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Decision Support Systems 44 (2007) 175 – 187

Decision Support Systems

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Media naturalness and compensatory encoding: The burden of electronic media obstacles is on senders

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Received 26 March 2007; accepted 26 March 2007
Available online 31 March 2007

Abstract

Compensatory adaptation theory makes two key predictions. On one hand, the theory predicts that electronic communication media in general will pose obstacles to complex communication between collaborators, when compared with the face-to-face medium, which will lead to an increase in cognitive effort and communication ambiguity. On the other hand, the theory also predicts that those obstacles will be met with compensatory adaptation, whereby electronic communication users will attempt to make up for the obstacles by modifying their communication behavior. This will in turn lead to a reduction in communication fluency. This study extends compensatory adaptation theory by also predicting that the burden of compensating for electronic communication media obstacles will fall primarily on those who attempt to convey information, as opposed to those who receive it. Those predictions are tested through an experiment involving 230 students, whose data are analyzed through nonparametric tests. All predictions are supported by the data analysis results. The use of a Web-based quasi-synchronous electronic communication medium, when compared with the face-to-face medium, increased perceived cognitive effort by approximately 12% and perceived communication ambiguity by about 19%. Communication fluency was reduced by about 90%. Perceived compensatory encoding effort (i.e., the effort spent by information givers) was increased by approximately 26%, and perceived compensatory decoding effort (i.e., the information receivers' effort) by a statistically insignificant percentage.

Keywords: Human factors; Electronic communication; Communication media; Computer-mediated communication; Biological influences; Compensatory adaptation

1. Introduction

Research on electronic communication (EC) issues has a long history, arguably dating back to the 1970s [3,24,53]. The emergence of what some refer to as the "digital economy", where many products and services are traded electronically, has led to a renewed interest in behavioral issues in connection with EC [23,31].

The issue of whether an EC medium creates or removes obstacles for successful communication, when compared with the face-to-face (FtF) medium, has been perhaps one of the central issues around which EC research has gravitated. While it has been both argued and empirically demonstrated that EC media create obstacles for successful communication [11,22,29,53], there also is a substantial amount of evidence that the

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doi:10.1016/j.dss.2007.03.011

impact of those obstacles on media choice and task outcomes is uncertain [13,17,43].

Some have argued that EC media may both create and remove obstacles to successful communication at the same time, an argument that has been incorporated into several theoretical frameworks, notably the gains and losses model [45]. This view is consistent with the fact that even though EC media suppress elements found in FtF communication, technologies that create EC media are widely used today for communication in both organizations and society in general.

While the above-mentioned view does not deny the existence of obstacles, it is well aligned with the notion that, in spite of the obstacles that they pose to communication, EC tools may remove key constraints to successful communication [59]. For example, the support for asynchronous communication provided by technologies like e-mail is seen as also creating obstacles to quick exchange of ideas [22]. Support for asynchronous communication is nevertheless a feature that is advantageous in the context of geographically distributed groups of collaborators [63].

There is also evidence that even though EC media create obstacles for successful communication, media users invariable react by attempting to compensate for those obstacles, often successfully [15,32]. Those compensatory adaptation attempts have been presented as a key reason why electronic media obstacles have led to uncertain results in terms of task outcomes. Kock [33,36] has developed this perspective into a theoretical framework called compensatory adaptation theory (CAT).

Other theoretical frameworks have been put forth with similar arguments, even if not as directly and with the same emphasis as CAT. Such frameworks date back to the 1970s, when the proponents of the social presence model already hinted at compensatory adaptation in connection with communication media of low social presence: "… aware of the reduced-cue situation, the actor will modify his behavior; thus head-nods indicating agreement may be replace by verbal phrases such as 'I quite agree'" [53, p. 64]. More recently, the proponents of channel expansion theory [9] have argued that the repetitive use of a communication medium to accomplish a particular task is likely to lead over time to that medium being perceived as "richer" than before. That takes place as the medium's users adapt to what they perceive as the medium's initial lack of richness, an argument analogous to CAT's compensatory adaptation contention.

CAT incorporates ideas that reflect Darwinian perspectives of behavior toward electronic communication tools, and is especially rooted in ideas developed within the field of evolutionary psychology [4,7,58]. Other theoretical frameworks and related studies have been published that also address issues in connection with electronic communication behavior from an evolutionary psychological perspective. Notable examples exist in the areas of electronic consumer behavior [50,55], virtual team leadership [15], electronic user interface design [27], and information search and use behavior [56].

It has been shown that CAT makes predictions that are consistent with a large body of literature, explaining findings that have previously been seen as contradictory [36]. However, the theory in its current form does not make normative predictions about the underlying phenomenon of compensatory adaptation. As it is now, CAT fails to provide a basis for the development of EC tools that facilitate compensatory adaptation.

