17th ICCRTS
"Operationalizing C2 Agility"

Improving Judgment Performance by Examining the Relationships between Task Properties and Cognitive Mode

Topics:
Primary Topic: Experimentation, Metrics and Analysis
Alternate Topic: Data, Information and Knowledge
Alternate Topic: Concepts, Theory and Policy

Authors:
Dr. Robert Holcomb
Institute for Defense Analyses
Alexandria, VA 22311

Dr. Leonard Adelman
George Mason University
Fairfax, VA 22030

Point of Contact:
Dr. Robert Holcomb
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
(703) 578-2816 (office)
(703) 346-5749 (mobile)
rholcomb@ida.org

ABSTRACT

This research describes an examination into the relationship between task properties and cognitive mode. Previous research had demonstrated weak support for the hypothesis that judgment performance could be improved if cognitive mode matched task properties. This research devised new metrics for measuring task properties and cognitive mode, and demonstrated better support for the hypothesis than previous attempts. Frequently an argument is put forward that analytical methods are preferable to intuition in judgment tasks, including command and control tasks in military decision-making. The current research instead supports the concept that the best decisions are made when the cognitive mode is matched to the task conditions. The results of this experiment have validity in military command and control research because they relate together the properties of an information integration task with judgment performance on that task. The research demonstrated that task properties were related to cognitive mode as predicted, and demonstrated improved judgment performance when there was close correspondence between the task properties and the cognitive mode. The results of this experiment have provided stronger empirical support than previous experiments and should serve to operationalize Cognitive Continuum Theory.

Introduction

The relationship between intuition and analysis in cognition has been a subject of debate for many years. Most of the debate has existed as a dichotomy, with authors arguing that one or the other cognitive mode is preferable for decision-making [for examples, see Klein, 1993; Kahneman & Tversky, 1982 and Zsambok & Klein, 1997]. In an effort to avoid this dichotomous characterization, Hammond developed *Cognitive Continuum Theory (CCT)*, postulating that cognitive modes exist on a continuum consisting of a combination of elements that ranges from pure intuition on one pole to pure analysis on the other [Hammond, 1987, 1996a, and 1996b]. Information-processing tasks exist on a similar and parallel continuum, with task characteristics that induce intuitive cognition at one pole and task characteristics that induce analytical cognition at the other pole. Under Hammond's theory, judgment success (*achievement*) should be optimal if there is correspondence between the task characteristics and the cognitive mode they induce. There also exists a middle ground between the two poles, labeled quasi-rational, which has characteristics from both intuitive cognition and analytical cognition.

Hammond's CCT work is based upon Brunswik's lens model [Hammond, 1996a], using multiple linear regression techniques to relate together the weights various cues have in representing the true state of the environment (called ecological validity weights), and the degree of correlation between the different cues. The subject also employs weights reflecting his or her preferences in using the various cues (called cue utilization weights). For a detailed description of the lens model, see [Cooksey, 1996].

The correspondence between task properties and cognitive mode should be of interest to military command and control tasks. For example, task characteristics that are present in many military situations (such as a large number of cues presented simultaneously, without a specific principle for organizing the information into a judgment, when judgment time is short) will tend to induce intuitive cognition. In more analytical military situations, relatively few cues presented sequentially with a clear organizing rule or principle, when there is plenty of time available to make the judgment, will tend to induce analytical cognition. A theory that can predict high achievement in information-processing decision tasks can be of vital importance in presenting information to a military commander.

There have been few published attempts to demonstrate CCT, and those have shown weak support. The root cause for the relatively weak empirical support for the Cognitive Continuum Theory could be a result of the variety of indices devised to measure location on the task continuum. The indices previously used were based on an arithmetic average of quantitative aspects of several task and cognitive mode characteristics, and varied from experiment to experiment. The variation in the elements of index scores between different experiments does not lend confidence that the empirical scores have general validity.

For example, Dunwoody et al. conducted an experiment using a naval threat assessment task to test some of the precepts of CCT, but failed to show support in a critical hypothesis [Dunwoody et al., 2000]. In that experiment, they attempted to show that the score of the task continuum index they devised was correlated with the index of cognitive mode. Instead, their results showed that the cognitive mode index expected to be the highest (analytical mode for a numeric, analytical display) was in fact not significantly different than the lowest (intuitive cognitive mode for a visual, intuitive display). A graph of their results is shown below.

