tailed)
R-W FTF	0.118	0.347	0.079	-0.048	0.285	1.486	18	0.155
R-W CM	0.187	0.302	0.067	0.046	0.328	2.77	19	**0.012***
DP FTF	-4.75	5.83	1.33	-7.56	-1.94	-3.54	18	**0.002***
DP CM	-1.02	3.41	0.76	-2.62	0.57	-1.34	19	0.196

Table H.6 T-test result of comparison of decision time between FTF and CMC conditions

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
AverageT	Equal variances assumed	.060	.808	.071	30	.944	.00858	.12114	-.32455	.34172
	Equal variances not assumed			.071	26.720	.944	.00858	.12008	-.32438	.34154
TotalTime	Equal variances assumed	.002	.965	.123	30	.903	.11725	.95618	-2.51225	2.74674

	Equal variances not assumed			.124	27.021	.902	.11725	.94447	-2.49942	2.73392
LCtime	Equal variances assumed	.027	.871	-.350	30	.729	-.17846	.51040	-1.58205	1.22512
	Equal variances not assumed			-.358	27.859	.723	-.17846	.49892	-1.55761	1.20069
HCtime	Equal variances assumed	.041	.841	.417	30	.679	.24713	.59208	-1.38110	1.87535
	Equal variances not assumed			.414	25.174	.682	.24713	.59708	-1.41625	1.91050

Table H.7 Group statistics of questionnaire data for FTF and CMC conditions

	Condition*	N	Mean	Std. Deviation	Std. Error Mean
OPSat	1	57	3.0351	1.28125	.16971
	2	60	3.1000	.91503	.11813
Cooperation	1	57	4.3509	.83434	.11051
	2	57	4.3246	.82641	.10946
MyEffort	1	57	4.4211	.70578	.09348
	2	57	4.4561	.68322	.09049
MyPerformanceImprove	1	57	3.5789	1.14872	.15215
	2	57	3.9123	.85106	.11273
GroupPerformanceImprove	1	57	3.7544	1.15389	.15284
	2	57	3.5965	1.01523	.13447
Stress	1	57	2.5263	1.10365	.14618
	2	57	2.7368	.99151	.13133

H.8 T-test result of comparison of questionnaire data between FTF and CMC groups

Test Statistics[a]

	OPSat	Cooperation	MyEffort	MyPerformanceImprove	GroupPerformanceImprove	Stress
Mann-Whitney U	1.698E3	1581.000	1.586E3	1393.000	1458.500	1.444E3
Wilcoxon W	3.350E3	3234.000	3.238E3	3046.000	3111.500	3.097E3
Z	-.072	-.272	-.249	-1.391	-.976	-1.062
Asymp. Sig. (2-tailed)	.943	.786	.804	.164	.329	.288

a. Grouping Variable: Condition

H.9. Observed and expected frequency for the relation between "preference of working in the same group" and type of communication

			PreferWorkSameGroup		
			Same	Different	Total
Condition	FTF	Count	45	12	57
		% within Condition	78.9%	21.1%	100.0%
	CM	Count	49	11	60
		% within Condition	81.7%	18.3%	100.0%
Total		Count	94	23	117
		% within Condition	80.3%	19.7%	100.0%

H-10. Chi-square results for the relation between "preference of working in the same group" and type of communication

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.137[a]	1	.711		
Continuity Correction[b]	.019	1	.891		
Likelihood Ratio	.137	1	.711		
Fisher's Exact Test				.817	.445

Linear-by-Linear Association	.136	1	.713			
N of Valid Cases[b]	117					

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 11.21.

b. Computed only for a 2x2 table

H.11. Observed and expected frequency for the relation between "presence of a leader" and type of communication

			Condition		Total
			FTF	CM	
LeaderPresence	Leader	Count	24	22	46
		% within LeaderPresence	52.2%	47.8%	100.0%
	NoLeader	Count	33	38	71
		% within LeaderPresence	46.5%	53.5%	100.0%
Total		Count	57	60	117
		% within LeaderPresence	48.7%	51.3%	100.0%

H.12. Chi-square results for the relation between "presence of a leader" and type of communication

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.362[a]	1	.547		
Continuity Correction[b]	.170	1	.680		
Likelihood Ratio	.362	1	.547		
Fisher's Exact Test				.575	.340
Linear-by-Linear Association	.359	1	.549		
N of Valid Cases[b]	117				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 22.41.