This paper takes a solid step in the direction of correcting the above shortcoming by extending CAT so that it makes predictions regarding differentials in compensatory adaptation efforts between those who convey and receive information, referred to here as "encoders" and "decoders", respectively. It seems, from the findings of this study, that EC tools should be designed to facilitate compensatory adaptation by encoders, because they are the ones on which the burden of compensating for electronic media obstacles seems to fall more heavily. The study also assesses the basic tenets of CAT, and finds support for them.

2. Media naturalness and compensatory adaptation

CAT is founded on the notion that different communication media present different levels of an attribute called "naturalness" [33,36]. The term naturalness comes from the idea that our brain is naturally designed for FtF communication, because the Darwinian forces that shaped the human brain operated largely during a time period in which other forms of communication were absent [35]. The first forms of writing emerged about 5000 years ago among the Sumerians [41,44]. That 5000-year period can be seen as a "blink in a lifetime" in evolutionary terms, and most likely too short to have significantly shaped our brain design away from FtF communication and toward text-based communication. Moreover, writing was originally developed as a record-keeping solution, and not as a tool used primarily for communicating information. The latter use is arguably much more recent.

A fundamental argument made by CAT is that the degree of naturalness of a communication medium depends on how closely it incorporates all of the elements found in the FtF communication medium. In this sense, most EC media will present lower degrees of naturalness than the FtF medium, because they tend to selectively suppress elements found in FtF communication — e.g., the use of oral speech and facial expressions to convey ideas.

The selective suppression of FtF communication elements by EC media is often based on utilitarian reasons. For example, electronic text is much more widely used in computer-mediated communication than temporal files such as audio and video clips. This creates compatibility problems for the use of audio or video files for communication, since the number users capable of creating and viewing those files is smaller. Moreover, electronic text is more easily searchable than temporal files such as audio and video clips, which makes electronic text a more desirable choice for organizational communication in general.

Given the above, it is no surprise that a variety of text-based EC media, such as e-mail and instant messaging, are routinely used to accomplish collaborative tasks in organizations. In such task-related contexts, a decrease in the degree of naturalness of a communication medium is expected to cause an increase in the amount of cognitive effort experienced by the individuals engaged in the collaborative task. That is, the less natural (or FtF-like) a communication medium is, then the more cognitive (or mental) effort is needed to effectively use the medium for communication. This increase in cognitive effort is a direct result of our brain being naturally designed for FtF communication.

Cognitive psychology studies dating back to Bartlett's [5] studies of memory have shown that, in the absence of communicative stimuli, individuals tend to "fill in the blanks" based on their existing knowledge bases (see also [21]). Since different individuals have different knowledge bases, their "filling in the blanks" is likely to lead to different conclusions based on available communicative stimuli. Let us take for example a comment like this: "You are certainly wrong John". Such comment provided to someone in a FtF meeting, together with a smile and some "positive" body language, may be interpreted completely differently than if it were provided to someone via e-mail.

The above discussion has led to another of CAT's fundamental predictions. That prediction is that a decrease in the degree of naturalness of a communication medium is expected to cause an increase in the amount of communication ambiguity experienced by individuals engaged in a collaborative task through the medium. That is, the likelihood that communicative stimuli will be misinterpreted when EC media are used is higher than in FtF communication.

Increases in cognitive effort and communication ambiguity are usually accompanied by an interesting behavioral phenomenon, according to CAT. That phenomenon is called "compensatory adaptation", and is characterized by voluntary and involuntary attempts by the individuals involved in a communicative act to compensate for the obstacles posed by the unnatural medium. One of the key indications put forth to support the compensatory adaptation hypothesis is a decrease in communication fluency, or the number of words conveyed per minute through a communication medium. That is, communication fluency is believed to go down as a result of individuals making an effort to adapt their behavior in a compensatory way.

CAT is a relatively new theory, and thus has not been widely tested. Kock [36] has recently tested the theory in the context of a field study of a small number of managers and engineers at a large defense contractor. According to that study, which employed a repeated-measures design where all participants used two communication media (EC and FtF) to perform two similar complex tasks, EC media use caused several effects. Among those effects, it increased perceived cognitive effort by 41% and perceived communication ambiguity by 80%. The field study also found that EC use reduced actual fluency by 77%. Not only do these findings provide support for CAT, but also suggest that the magnitude of the predicted effects is relatively large.

3. Compensatory encoding and decoding

How do EC media users compensate for the obstacles caused by the suppression of FtF communication elements? Two possible answers to this question could be: (a) by trying to "encode" information in such a way as to make up for the absence of communicative stimuli; and (b) by "filling in the blanks", in the sense discussed in the previous section, and thus improving their "decoding" of messages. The first is related to what will be referred to here as the increased "compensatory encoding effort" solution; and the second to what will be referred to as the increased "compensatory decoding effort" solution.