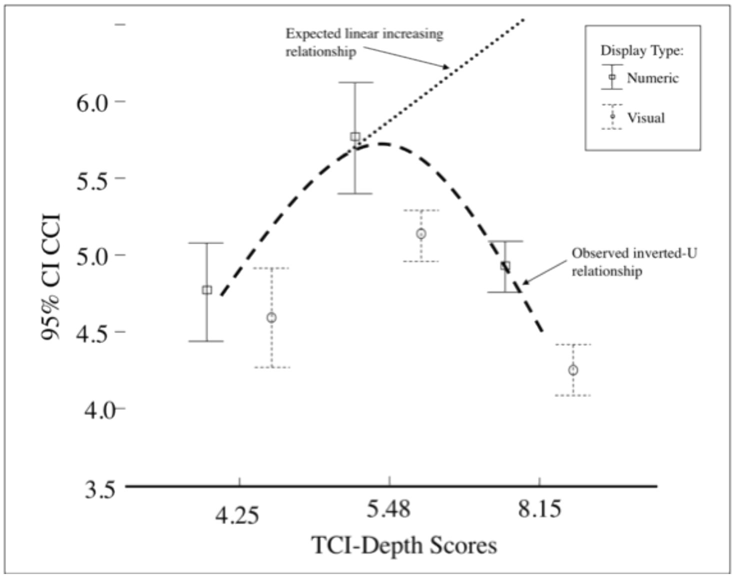

Figure 1. Task Index versus Cognitive Mode Index

Stewart has suggested an approach building on Hammond's CCT that could be used to develop a new task continuum metric [Stewart, 2001]. He noted that vicarious functioning (or the intersubstitutability of different judgment processes, Brunswik, 1952) is a hallmark of intuitive cognition. Moreover, the potential for vicarious functioning can be predicted by examining the corresponding intersubstitutability of task properties (called vicarious mediation by Brunswik, 1952) in the judgment task itself. Stewart proposed that the specific amount of vicarious mediation could be quantified by the vector created by the matrix product between the vector of cue ecological validity weights and the matrix of cue inter-correlations. Such a vicarious mediation index (VMI) could serve to locate a task on a specific location on a task continuum, relative to the degree of intuitive cognition these conditions may induce in the subject.

The experiment described here examined a vicarious mediation index (VMI) derived from Stewart's work to see if there is a predictable relationship between the task conditions and cognitive mode on the part of the subject (using a vicarious functioning index, VFI), and if correspondence between the VMI and VFI indices predicted task achievement better than earlier experiments.

Method

The concept of the experiment was to emulate the structure of the Dunwoody et al. experiment, employing the revised VMI and VFI indices in direct comparison to the TCI and CCI indices previously used (labeled TCI_D and CCI_D in subsequent notation, to reflect that they were the same indices used by Dunwoody, et al. in the prior research). Dunwoody et al. used undergraduate college students from the university research pool, making judgments about a naval threat assessment task even though the students were not experienced naval officers.

In our view the use of inexperienced subjects in the domain of naval operations had a more significant impact on Dunwoody et al.'s results than the domain itself. We did not have a pool of military subjects from which to draw, but instead focused our experiment on subjects who were experienced in the domain in which they were being asked to make judgments. We believe the results will be replicable in information integration tasks across a variety of domains, including military command and control tasks. We employed experienced middle school teachers making judgments on student placement using a variety of familiar cues.

Second, Dunwoody et al. employed a between-subjects design, while we employed a within-subjects design where each subject made each judgment on each task. The use of a within-subjects design enabled tracking of movement along a cognitive continuum as a function of task characteristics for each subject on each task.

A double-system lens model design was used to manipulate and measure the relevant variables (see Cooksey, 1996 for a description of the double-system lens model design). The experiment consisted of three task packages, designed to induce cognitive modes corresponding to intuitive, quasi-rational and analytical properties. Each task package had a TCI_D index computed in the same manner as in the Dunwoody et al. experiment, and a VMI index computed as described below, for comparison. The experimental results included a CCI_D index computed in the same manner as Dunwoody et al., and a VFI index for comparison.

Procedures

The task presented to the participants was an information-processing task given to a selection of schoolteachers. Participants were presented with a student placement task and were required to integrate a set of four cues (such as student scores on an aptitude test) and make a judgment about placement of the student. The cues were representative of those typically used by the teachers in student placement, drawn from the Scales for Rating the Behavioral Characteristics of Superior Students used in a local school system.

