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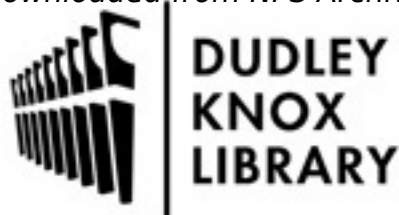
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Command & Control in Virtual Environments: Laboratory Experimentation to Compare Virtual with Physical

15th International Command & Control Research & Technology Symposium

23 June 2010

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Introduction

- Efficacy of Network Centric Operations / Virtual Environments
 - Evidence to support the asserted superiority of Network Centric Operations remains sparse, and the capability enhancing properties of virtual environments remain more in the domain of lore than empirical assessment.
- Educational Psychology and Media Richness Theory
 - Drawing from substantial research in both Educational Psychology and Media Richness Theory, the counter argument that performance in virtual environments will be *worse* than in physical counterparts offers substantial merit and empirical support. Hence we find some controversy between the tenets of NCO and empirical evidence in related fields.
- The impact of virtual versus physical environments on organizational performance.
 - Building upon these separate streams of research, we continue a campaign of experimentation to assess the relative performance of different C2 organizational approaches across a diversity of environments and conditions. In this present study, we investigate explicitly the impact of virtual versus physical environment on organizational performance, focusing first here on the near-ubiquitous Hierarchy, which remains the predominant approach to C2 organization.



Background

- *Educational Psychology prescribes distributed, virtual environments for work performance.*
 - *mitigating rank and status differences, overcoming shyness and language difficulties, developing higher quality work products, examining a more complete range of alternatives and perspectives*
 - ◇ ***Hypothesis 1a. The efficacy of military activities performed through virtual environments will exceed that of the same activities performed through physical environments.***
 - ◇ ****Hypothesis 1b. The efficacy of some military activities performed through virtual environments will increase in proportion with the degree of immersiveness.***
- Media Richness Theory suggests instead that a more personal, physical environment offers potential to improve performance.
 - high and low levels of media richness provide distinct advantages in terms of reducing either equivocality or uncertainty
 - ◇ ***Hypothesis 2. The efficacy of some military activities performed under conditions of high media richness will exceed that of the same activities performed under conditions of low media richness.***



Research Design

- Task Environment
 - Team of participants performing the roles of intelligence analysts to collaborate and identify a fictitious and stylized terrorist plot. (i.e., Who, What, Where, and When)
 - The fictitious terrorist plot is described through a set of informational clues called “factoids”
 - The factoid distribution is designed so that no single player can solve the problem individually and that the team of players cannot solve the problem until after the final distribution.
 - Participants play the game in one or two modes. 1) via ELICIT client applications on separate computer workstations 2) a face-to-face environment, participants interact in rooms equipped with tables and white boards. Factoids are distributed on pieces of paper
- Participants
 - PhD students and faculty at a major US university.
 - Most participants have direct military service as well, and some of the participants have worked professionally in military or government intelligence organizations.
 - Organized as a hierarchically
 - Stratified into three functional levels
 - Assigned to one of four task based teams (Who, What, Where, and When)

Research Design

- Treatment Groups
 - Face-to-Face
 - Virtual
 - Participants are assigned randomly to the 17 different roles in each game
 - Random ordering of the two groups
 - Equivalent versions of the game are played three months apart.

- Protocols and Manipulations
 - Virtual
 - ◇ (10 minutes) All participants read and ask questions about a set of instructions pertaining to both the experiment and the ELICIT environment.
 - ◇ (5 minutes) Team Leader and team members to discuss their approach to the problem-solving scenario with others in their group
 - ◇ (5 minutes) Senior Leader and four Team Leaders discuss their approach to the problem-solving ; the discussion is via e-mail, and Operators do not participate.
 - ◇ (45 minutes) Play the game, each participant receives unique factoids in three phases: 1) two factoids initially when the game begins, 2) one after five minutes, and 3) one at the ten-minute mark. Role-specific factoids are distributed automatically by ELICIT and in a manner ensuring: a) that no player can solve the plot alone, and b) that the plot cannot be solved until all factoids have been distributed.
 - ◇ Participants communicate with one another during game play using only the computer-network capabilities supported by ELICIT (esp. Post, Pull and Share) and readily available network communication technologies (esp. e-mail); no verbal communication is allowed.