b. Computed only for a 2x2 table

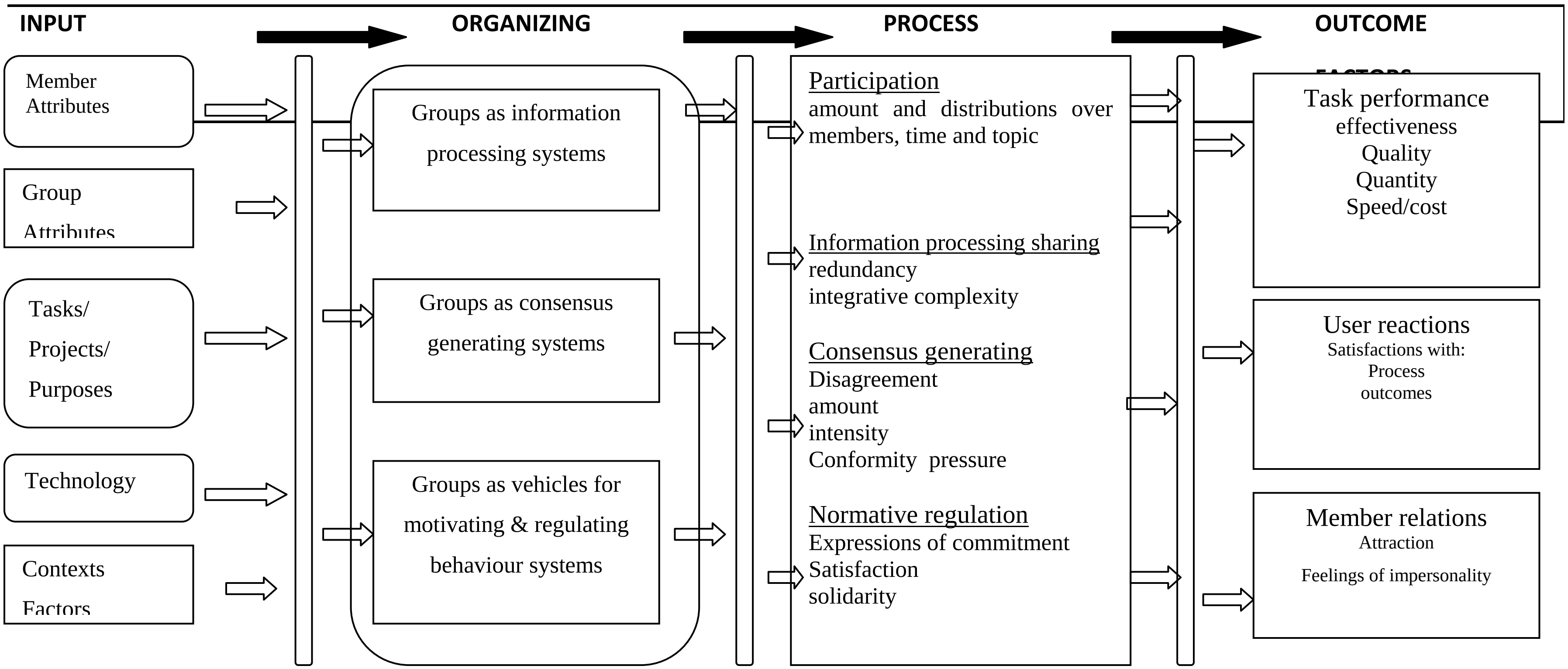
Appendix I Description of the innovative strategies

Group FTF	Description of strategy	Performance R-W	Performance Dev
16	*Station A:* adds all 1s,2s,3s,10s *Station B:* adds all 4s,5s,6s *Station C:* adds 7s,8s,9s	0 Best group: 0.875	126 Best group: 14
19	This group has three different strategies: ***First*** *Station A:* adds all under 10 *Station B:* adds all odds above 10 *Station C:* adds all even above 10 ***Second*** *Station A:* adds only the prime 15 *Station B:* adds all odds *Station C:* adds all evens ***Third*** *Station A:* adds all under 5 *Station B:* adds all even *Station C:* adds all odds	0.375	65