There were three sets of task conditions in the experiment, each manipulated to produce different locations on the task continuum. The task packages were designed to induce intuitive, quasi-rational and analytical cognition by virtue of the task properties each task was given. Task Package 1 was created to represent intuitive task conditions and to induce intuitive cognition. Task Package 2 cues were created to represent quasi-rational task conditions and induce quasi-rational cognition. Task Package 3 cues were created to represent analytical task conditions, to induce analytical cognition.

As described below, the task packages were created by manipulating the lens model parameters on the left-hand side of the lens model: the ecological validity multiple regression weights ($ß_e$) and the cue inter-correlations (i.e., the matrix of r_{ij} values, with each entry representing the correlation coefficient between cue *i* and cue *j*). The subjects developed their own cue utilization weights ($ß_s$) based on their student-placement judgments (Y_s) (the right-hand side of the lens model). Achievement (r_a) was the correlation coefficient between the resulting subject's judgment (Y_s) and the actual student placements (i.e., the environment criterion Y_e). Other parameters were manipulated to match the values used by Dunwoody, et al. in their experiment.

Independent variables

Three independent variables were used to create the task packages: the ecological validity coefficients vector ($ß_e$) weights for the four cues, the cue inter-correlations matrix (the 4 x 4 matrix of r_{ij} values, **R**), and the task predictability (R_e^2 the squared multiple correlation coefficient for the best fitting regression equation predicting the environmental criterion).

Two levels of $ß_e$ were used in the experiment, drawn from research by Gigerenzer (e.g., see Gigerenzer, 2008, and Gigerenzer, 2001). Gigerenzer describes two basic heuristics used by subjects in representing ecological validities, “Take the Best” and “Tallying”.

The Tally heuristic reflects a case where the ecological validities of the cues are uniform, and hence reflect compensatory information. This heuristic was represented by a vector of $ß_e$ weights with values of [0.25, 0.25, 0.25, 0.25] for the four cues, and was used in Task Package 1 as being representative of an intuition-inducing task because the weights are perfectly interchangable.

The Take the Best heuristic is one in which the ecological validities of the cues are non-compensatory, and the $ß_e$ values of the cues decrease exponentially (so that the weight of the first cue ($ß_{e1}$) is higher than the sum of the validity weights of the remaining cues). This heuristic was represented by a vector of $ß_e$ weights with values of [0.8, 0.4, 0.2, 0.1] for the four cues, and was used in Task Package 2. Task Package 3 also employed the Take the Best heuristic, but with the first cue assigned a negative weight, to reflect the fact that the first cue was chosen to be negatively correlated with Y_s. The $ß_e$ weights for Task Package 3 are [-0.8, 0.4, 0.2, 0.1].

The second of the independent variables was the cue inter-correlations, consisting of the matrix [**R**],

$$R = \begin{bmatrix} 1 & r_{12} & r_{13} & r_{14} \\ r_{21} & 1 & r_{23} & r_{24} \\ r_{31} & r_{32} & 1 & r_{34} \\ r_{41} & r_{42} & r_{43} & 1 \end{bmatrix}$$

where $r_{ii} = 1$ and $r_{ij} = r_{ji}$.

The VMI score was arrived at by computing the mean deviation of the vector that resulted from the matrix product of $ß_e$ and [**R**].

The third independent variable was the task predictability. For consistency with the Dunwoody et al. experiment, three specific R_e^2 values were used: $R_e^2 = 0.5$ for Task Package 1 (Intuitive), $R_e^2 = 0.65$ for Task Package 2 (Quasi-rational), and $R_e^2 = 0.9$ for Task Package 3 (Analytical).

Rationale for the selection of the VMI scores

As mentioned above, the vicarious mediation index (VMI) quantifying the task continuum index was created by manipulating the vector created by the matrix product between the vector of cue ecological validity weights and the matrix of cue inter-correlations. In order to see where interesting combinations of [**R**] and $ß_e$ existed, and thereby select the three task packages, we examined ten cases with differing combinations of cue weights and cue inter-correlations. The cases were examined to see where we could expect to find discernable differences in the vicarious mediation inherent in the task, and hence could expect to see variation in the cognitive modes. A complete discussion of the process used to examine the ten cases is in Holcomb (2011). The three cases chosen for inclusion in the experiment include one at the intuitive end of the continuum, one at the analytical end of the continuum, and one to represent the quasi-rational location on the continuum.