One can see relatively easily how compensatory encoding could take place by looking at research on how communicative behavior differs in EC and FtF media. As early as the 1970s, Short et al. [53] already pointed out that telephone communication presents a significantly higher presence of verbal expressions of agreement and disagreement than FtF communication, which they interpreted as compensating for the suppression of non-verbal cues of agreement and disagreement (e.g., head nods). Walther [62] showed that individuals with significantly different cultural backgrounds exchange more personal information (including information about their physical appearance) when communicating electronically than they do FtF; something that he refers to as hyperpersonal communication (see also [61]). Burke and Chidambaram [6] and Majchrzak et al. [39] make similar points based on data from groups performing complex tasks. Ulijn et al. [60] argue that the reduction in non-verbal cues associated with EC, particularly among individuals from different national cultures, drives the compensatory use of what the authors refer to as "meta-languages". Those meta-languages are characterized by a higher frequency of use of certain grammatical constructions, such as sentences employing first-person pronouns.

Not as clear is how compensatory decoding can take place. The key problem here is that while attempting to compensate for missing communicative stimuli by "filling in the blanks", it is reasonable to assume that decoders are likely to make attributive and interpretive errors. For example, they may interpret constructive criticism as a personal attack, which may in turn lead to an EC medium phenomenon called "flaming" [1,40].

The above conclusion is at the source of CAT's prediction that a reduction in media naturalness is likely to lead to increased communication ambiguity [36]. In other words, successful compensatory decoding would seem to require information elicitation abilities that human beings likely do not have (e.g., extra-sensorial or telepathic abilities), if taking place in the absence of compensatory encoding (see, e.g., [36]). According to this view, compensatory encoding would be a significantly more important source of compensatory adaptation than compensatory decoding.

4. Hypotheses

Underlying CAT is the notion that evolutionary forces have designed our brain primarily for FtF communication. As a corollary, it can be concluded that the selective suppression of FtF communication elements is likely to lead to increased cognitive effort [35,36], as we mentally adapt to a less natural communication medium than the one used during the millions of years that led to our brain's evolution [10,48]. Generally speaking, the vast majority of EC media will suppress FtF communication elements; e.g., even a high-quality teleconferencing suite cannot fully duplicate the experience of communicating FtF, and all the cues exchanged therein. This leads to hypothesis H1 below.

H1. The use of an EC medium by pairs will significantly increase the level of cognitive effort experienced by the members of the pairs.

The selective suppression of communicative stimuli present in the FtF communication medium is also likely to lead to other effects, in addition to an increase in cognitive effort. Notably, in the absence of communicative stimuli individuals generally try to "fill in the blanks" based on their own contextualized knowledge [48,52]. And, most people's contextualized knowledge will be different from that possessed by other people, because all human beings (even identical twins) go through different experiences and acquire different knowledge bases during their lifetimes.

Thus, it is reasonable to expect the suppression of FtF communication stimuli to lead to higher levels of communication ambiguity (and thus communication misunderstandings), as different individuals fill in the gaps caused by the suppression of communicative stimuli in different ways. This leads to hypothesis H2 below.

H2. The use of an EC medium by pairs will significantly increase the level of communication ambiguity experienced by the members of the pairs.

One of the fundamental predictions of CAT is that the communication obstacles posed by an EC medium will lead to compensatory adaptation, where users of the EC medium will attempt to overcome its limitations. Past research on behavioral EC media effects has shown that high levels of cognitive effort are often reflected in a reduction in the speed with which tasks are accomplished (see, e.g., [38]). It is reasonable to argue that this reduction in speed is associated with compensatory adaptation; that is, if the previous speed were to be maintained, task outcome quality would arguably suffer substantially. EC media users are apparently aware of this, often subconsciously, which frequently leads to involuntary compensation. That is, as individuals compensate for obstacles, they may not be consciously aware of their compensatory adaptive behavior [32,60].

Communication fluency, as defined earlier, is essentially a measure of the speed with which words are communicated through a particular medium. Therefore, one would expect the use of an EC medium to reduce communication fluency, in comparison with the FtF medium. However, it is important to qualify this prediction to account for the purely "mechanical" reduction in communication fluency that is to be expected when any EC medium that requires typing through a keyboard is used [14].

Kock [36] has dubbed the above-mentioned "mechanical" effect the "typing-versus-speaking" (TvS) effect. He has also built on empirical data and reviews of previous literature on typing speeds (see, e.g., [42]) to conclude that the TvS effect usually accounts for FtF-to-EC medium communication fluency reductions of no more than 50%. Within that 50% reduction band, variations seem to occur depending on the features of the EC medium used and collaborative task characteristics. This and the discussion in the paragraphs above provide the basis for the formulation of hypothesis H3, which is shown below.