Group CMC	Description of strategy	Performance R-W	Performance Dev
5	1) *Station A*: Adds all *Station B*: Adds odds *Station C*: Adds even 2) *Station A:* adds 1 – 5 numbers *Station B*: adds 6 – 9 numbers *Station C:* adds 10 -19 numbers	0.375 Best group: 0.75	53 Best group: 4
7	*Station A:* adds all single even under 10 *Station B:* adds double digits *Station C:* adds all single odds under 10	0.375	17
11	*Station A:* adds numbers ending in 1-4 (1,2,3,4,11,12,13,14) *Station B:* adds numbers ending in 5 -7 (5,6,7,15,16,17) *Station C:* adds numbers ending in 8-10 (8,9,10,18,19)	0.625	41
13	*Station A: starts adding the units and when it becomes a ten, gives a signal to station B* *Station B: adds the tens and it becomes a hundred, gives signal to station C*	0.375	7.25

	Station C: adds the hundreds		
16	*Station A:* Adds numbers from 1 – 5 *Station B:* Adds numbers from 6 – 10 *Station C:* adds numbers from 11 - 19	0.25	52
19	*Station A:* adds numbers ending in 0,1,4,9 *Station B:* adds numbers ending in 2,5,8 *Station C:* adds numbers ending in 3,6,7 So that there is a chance that the persons will simplify the counting like this: 1's & 9's to 10, 2's & 8's to 10 and 3's & 7's to 10.	0.375	18

Appendix J A conceptual framework for studying the impact of technology on groups



McGrath, J and Hollingshead, A (1994) Groups interacting with technology SAGE publications

Appendix K Ashby's Law of Requisite of Variety (Cybernetics, 1956)

This section describes the concepts of variety, disturbances, and regulations; concepts used by Ashby in his law requisite of variety from the field of cybernetics. The field of cybernetics focuses on "the science of control and communication, in the animal and the machine" (Wiener, 1948). Cybernetics is also seen as a powerful concept because it has been able to explain a diverse set of complex situations in different fields (i.e., biology, management, mathematics, computer science, psychology, etc). This power is mainly due to its peculiar attribute of explaining complex systems by using a simple (economical) language approach. The law of requisite of variety uses the concept of "variety" very closely from that of "information".

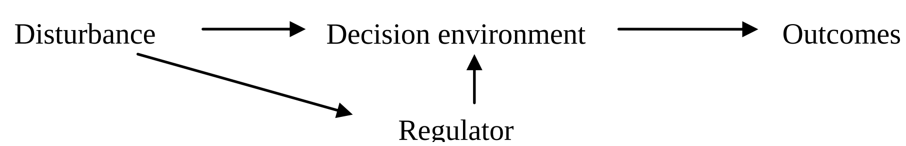
Variety is defined as the number of distinct element in a set – the set of possible outcomes within some defined situation. Scala *et al*., (1996) bring a simple but practical example to explain this concept:

> "The task of issuing license plates, each of which has six numeric characters. The set of all possible plates that can be produced has a variety of one million $(10)^6$. Consequently, at most, one million vehicles can be license, if each plate is limited to six numeric characters. In practice, however, it is important to recognize that this overall measure of variety may not reflect the amount of variety at the task level. That is, the objectives of the task and the process by which the task are conducted determine the relevant variety to be dealt with. For instance, assume that before the local office distributes plates to vehicle owners, it is decided that the plates are to be sorted into piles based on the colour of the plate as well as the first letter appearing on the plate. If five colours are available, and these are independent of the letters, then the variety that the sorter must contend with is 130 (5 x 26= 130). If instead the plates are to be sorted based solely on colour, then the variety drops to 5. Thus, the variety that must be dealt with has changed, although the plates themselves have remained the same. To respond to the variety in the environment and, hence, to control the outcome, a system requires, what Ashby calls, a "regulator".

Regulator is defined in terms of disturbances, responses and outcomes (as well as the variety in each of these sets). Ashby (1956) states that "There is fist a set of disturbances, that start in the world outside the organism, often far from it, and that threatens, if the regulator does nothing, to drive the essential [outcomes] outside their proper range of values. Of all these [outcomes] only a few are compatible with the organism's life, or are unobjectionable, so that the regulator, to be successful, must take its value in a way so related to that of disturbance of the outcome is, if possible, always within the acceptable set [desired]"(209)[13]. To continue with the Scala *et al*.' example, the law of regulation can be described as follows:

> "If 200 million vehicles fall under the licensing agency's jurisdiction, then this number represents the variety in demand, or in Ashby's terminology, the variety in disturbance. However, it was previously determined that the variety in response when using only numeric characters is limited to one million. Hence, the varieties are unbalanced and control is unobtainable. Variety in outcome results; in this case, the variety takes the form of some vehicles with plates, many more without. To rectify this problem, the agency may decide to use alphabetic characters for its plates. With this change, the variety in response exceeds 300 million ($(26)^{6}$= 3.089 x 10^{8}) and, thus, requisite variety is achieved. That is, Ashby's Law of Requisite Variety has been fulfilled since the variety in disturbance has been absorbed by the variety in the response set."