There is high variation in the VMI index between Task Package 1 (VMI = 0) and Task Package 3 (VMI = 0.63). Since a high degree of variation in the VMI index should lead to discernable differences in vicarious mediation in the tasks and hence cognitive mode and VFI scores, these two cases were included. Task Package 1 (the Tally heuristic and uniform (0.1) cue inter-correlations) represents the *a priori* intuitive-inducing task, and Task Package 3 (the Take the Best heuristic and non-uniform cue inter-correlations, including a negative correlation) representing the *a priori* analytical-inducing task.

For the quasi-rational task, a value of VMI in the middle range of the task continuum is appropriate. Task Package 2 (another combination of the Take the Best heuristic and non-uniform cue inter-correlations) represents a middle value of the VMI index, and was used to create the quasi-rational task package.

Table 1 below summarizes the independent variable characteristics of the three task packages used in the experiment.

Table 1. The independent variable characteristics

Variable	Task Package 1 (Intuition)	Task Package 2 (Quasi-rational)	Task Package 3 (Analytical)
Ecological Validities	Tally (0.25 for all)	Take the Best (0.8,0.4,0.2,0.1)	Take the Best (-0.8,0.4,0.2,0.1)
Cue Intercorrelations	**R** uniform (0.1)	**R** non-uniform (0.8,0.2,0.1)	**R** non-uniform (-0.7,0.2,0.1)
VMI score	0	0.385	0.625
average r_{ij} (used in TCI_D)	0.1	0.267	-0.060
Std Dev of βe (used in TCI_D)	0	0.310	0.532
Task Predictability	R^2_e=0.55	R^2_e=0.59	R^2_e=0.94
Overall TCI_D score	0.51	0.56	0.78

Dependent variables

There were two dependent variables in the experiment, the cognitive mode employed by the subjects on the tasks and achievement (r_a). The cognitive mode was operationally defined through two different CCI indices, the formula employed by Dunwoody et al. (CCI_D), and a Vicarious Functioning Index (VFI).

The VFI index was defined as the mean deviation of the vector produced by the matrix product of the cue utilization weights ($ß_s$) and the cue inter-correlations [**R**], in a similar fashion to the VMI index described above as proposed by Stewart (2001). The cue utilization weights were derived from a multiple linear regression fit to the subject judgments (Y_s). A model of the subject's "policy equation" was created by the formula:

$$\hat{Y}_s = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$$

Each of the coefficients were converted to standardized $ß_s$ values by multiplying by the ratio of the standard deviations of each cue with the standard deviation of the subjects judgments (Y_s), to derive scale-free cue ß-weights:

$$\beta_i = b_i \frac{sd_{X_i}}{sd_{Y_s}}$$

The result was a vector of four elements reflecting the scale-free cue utilization weights, $ß_{s1}$ through $ß_{s4}$. The intercept term was ignored as is typical in judgment analyses.

We created the CCI_D index in a similar manner to that employed by Dunwoody et al., in their prior experiment by combining five properties. The first four properties were: (1) judgment consistency, which was the multiple correlation coefficient (R_s for the participant's policy equation for a task package); (2) the kurtosis of the error distribution of the participant's judgments for a package; (3) the participant's judgment response rate; and (4) the participant's self-insight into his or her "policy" model. The fifth property used in the construct of CCI_D was differential confidence, as measured by the difference between the confidence expressed by the subject in their strategy used and their confidence in the answer they produced. If strategy confidence is higher than answer confidence, then analytical judgment is indicated. For a detailed explanation of the Dunwoody et al. procedures, see Dunwoody et al., (2000).

The VFI index was defined as the mean deviation of the vector produced by the matrix product of the cue utilization weights ($ß_s$) and the cue inter-correlations [**R**], in a similar fashion to the VMI index described above.

Achievement was defined as the correlation between actual student placements (i.e., environmental criterion values) and the subject's judgments.

The experiment was conducted in the summer of 2010. Sixty-four surveys were prepared, numbered, and given to teachers for response; of these 52 responded. The respondents consisted of 43 females and 9 males, with a mean of 17.3 years of teaching experience (median = 15 years). The respondents taught a wide variety of subjects, including foreign languages, mathematics, science, history, English, art and special education.

Hypotheses

Two hypotheses were considered:

H_1 (VFI increases as VMI increases): There will be a statistically significant difference between the means of the VFI score for the three levels of the VMI score in the direction predicted by CCT; specifically that the VFI scores will increase as VMI scores increase from Task Package 1 (intuitive) to Task Package 2 (quasi-rational) to Task Package 3 (analytical), with significant differences between each. In contrast, consistent with our basic argument that these new metrics were better indices for measuring task properties and cognitive mode, we hypothesized that the TCI_D and CCI_D indices would not show this linear relationship, thereby helping to explain why previous CCT research had not shown a direct relationship between task properties and cognitive mode.