H3. The use of an EC medium by pairs will significantly decrease the fluency displayed by the members of the pairs beyond what would be expected due to the TvS effect.

Much of the past empirical research on the use of EC media and its effects suggests that the communication obstacles posed by EC media are likely to be met with a form of compensatory adaptation that is referred to here as compensatory encoding. This form of compensatory adaptation refers to attempts to encode information in such a way as to make up for an EC medium's suppression of important FtF communicative stimuli. Some examples of compensatory encoding are provided by Majchrzak et al. [39], Short et al. [53], Ulijn et al. [60] and Walther [61,62]. Hypothesis H4 below provides a formal enunciation of a prediction that is aligned with this conclusion.

H4. The use of an EC medium by pairs will significantly increase the level of compensatory encoding effort experienced by the members of the pairs.

While CAT makes no predictions in connection with differences in compensatory encoding and decoding, it is difficult to see how compensatory decoding can be successful without being accompanied by compensatory encoding. For example, making up for the absence of certain forms of non-verbal FtF communicative stimuli (e.g., a smile), without corresponding verbal elements (e.g., a verbal indication that a joke is being made), would arguably be impossible for human beings in the absence of extra-sensorial or telepathic abilities [26]. If compensatory encoding is unconstrained, CAT suggests that EC medium users will likely engage in it [32,33,36]. In this case, compensatory decoding is likely to require relatively little effort from EC medium users. This is formalized through hypothesis H5 below.

H5. The use of an EC medium by pairs will have an insignificant effect on the level of compensatory decoding effort experienced by the members of the pairs.

As a whole, the above hypotheses form a framework that both allows for a valid test of CAT and that also extends CAT in a meaningful way. The framework incorporates predictions based on CAT's original formulation, through hypotheses H1–H3. It also incorporates predictions that expand CAT to address possible differences associated with compensatory encoding and decoding, through hypotheses H4 and H5. Finally, it is important to note that both hypotheses H4 and H5 are compatible with CAT's original formulation, as they both refer to the underlying compensatory adaptation phenomenon.

5. Research method

5.1. Experimental design

Data collected from 230 undergraduate and graduate business students were used in this study. The setting where data collection took place was a large public university in Northeastern US. At the time of the study, those students were enrolled in 12 different course sections, 11 of which were undergraduate sections. The students' ages ranged from 18 to 46, with a mean age of 24. Fifty-four percent of the students were males.

Students from a given section were randomly assigned to pairs and to one of two communication media conditions — EC or FtF. Each pair was asked to complete the same two-stage business process modeling and redesign task developed and used by Kock [36]. Students participated in a 20-minute training session on business process modeling and redesign, and were subsequently given 40 min to complete the task. The task entailed generating a model of a software acquisition business process, redesigning the process, and then generating a model (in diagrammatic form) of the redesigned process. The participants were not allowed to exchange diagrams, nor see each other's diagrams during the task. Only verbal communication was allowed, in either written (electronic) or oral interactions.

No student pair completed the task in less than the allotted time — i.e., 40 min. Student pairs completed the task based on instructions and business process guidelines provided in writing to them. Each member of the pair received complementary instructions and guidelines. Without each other's instructions and guidelines, no student could successfully complete the task.

The EC medium was implemented through a Web-based conferencing site, built with active server pages technology [18,28]. Each pair of students assigned to the EC condition participated in a multi-threaded text-based EC discussion. The EC discussions were conducted in a quasi-synchronous manner; the Web-based conferencing site was "refreshed" at short time intervals. One Web-based online discussion board was created for each pair of students and used for the completion of the experimental task.

5.2. Measures and analysis

The goal of this study was to investigate the effect of one main independent construct, namely the communication medium, on a series of dependent constructs. As discussed above, the main independent construct was categorical, and distinguished between two communication conditions — EC or FtF. The dependent constructs were cognitive effort, communication ambiguity, communication fluency, compensatory encoding effort, and compensatory decoding effort.

The cognitive effort and communication ambiguity constructs were measured through single indicators taken from the instrument developed and validated by Kock [36]. The communication fluency construct was also measured as suggested by Kock [36], namely through the ratio between the number of words exchanged by each pair, and the time that each pair took to complete the task (40 min for all pairs).

New measures were developed for the constructs compensatory encoding effort and compensatory decoding effort, under the assumption that they are reflectively associated with the underlying “compensatory adaptation effort” construct. Those measures, as well as the measures used for other constructs, are shown in the Appendix together with the scales used (mostly Likert-type scales). A factor analysis employing Varimax rotation suggested that the measures for those constructs loaded well on the underlying construct (i.e., compensatory adaptation effort); with loadings of .872 and .811 for compensatory encoding and decoding effort, respectively. Cross-loadings with other constructs were all below .228. Finally, the Cronbach alpha coefficient [51] for the underlying construct was .702, which suggests an acceptable level of reliability [46] associated with the component measures for compensatory encoding and decoding effort.