Research Design

- Protocols and Manipulations
 - Face-to-face
 - ◇ Same as “Virtual” with the following modifications
 - Face-to-face conversation and the white board; no computer-mediated communication is allowed. Each team leader has access to one mobile phone.
 - All communication occurs via face-to-face conversations, no electronic communication
 - Role-specific factoids are distributed manually on pieces of paper via the senior leader.
- Measurements
 - Performance as a two-dimensional dependent variable comprised of:
 - ◇ 1) *speed* (i.e., time to identify plot details correctly)
 - The scale for the speed measurement was normalized to a 0-1 scale
 - faster speeds (i.e., shorter times to Identify) result in larger values
 - ◇ 2) *accuracy* (i.e., correct identification of plot details)
 - Identify action is scored with a value of 1 for each correct answer to the Who, What and Where aspect of the solution.
 - When aspect of the solution includes three components (i.e., Month, Day, and Time) and is assigned a value of 1/3 for each correct answer.



Statistical Results

TABLE 1 - Descriptive Statistics

Variable	Mean	N	Standard Deviation	Standard Error
ID Time CM (in Seconds)	2685	14	219	58
ID Time FTF (in Seconds)	2554	14	279	74
Who Score CM	.140	14	.363	.097
Who Score FTF	.790	14	.426	.114
What Score CM	.321	14	.249	.066
What Score FTF	.536	14	.365	.098
Where Score CM	.570	14	.514	.137
Where Score FTF	.790	14	.426	.114
When Score CM	.262	14	.297	.079
When Score FTF	.333	14	.320	.086
Identify Composite CM	.324	14	.206	.055
Identify Composite FTF	.610	14	.327	.087

Participants in the physical environment appear to outperform their counterparts in the virtual environment, but variability of such performance is greater.



Statistical Results

Because the same players participated in both experiment sessions, we employ the two-tailed t-test of paired samples to take advantage of the blocking and increase statistical power.

TABLE 2 - Results of Hypotheses Tests

Variable	Mean Value	Statistical Support		
		t	df	Significance (2-tailed)
ID Time CM - ID Time FTF in Seconds	131	1.242	13	.236
Who Score CM - Who Score FTF	-.643	-4.837	13	.000
What Score CM - What Score FTF	-.2143	-1.578	13	.139
Where Score CM - Where Score FTF	-.214	-1.000	13	.336
When Score CM - When Score FTF	-.071429	-.612	13	.551
CM Composite – FTF Composite	-.286	-2.362	13	.034

Identification speeds are not statistically significant ($p = 0.236$)
 All accuracy contrasts are not significant; the “who” component is highly significant ($p < .001$) and the composite accuracy score reflects considerable significance ($p < .05$)

Findings

- The results of this study support media richness theory, while at the same time they provide a plausible explanation for the theoretical conflict between the Educational Psychology literature and media richness theory.
 - Media Richness Theory and Educational Psychology
 - ◇ Performance in the virtual environment is worse than in the physical environment. This provides support *against* hypothesis one: ***The efficacy of military activities performed through virtual environments will exceed that of the same activities performed through physical environments.***
 - ◇ Virtual environments that are low in media richness provide little opportunity to reduce task equivocality, often resulting in reduced group accuracy. Although virtual environments can provide access to experts and accelerate information sharing among distributed decision makers, thus reducing uncertainty, such access does not appear to be compelling in this experiment.
 - ◇ In terms of accuracy performance in the media rich, face-to-face environment is better than in the low-immersive virtual environment. This provides support *for* hypothesis two: **The efficacy of some military activities performed under conditions of high media richness will exceed that of the same activities performed under conditions of low media richness.**
 - ◇ Speed appears to be relatively insensitive to physical or virtual environment, but such environmental choice affects accuracy.

Findings

- Theoretical conflict between the Educational Psychology literature and media richness theory.
 - ◇ **Variation in task uncertainty and task equivocality among tasks.**
 - Educational tasks focused on a particular set of learning objectives tend to be static, well defined, and operate within a pedagogical framework.
 - Military and business tasks that are focused on sense and response activities within an emergent environment are dynamic, often based on interpretation, and more closely align with the principles of andragogy.



Future Research

- *Immersiveness*
 - Work to develop more immersive environments (e.g., where participants play the game via avatars) to extend this series of experiments to examine explicitly the impact that immersiveness has on performance.
- *Edge Organizations*
 - Work to conduct additional experiments that examine comparative performance—in both physical and virtual environments—of hierarchical versus edge organization.
- *Combined Experiment Extensions*
 - Experiments to examine the interactions between immersiveness and organization.
- *Semi-intelligent Software Agents*
 - *Developing a set of semi-intelligent software agents to play the ELICIT game in a manner reflecting human performance*