H_2 (Achievement will be higher when cognitive mode matches task conditions): There will be a significant difference in the means of the r_a score for the three levels of the Correspondence Score (defined as the absolute value of the difference between the VMI score and the VFI score for each of the Task Packages), with the value of r_a high when the absolute value of the difference between VMI and VFI is low, and vice versa. In contrast, we predicted that there would no relationship between achievement and Dunwoody et al.'s prior metrics (TCI_D and CCI_D). Support for this hypothesis would reflect the condition of higher achievement when task conditions are matched to cognitive mode, as predicted by CCT.

Holcomb (2011) also considered additional hypotheses not considered relevant to this paper.

Results

An initial examination of achievement (r_a) for each respondent on each task showed that the mean calculated r_a score across all tasks was 0.58 (median = 0.69). Five teachers had a negative r_a score on Task Package 3, the only task that had a negative cue correlation between the first and second cues. All remaining teacher-task combinations had positive r_a scores. The average achievement score for each of the task packages was 0.56 for Task Package 1, 0.67 for Task Package 2, and 0.51 for Task Package 3. From this we concluded that the participants understood the task and were able to perform it satisfactorily.

There were 10 duplicate student profiles (out of 60) in each task package set of data to determine the degree of consistency in the subject's judgments. Consistency was defined as the correlation coefficient between the respondent's Y_s scores for the pairs of duplicate profiles. Mean consistency was 0.89 for Task Package 1; 0.93 for Task Package 2; and 0.84 for Task Package 3. The overall consistency mean was 0.89.

Hypothesis 1: VFI would increase with VMI

CCT predicts that there will be a positive correlation between task conditions and cognitive mode, indicating for this experiment that as VMI scores increase, so will the VFI scores. Forty-eight of 52 respondents showed a positive correlation between their VMI scores and their VFI scores across the three task packages. This proportion was significant ($\chi^2 = 37.23$, $p < 0.0001$). Forty-two of these 48 had a correlation coefficient that was greater than one standard deviation above zero (z-transformed to approach normality). The mean of the Fisher z-transform of these 48 correlations was 1.56, and this value is significantly different than zero ($t = 11.01$, $p < 0.0001$, DF=51, one-tailed). This result supports CCT because it supports the hypothesis that task properties influence cognitive mode as measured by VMI and VFI.

An examination of the within-subjects correlation between the TCI_D scores and the CCI_D scores using the Dunwoody et al. formulation showed that 29 of the 52 respondents showed a positive correlation between the TCI_D scores and their CCI_D scores. This did not reflect a significant departure from chance alone ($\chi^2 = 0.69$, $p = 0.41$). The Dunwoody et al. metric results in this experiment did not support CCT because that metric did not demonstrate a systematic increase in CCI_D scores corresponding to the increase in TCI_D scores across task packages.

In an order analysis of the results for the VMI-VFI metric formulation (see Table 2), the predicted order was observed in 40 of 52 respondent cases, significantly more cases than chance alone would have predicted ($\chi^2 = 138.3$, $p < 0.001$, DF = 5). This result supports CCT because it shows that cognitive mode scores increase as task continuum scores increase, demonstrating the relationship between them for individuals.

Table 2. Order analysis results

Order	Score Order	Task Pkg Notation	VFI Count	CCI_D Count	Expected by Chance Alone
Predicted order	A>Q>I	3>2>1	40	12	8.83
One departure:	A>I>Q	3>1>2	8	8	8.83
	Q>A>I	2>3>1	2	8	8.83
Two departures:	Q>I>A	2>1>3	0	7	8.83
	I>A>Q	1>3>2	2	7	8.83
Three departures:	I>Q>A>	1>2>3	0	10	8.83

The order analysis results for the TCI_D-CCI_D metric formulation are also shown in Table 2. Those results do not show significant deviation from chance alone ($\chi^2 = 2.21$, $p = 0.81$). The Dunwoody et al. metric of TCI_D and CCI_D did not demonstrate support for CCT because the cognitive mode (as measured by the size of the CCI_D score) does not move along the continuum as the TCI_D scores increases in the predicted order.

We examined VFI scores relative to the VMI scores using a between-subjects analysis as well. We predicted the relationship would show increasing VFI scores as VMI scores increased from Task Package 1 to Task Package 3. Figure 2 (left side) shows the VFI scores aligned by task package.