The inferential analysis aimed at testing the hypotheses relied on comparisons of means using a nonparametric technique, namely the Mann–Whitney *U* test. This test does not rely on assumptions of measurement normality, nor does it require the use of a fully experimental design. Such design would require that the individuals of each pair be selected randomly from the entire participant population. In our experimental design, each pair was selected randomly from a subsection of the participant population, namely a course section. However, each course section cannot be seen as randomly assembled. Thus, the use of a nonparametric comparison of means technique (i.e., Mann–Whitney *U* test) was seen as more advisable than the use of a parametric technique (e.g., ANOVA). Siegel and Castellan [54] provide more details on nonparametric analysis techniques and recommendations on their use.

Comparisons of means are widely used in experimental research [51]. In other research approaches, such as survey research, the effects of factors other than the experimental control can be factored out of the results by those factors being included in inferential models (e.g., multiple regression, or structural equation models) as control variables. In experimental research, the effects of other factors that might impact the dependent variables are normally controlled for by randomly assigning individual participants to each of the conditions that characterize the experimental treatment. This latter approach was the one employed in this study, by the members of each pair being selected randomly within each subsection (i.e., course section) of the population, and also being randomly assigned to each of the two experimental conditions.

6. Results

Table 1 summarizes the inferential analysis in connection with the five constructs discussed above, which are referred to in each of the hypotheses previously formulated. The columns labeled “Mean FtF” and “Mean EC” show the means for each construct — for the FtF and EC conditions, respectively. The columns labeled “SD FtF” and “SD EC” show the

Table 1
Descriptive and inferential statistics

	Mean FtF	SD FtF	Mean EC	SD EC	*Z*	*P*	ESV	ESM
Cognitive effort	71.56	27.47	79.97	23.30	2.50	<.05	0.33	medium
Communication ambiguity	3.55	1.68	4.24	1.75	2.36	<.05	0.40	medium
Communication fluency	74.24	8.86	6.38	4.25	4.43	<.01	4.42	large
Compensatory encoding effort	3.11	1.62	3.90	1.96	2.55	<.05	0.44	medium
Compensatory decoding effort	3.51	1.62	3.69	1.95	0.46	.65	0.10	small

SD = Standard deviation; FtF = face-to-face communication condition; EC = electronic communication condition; *Z* = *Z* score from Mann–Whitney *U* test; *P* = chance probability associated with *Z* score; ESV = effect size value; ESM effect size magnitude.

standard deviations for each construct — again for the FtF and EC conditions, respectively.

The column labeled "*Z*" shows the *Z* scores generated by the Mann–Whitney *U* test comparing the means for the FtF and EC conditions in connection with each construct. The column labeled "*P*" shows the chance probability associated with each *Z* score, which is interpreted as the statistical significance of the effect leading to the difference between means observed in the FtF and EC conditions. Values lower than .05 are seen as significant, and suggesting a chance probability of less than 5%.

The columns labeled "ESV" and "ESM" show the effect size values and magnitudes, respectively, associated with the differences between means. Effect size values (ESV's) were calculated by subtracting the means and dividing the result by the pooled standard deviation [51]. The pooled standard deviation is the root mean square of the standard deviations associated with each of the conditions. ESV's lower than .3 are indicated in the "ESM" column as "small", equal to or greater than .3 but lower than .8 as "medium", and equal to or greater than .8 as "large".

Table 1 suggests that the cognitive effort experienced by the members of the pairs was significantly higher ($P<.05$) in the EC condition (Mean EC=79.97) than in the FtF condition (Mean FtF=71.56), and that perceived communication ambiguity was also significantly higher ($P<.05$) in the EC condition (4.24 vs. 3.55). These results provide general support for hypotheses H1 and H2, respectively.

The results shown in Table 1 also suggest that communication fluency was significantly lower ($P<.01$) in the EC condition (Mean EC=6.38) than in the FtF condition (Mean FtF=74.24). The TvS effect was controlled for by adjusting the communication fluency values in the FtF condition prior to conducting the Mann–Whitney *U* test.

The TvS effect would explain a reduction in fluency in the EC condition, compared with the FtF condition, of no more than half the FtF fluency. That is, one could reasonably expect fluency to go down to about half of 74.24 (approximately 37 words per min), due to the TvS effect. The EC fluency of 6.38 words per min is much lower than that, which provides general support for hypothesis H3.

The results in Table 1 suggest that perceived compensatory encoding effort was significantly higher ($P<.05$) in the EC condition (Mean EC=3.90) than in the FtF condition (Mean FtF=3.11), providing general support for hypothesis H4. Finally, those results suggest that there was a difference in perceived compensatory decoding effort between the EC condition (Mean EC=3.69) and the FtF condition (Mean FtF=3.51), but that the difference was too small to be considered significant ($P=.65$). This latter result provides general support for hypothesis H5.