The general picture of this law is:



Application of Ashby's Laws in organizations[14]

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[13] The analogy for the regulator is the function of a central air conditioning system of a building. It faces a set of disturbances as a result of changes in the outdoor temperature and wind conditions, the number of occupants, and the operation of heat-generating equipment. The action taken by the air conditioner, its response to a disturbance, will determine the outcome. Several outcomes are possible; each represents a distinct indoor temperature and humidity combination. The ideal air conditioner would be one that dynamically maintains these outcome variables at a desired level, in spite of fluctuations within the set of disturbances. In essence, it reduces the variety in outcome to one: the desired state. Thus, an effective regulator blocks the flow of variety from disturbances to outcomes. The amount of regulation that can be achieved has an upper limit specified by Ashby's Law of Requisite Variety – only variety in the regulator can force down the variety due to the disturbance; only variety can destroy or absorb variety.

[14] The following examples were taken from the lectures notes and discussions in the Msci 605 (Organizational theory and behavior) Fall 2007

There have been some applications of Ashby's law of requisite variety in the organizational context. The following are general examples of this:

- ***Coupling in organizations***

Internal vs. external: The coupling happens inside and outside the organization. For example, if you are coupling design and manufacturing, the question is if manufacturing has sufficient requisite of variety to handle what design does. This situation does not usually happen. (e.g., with the introduction of CAD, design has a huge amount of variety that manufacturing couldn't handle this variety.). However, the common situation in organizations is that instead of trying to match this variety instead, the relationship between these two highly interdependent departments starts to be affected by the bad feelings arisen from this mismatch of variety, manufacturing people start to have bad opinion of the design people and vice versa.

Measure of effectiveness: Variety can be used as an effective measure because every time there is a mismatching variety in the system, it is a sign that something wrong is happening in the system.

- ***Job design***

Variety matching. When there is mismatch of variety, people start developing bad feelings towards those from which the variety is being generated. The same situation can even happen is there is low variety, people start feeling not satisfied with what they are doing (e.g., long routine tasks). The human system has optimal level of variety, it needs to be balanced. The variety needs to be just right what is natural for people to have it.

- ***Information system***

Personal data base: There was a research that investigated the design of personal data bases. In the experimental setting, participants were given some proverbs to categorize. They were told the situation of that they were working for a newspaper and the editor would come and ask for queries for some of these proverbs. The nature of these queries was intense in terms of their variability, some of participants were asked to match the right word that appears in the query itself, other participants were asked to relate them to a broader category. For example, a question from the editor was: "I am writing an article about education, can you come up with a good proverb for this topic". Then, the participants categorized the information in order to create a data base that responds to the queries requested. Consequently, the way the participants categorized the information was the following:

When the information was ambiguous, the participants organized it according to meaning since there is not objective properties in the use of these proverbs that can allow retrieving them. On this situation, the categorization occurred in a higher level (e.g., for the case of education, the categorization was: learning, knowledge, etc).
In this situation, the underlying process of categorization is related to the match of variety originated by the queries. If the variety increases, as the case of more ambiguous items are introduced, the way the system operates so that the ambiguous variety can be handled was on developing categories based on meaning, the more abstract the information is, the more higher the level of organization of the information will be.

- ***Just- in- time manufacturing***

What is inventory?

If the inventory level is low, what does it mean to the organization..? What truly inventory does in the system is to provide a nice variety in the system. (e.g., if you have a raw material inventory and you suppliers give you the wrong material, they are late, or etc. This situation does not affect your organization, because there is a optimal level of inventory to keep the production going. In this manner, inventory handles the variety generated by the suppliers. The inventory works even to handle the variety from customers (e.g. variety the cars, then the customer can pick whatever he wants)
Then the question is: what are the implications for the organization when the inventory is reduced?

Japanese industries opted for different regulator in the system. The way these industries reduce the variety, either external (supplier's variety) or internal (production's variety), is to select reliable and constant suppliers that assure the shipments will be on time always. For internal variety, these industries is to schedule the production based on the shipments so that low levels of inventory are kept in the plant as well as to have multifunctional workers in case a worker does not show up the variety can be handled by other workers. These regulations offer a better coordination and communication mechanisms to achieve desired outcomes in the organizations.