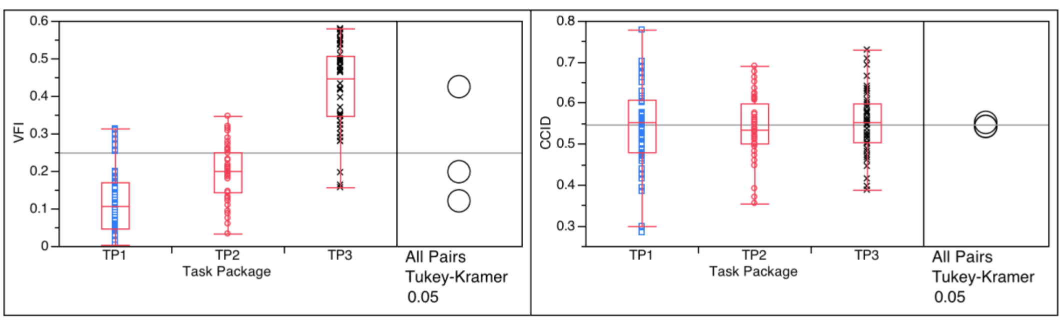

Figure 2. Cognitive mode scores by task package

A one way ANOVA showed the means of the task package VFI scores were not equal ($F_{(2,153)} = 159.5$, $p < 0.0001$). A Tukey-Kramer HSD test indicates that all three means are significantly different from one another at the 0.05 level. Consistent with our predictions, the mean for Task Package 3 (Analytical) was significantly higher than both Task Package 1 ($q_{(153,3)} = 24.3$) and Task Package 2 ($q_{(153,3)} = 18.1$). Task Package 2 was also significantly higher than Task Package 1 ($q_{(153,3)} = 6.2$).

Figure 2 (right side) shows the plot of CCI_D scores by task package. There is no significant difference between the means of the CCI_D scores for the three task packages ($F_{(2,153)} = 0.24$, $p = 0.78$). This result is inconsistent with CCT; the CCI_D scores should have shown the same linear increasing function form as the TCI_D scores indicated. The Dunwoody et al. formulation of the metric does not support CCT because the cognitive mode shows no variation when the task conditions vary, in contrast to the VMI-VFI metric.

Hypothesis 2: Achievement will be higher when the Correspondence Score is low

The second hypothesis predicted that achievement is a function of the close correspondence between vicarious mediation and vicarious functioning. In this experiment, this was expected to manifest itself in a linearly decreasing relationship between the achievement scores and the Correspondence Score (which is defined as the absolute value of the difference between the VMI and VFI scores). This relationship was expected to be present in all three task packages.

Figure 3 is a plot of the achievement scores against the Correspondence Scores for the participants. The graph on the left is for the VMI-VFI metric, while the graph on the right is for the TCI_D-CCI_D construct. Blue squares represent Task Package 1, red circles represent Task Package 2 and black crosses represent Task Package 3.

In the VMI-VFI construct there is a decreasing relationship with the coefficient of determination $r^2 = 0.22$ (significant at the $p = 0.05$ level). The linear fit exhibits a negative slope that is significantly different from zero ($t = -6.64$, $p < 0.0001$). For each task package considered independently, the trend line decreases in the expected direction (that is, with a negative slope) and the slope is significantly different from zero ($r^2 = 0.42$ for Task Package 1 ($t = -6.04$, $p < 0.0001$); $r^2 = 0.12$ for Task Package 2 ($t = -2.64$, $p = 0.011$); and $r^2 = 0.30$ for Task Package 3 ($t = -4.60$, $p < 0.0001$)).