Table 1 also indicates, through the columns labeled "ESV" and "ESM", that the effect sizes associated with the differences between means for the statistically significant effects (i.e., for all variables except compensatory decoding effort) were either medium (ESV>.3) or large (ESV>.8). Effect size magnitudes were medium for cognitive effort, communication ambiguity, and compensatory encoding effort. The effect size was large for communication fluency.

7. Discussion

In spite of the fact that successful compensatory decoding seems to require information elicitation abilities that human beings likely do not have (e.g., extra-sensorial or telepathic abilities), if taking place in the absence of compensatory encoding, the original formulation of CAT makes no mention of the possible compensatory effort difference that may exist between encoders and decoders. That is, those who convey information and those who receive it have been originally treated by CAT as spending the same amount of communicative effort. This is problematic, due to at least one key reason. If one is to design EC technologies so as to make compensatory adaptation easier, it is important to understand the underlying nature of the phenomenon, including whom (i.e., encoder or decoder) to target — since he or she is really the one responsible for most of the compensatory adaptation effort. This study corrects this problem.

According to this study's findings, the use of an EC medium by pairs of individuals performing a complex task, when compared with the FtF medium, increased perceived cognitive effort by approximately 12% and perceived communication ambiguity by about 19%. The use of an EC medium by the pairs reduced actual fluency by about 90%. Perceived compensatory encoding effort was increased by approximately 26%. Perceived compensatory decoding effort was increased by about 5%, which is a statistically insignificant variation. This latter statistically insignificant variation is not due to sample size or measurement reliability problems (as noted earlier). The sample is of appropriate size for the test employed in this study [54], and the measurement instrument seems to be reliable based on previous validations and the additional validation tests performed in this study [36]. Also, the lack of statistical significance is consistent with the small effect size value of 0.10 associated with the variation. These results provide general support for CAT in its original form, as well as in the expanded form presented here — the latter is the recommended version to be used as a basis for future tests, expansions, and refinements of the theory.

The findings from this study are generally consistent with the findings from a previous study that served as a basis for the development of CAT [32], as well as studies aimed at testing the theory [12,33,36]. The findings from this study are qualitatively identical to previous studies' findings regarding perception measures (e.g., perceived cognitive effort, communication ambiguity etc.). A rather striking similarity, in absolute terms, was that in connection with communication fluency. This study and Kock's [33,36] studies suggest a reduction in communication fluency due to the use of an EC medium of between 77% and 95%.

The communication fluency through the Web-based quasi-synchronous EC medium used in this study was found to be approximately 6.4 words per min. Communication fluency was found to be 16.6 words per min in Kock's [36] study, which employed a very similar EC medium, but whose subjects were managers and professionals studied in their own organization. In Kock's [33] study, where the EC medium was implemented through e-mail, the EC medium communication fluency was found to be 5.9 words per min. Other studies suggest similar findings. In DeLuca's [12] study, using an asynchronous listserv-based EC medium, the communication fluency was found to be 4.8 words per min. These figures are all consistent with the notion that EC media use tends to have a drastic impact on communication fluency.

It is useful to understand what the above reduction in communication fluency means from a practical perspective. Let us consider the situation in which two individuals need to exchange a certain number of ideas, and assume that it would take about 10 min for them to do that FtF. Let us also consider a communication fluency reduction of 80%. One can thus conclude that those two individuals would have to spend approximately 50 min interacting through an EC medium – five times more than they would have to spend FtF – to exchange the same number of ideas.

This study suggests that the difference in compensatory effort, which is reflected in the reduction in communication fluency, would be primarily on the side of the information givers. That is, the individuals trying to convey information, instead of the ones receiving it. In the extreme case of only one individual of a pair conveying information, and the other only receiving it, the findings of this study would enable us to speculate that the split would be approximately 40 min for the former (i.e., the information giver), and 10 min for the latter (i.e., the receiver). That is, there would be little extra cost, in terms of time spent, from the information receiver's perspective, at the expense of the information giver. In fact, this could make the use of an EC medium attractive for the receiver, since other losses such as disruption of normal activities or need to walk to someone's office would be mitigated.

In a nutshell, whenever the amount of information giving and receiving is unbalanced, communicating electronically becomes a problem for the information giver. And this is likely to be the case in many practical communication interactions, since it is reasonable to believe that only rarely information giving and receiving will be perfectly balanced. Let us take the example of two individuals: John, a mechanical engineer, and Mary, a production manager. John and Mary need to discuss changes in the shop floor of a factory; the changes are needed to produce a newly designed product. Let us also assume that John, the mechanical engineer, designed the new product. Because of that, John needs to convey about 10 key ideas about the design of the product to Mary, whereas Mary needs to convey 5 key ideas to John regarding production issues.

If John and Mary need a 3-hour meeting to reach a consensus FtF, the corresponding amount of time interacting through an EC medium similar to the one employed in this study would arguably be much higher, in the order of 15 h. Given the higher number of ideas that John would have to convey, he would spend about 8 h writing his electronic messages, whereas Mary would spend 4 h writing her messages. This makes the reasonable assumption that the "sending time" is of little significance — e.g., the time needed to click on the "send" button of an e-mail system.

Since John receives about half as many ideas as Mary, he would spend approximately 1 h reading electronic messages, whereas Mary would spend 2 h reading. Therefore, the total balance of hours spent reading and writing electronic messages would be 9 h for John, and 6 h for Mary. Compared with 3 h interacting FtF, this is bad for both John and Mary; but worse for John, who will end up spending a lot more time (three times more, to be precise) interacting through the EC medium than he would FtF.

One can build a "what-if" table that would give a general idea of the threshold, in terms of balance between information giving and receiving, beyond which it would be more costly for the main information giver to conduct discussions electronically. This is suggested as future research because it needs to take into account a number of task-related and contextual characteristics, including the geographical distribution of the communicators and the features of the EC medium used.

Costs associated with the geographical separation between communicators may significantly outweigh the costs stemming from communication fluency reduction. Nevertheless, this study seems to provide support for the general notion that the burden to cope with EC media obstacles falls mostly on the information givers' shoulders, especially when the suppression of FtF communication elements is substantial. This is usually the case with the ubiquitous text-based EC tools used today in organizations and society as a whole, such as e-mail and instant messaging tools.

8. Research limitations

One of the limitations of this study is the use of single measures for two of the perception-based constructs, namely cognitive effort and communication ambiguity. Those single measures have been previously validated through the test–retest method [51]. The test–retest method entails the following steps. The first step is to administer a questionnaire to a sample of respondents, under certain environmental conditions. Then, after a certain amount of time has passed (e.g., 2 weeks), the questionnaire is administered again, under the same environmental conditions.

The time lag between the two administrations of the questionnaire in the test–retest method must be long enough to ensure that the respondents cannot remember their previous answers. The answers are then correlated using a coefficient of stability such as Cronbach's alpha. If the stability coefficient is above a certain threshold (usually 0.7), then it can be assumed that the questions were understood by the respondents in the same way, and likely in the way they were meant to be understood by the designer of the instrument. That is, the test–retest method assesses whether a measurement instrument (i.e., a questionnaire) presents an acceptable level of reliability as well as validity.

A Conbrach's alpha coefficient was calculated based on answers to the questions used here. The calculation was conducted in the context of the test–retest method, and yielded an alpha coefficient of .88 [36]. This suggests appropriate reliability and validity. However, the use of multiple measures (or multiple indicators) would be advisable, and is suggested in future research. The use of multiple indicators would allow for confirmatory tests of the reliability and validity of the measurement instrument employed. Multiple indicators would also enable more complete and detailed validity tests, such as tests of convergent and discriminant validity [20,47].

The strong loadings for the measures for compensatory encoding and decoding effort on the underlying construct, namely compensatory adaptation effort, as well as the weak loadings on other constructs (or factors) suggest acceptable validity in connection with part of the measurement instrument. The same can be said for the Cronbach alpha coefficient of .702 in terms of indicated reliability. Since the instrument is relatively small, with four perception-based measurement items, these can also be seen as indications of likely acceptable validity and reliability in connection with the remainder of the instrument.

Another limitation of this study is that its results build on the analysis of self-perceptions about cognitive phenomena. For example, CAT's hypothesized effect in connection with cognitive effort is assessed based on a scale (ranging from 0 to 150) of perceived cognitive effort, which itself is based on the widely used NASA-TLX mental effort measurement instrument [25]. Previous research suggests that such self-perceptions are prone to distortion in a number of situations [48,52], such as in mental attribution errors (see, e.g., [2]). Nevertheless, the striking similarities between the results of this study and those of other studies that served as a basis for the development of CAT [32], as well as studies aimed at testing CAT [12,33,36], mitigate concerns regarding possible self-perception bias. That is, if marked differences had been found among the studies, then one could reasonably assign them to self-perception bias and other methodological problems. This is not the case here.

Finally, the large observed differences in communication fluency should be taken with some caution, because the communication fluency measure used here refers to the exchange of words and not actually ideas. The problem here is that individuals who are succinct but clear in their communication of ideas may use fewer words to communicate the same number of ideas than other more verbose individuals. It is reasonable to assume that the number of words exchanged is strongly correlated with the number of ideas exchanged; something that has been suggested by previous research (e.g., [34,36]). However, future research should employ other measurements that could be triangulated with communication fluency (as defined in this study) to provide a better picture of the amount of ideas exchanged.