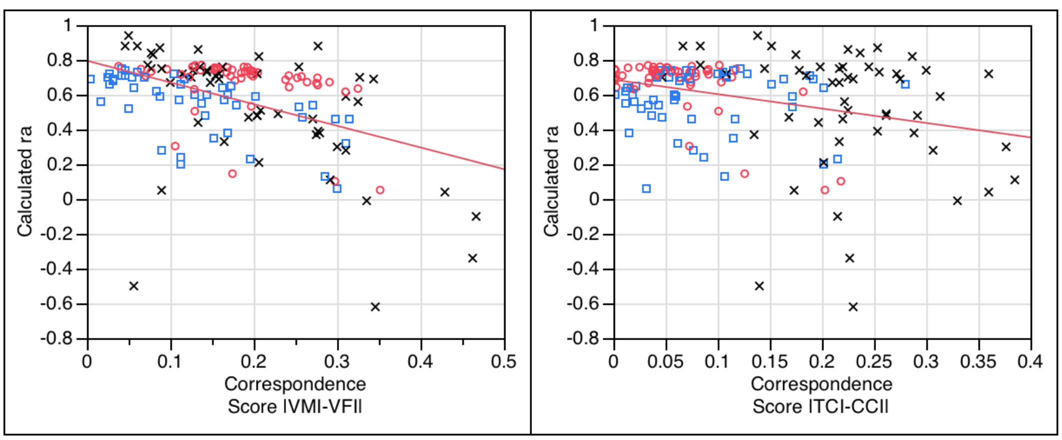

Figure 3. Achievement plotted against Correspondence Score

We also examined the relationship between achievement and correspondence score created by using Dunwoody et al.'s formulation of TCI and CCI (i.e., $|TCI_D$-$CCI_D|$, Figure 3, right side). Over the three task packages combined, the relationship also was linearly decreasing, with the coefficient of determination r^2 =

0.10 (significantly different from zero at the $p = 0.05$ level), and a negative slope significantly different than zero ($t = -4.06$, $p < 0.0001$).

When assessed by task package in the Dunwoody et al. construct, however, only Task Package 2 demonstrated the predicted negative slope that was significantly different from zero ($r^2 = 0.39$, $t = -5.64$, $p < 0.0001$). The result for Task Package 1 using the Dunwoody et al. metric was $r^2 = .0003$, $t = -0.13$, $p = 0.90$, and the result for Task Package 3 was $r^2 = .057$, $t = -1.74$, $p = 0.089$. The result for Task Package 2 supports CCT, while the results for the other two task packages do not.

Discussion and suggestions for future research

The results of the experiment support the precepts of CCT when using the VMI and VFI metrics. Regarding the first hypothesis, our construct demonstrated support for the CCT premise that there is a parallel relationship between task conditions present in the environment and cognitive mode. In contrast, Dunwoody et al.'s TCI_D and CCI_D indices did not show support for CCT in either this experiment or in their own.

Regarding the second hypothesis, we found support for the CCT premise that achievement was improved when there was correspondence between the task continuum index as measured by VMI and the cognitive continuum index as measured by VFI in all three task packages. This relationship was not seen in the Dunwoody et al. TCI_D and CCI_D construct for Task Package 1 or Task Package 3, but was seen in Task Package 2 in this experiment. This predicted result was not seen in the Dunwoody et al. earlier experiment.

The relationship between task conditions and cognitive mode is the central feature of CCT, and the result of this experiment showed support for that central feature, in contrast to the previous experiment of Dunwoody, et al. The experimental result demonstrated the relationship between the vicarious mediation present in the environment and the vicarious functioning on the part of the subject as captured in the VMI and VFI metrics. Stewart's idea that the variation inherent in the matrix product of the ecological validity weights and the cue inter-correlations could be used as an indicator of the potential for vicarious functioning (i.e., intuition versus analysis) was demonstrated in this experiment. This variation reflects the degree of vicarious mediation present in the task, and is indicative of the potential for vicarious functioning on the part of the subject, which is an indicator of cognitive mode. Knowledge of the VMI characteristics in the task enables prediction of the VFI characteristics in the cognitive mode, with 92 percent of the participants showing a positive correlation between their VMI scores and their VFI scores.

While the relationship between task conditions and cognitive mode is the central feature of CCT, the relationship between their correspondence and *achievement* has the most practical benefit. Achievement is the correlation between the subject's judgments and the environmental criterion, and as such is the fundamental reason to examine CCT. Improving performance is the goal of those who work on human-technology interfaces, and these experimental results indicate that when task conditions and cognitive mode are matched, then judgment performance can be improved.

This is a central feature of CCT: no particular method of cognition by itself is superior to any other method of cognition. As the results of our experiment showed, the highest achievement is linked, not to cognitive mode alone, but to the congruence between cognitive mode and task properties. This result supports Brunswik's probabilistic functionalism and Hammond's CCT, providing a link between their psychology research and the cognitive systems engineering designs of human-technology interfaces.

The lower achievement values in Task Package 3 are reflective of the difficulty of coping with a negative cue correlation, even when high achievement was seen when task properties matched cognitive mode. The impact of negatively correlated cues should be examined further. The ten cases we examined to select our independent variables only represents a small fraction of potential cases that exist in reality and an expansion of that work is necessary to more fully understand the issues that negatively correlated cues can cause. For example, having multiple negatively correlated cues should be examined. Other cue function forms, such as those that exhibit an inverted U-shape represent a combination of both positive and negative correlations for a cue (e.g., more is better up to a point, then less is better). The current research did not attempt to examine this area, but the methodology of the VMI and VFI metrics may be useful in illuminating these cases.