As with most empirical research, data analysis support for the hypotheses can be only interpreted as such, and not as a definitive "proof" of the hypotheses. That is, this study provides general support for the hypotheses by rejecting the negative of the hypotheses, or the respective null hypotheses. This is an epistemological issue that is related to Popper's [49] falsifiability criterion, which essentially states that a theoretical framework (e.g., one framed as a set of related hypotheses) must be falsifiable to be useful. If a set of hypotheses that is clearly falsifiable (such as the ones tested here) is supported, one can conclude that the underlying theory may be correct. Nevertheless, one cannot conclude that the theory is absolutely correct or complete without further empirical research aimed at testing the same or other hypotheses derived based on the theory. Ideally those tests should incorporate variations (e.g., sample, task) but preserve enough similarities so that their results can be compared and contrasted [57].

9. Conclusion

This study assessed the impact of an EC medium's use on communication fluency and on individual perceptions of EC medium-related effects on several constructs, namely cognitive effort, communication ambiguity, compensatory encoding effort, and compensatory decoding effort. The study's findings build on data obtained from 230 undergraduate and graduate students conducting a complex task using either a Web-enabled text-based quasi-synchronous EC medium, or FtF interaction. Those findings suggest that the use of an EC medium, when compared with the FtF medium, significantly increased perceived cognitive effort (by approximately 12%) and perceived communication ambiguity (by about 19%), significantly decreased communication fluency (by about 90%), and significantly increased perceived compensatory encoding effort (by approximately 26%). The findings also suggest that the use of an EC medium had no significant effect on perceived compensatory decoding effort.

The findings of this study are aligned with CAT's original formulation [33,36] in that they suggest that the use of an EC medium that suppresses FtF communication elements poses obstacles for communication in complex collaborative tasks. The findings also suggest, in support of the expanded version of the CAT proposed here, that most of the burden to compensate for those obstacles is carried by those who are the main information givers in communication interactions. That burden is reflected in a reduction in communication fluency, measured in words per minute conveyed through the EC medium. Apparently, information givers are likely to spend much more time composing electronic contributions to a discussion conducted through an EC medium than FtF.

The above findings suggest some directions for future research and practice in connection with human-computer interface design aimed at facilitating compensatory adaptation. Also, the above findings suggest the need for future research on the use of collaborative technologies in the context of complex collaborative tasks. These future research directions and opportunities are briefly discussed in the following paragraphs.

Much research on human-computer interaction in the past has focused on improving information visualization [16,19,30,37]. That research places emphasis on extracting visual patterns from data, of which textual data holds particular promise. That is, the emphasis is on the development of text-to-visual representations transformation techniques and tools. Our study indicates the need for research in the opposite direction. Visual representations are seen as more natural [35] and, if appropriate types of representation are used, likely to be easier to generate than written text. Therefore, electronic collaboration employing text could successfully make use of human-computer interfaces with functionality enabling visual representation-to-text conversion, which could in turn significantly facilitate compensatory adaptation.

The suggested line of research mentioned above is likely to lead to important findings in the future. However, the findings from this research also lead to relevant implications for managers and users of collaborative technologies who need to use current technologies to communicate in the context of complex collaborative tasks. One of those implications is that managers and users should use a combination of media in their communication interactions, and should choose the media in such a way that it reduces the compensatory adaptation effort for heavy information givers. Two key factors that are likely to lead to a disproportionate burden on information givers are the number and complexity of ideas that need to be conveyed by them. When the number and complexity of ideas to be conveyed is high, information givers may benefit from the use of more natural encoding mechanisms.

A simple rule of thumb would be that users of e-mail should use video or audio clip attachments to compose electronic messages that contain a large number of complex ideas, and use text to convey a small number of simple ideas. As long as video or audio clip players are properly installed and are easy to use, this should create no significant extra cost for information receivers. The literature on task-technology fit provides a basis on which users can be trained on how to classify messages in terms of number and complexity of ideas [8,64,65]. One obvious result of users following this rule of thumb, beyond the more frequent use of video or audio clip attachments, will be a reduction in the amount of text exchanged through e-mail messages. One can reasonably assume based on the findings of this study that this will lead to an overall increase in communication efficiency in organizations.

Appendix A. Data collection instrument

Appendix A.1. Cognitive effort

Indicate how much mental effort it took for you to complete the task.

0	25	50	75	100	125	150
Absolutely no effort						Extreme effort

Appendix A.2. Communication ambiguity

Communication between my partner and myself was ambiguous.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Appendix A.3. Compensatory encoding effort

I had to work hard to ensure that my partner understood what I intended to communicate.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Appendix A.4. Compensatory decoding effort

I had to work hard to understand what my partner tried to communicate.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

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