Conclusions

Warfare is a human social activity, not a purely analytical one. Asserting that an analytical cognitive mode is always superior to an intuitive cognitive mode can be counter-productive. CCT predicts instead that the optimum performance in making judgments involving integrating information comes when the cognitive mode is matched to the task properties; this experiment lends support to that prediction. An over-reliance on analytical techniques can cause commanders and staffs to overlook critical information that cannot be captured in mathematical models. Daniel Patrick Moynihan observed, when discussing the failure of the intelligence community to predict the dissolution of the Soviet Union,

> "We confined our analysis to 'hard', quantifiable (or so we thought) measures that made no provisions for the passions–the appeal of ethnic loyalty and nationalism, the demands for freedom of religious practice and cultural expression, and the feeling that the regime has lost its moral legitimacy." [Moynihan quote in Hammond, 1996a, p.189].

Analytical methods are well suited to large-scale problems such as assessing the performance of a counter-IED campaign, involving thousands of data points, summary statistics and moving averages. Intuition is a more suitable cognitive mode where the commander is faced with multiple, fallible indicators that have a low degree of inter-correlation. For example, suppose a commander is faced with having to make an assessment of a subordinate commander's unit fitness for continued combat. He will likely utilize the statistics of the unit strength, types and frequency of casualties and other statistics, but he will also go and visit the unit in person and judge the subordinate commander, his body language, his level of strain, the words he chooses. This is an example of utilizing both analytical methods and intuitive methods, called quasi-rationality in CCT.

Research in CCT has been largely dormant for lack of strong empirical support; the metrics devised in this paper and the empirical results achieved should serve to revitalize interest in Hammond's theory. Our approach has provided stronger empirical support than previous experiments, and should serve to operationalize Cognitive Continuum Theory.

Relating task properties for an information integration task to cognitive mode and achievement, as was demonstrated in this experiment, can have significant implications for military command and control tasks. Understanding the relationships between task properties and cognitive mode can assist in understanding how cognitive mode changes over time, and can be beneficial in the design of military command and control displays. The finding that achievement can be improved if there is a close correspondence between the VMI and VFI indices can serve to optimize display design and the relationship between the operational environment and the commander's interactions with it.

References

Brehmer, B. & Joyce, C.R.B. (Eds.), (1988). *Human judgment: the SJT view*. Amsterdam: Elsevier Science Publishers.

Brunswik, E. (1952) *The conceptual framework of psychology*. Chicago: University of Chicago Press.

Cooksey, R.W. (1996). *Judgment analysis: Theory, methods and applications.* San Diego, CA: Academic Press.

Dunwoody, P.T., Haarbauer, E., Mahan, R.P., Marino, C. & Tang, C. (2000). Cognitive Adaptation and its Consequences: A Test of Cognitive Continuum Theory. *Journal of Behavioral Decision Making, 13,* 35-54.

Gigerenzer, G. (2008). *Rationality for Mortals: How People Cope With Uncertainty.* New York, NY: Oxford University Press.

Gigerenzer, G. (2001). Ideas in exile: The struggles of an upright man. In K.R. Hammond and T.R. Stewart (Eds.), *The Essential Brunswik: Beginnings, explications, applications* (pp. 445-452). Oxford: Oxford University Press.

Hammond, K.R., Hamm, R.M., Grassia J., & Pearson, T. (1987). Direct comparison of the efficacy of intuitive and analytical cognition in expert judgment. *IEEE Transactions on Systems, Man and Cybernetics, 17,* 753-770.

Hammond, K.R. (1996a). *Human judgment and social policy: Irreducible uncertainty, inevitable error, unavoidable injustice.* New York: Oxford University Press.

Hammond, K.R. (1996b). Upon reflection. *Thinking and Reasoning, 2*, (2/3), 239-248.

Holcomb, Robert C. (2011). *Improving Judgment Performance and Cognitive Systems Engineering by Examining the Relationship between Task Properties and Cognitive Mode*, diss., George Mason University.

Kahneman, D. and Tversky, A. (1982). On the study of statistical intuitions. *Cognition*, 11, 123-141, reprinted in D. Kahneman, P. Slovic, A. Tversky (Eds.) Judgment under uncertainty: heuristics and biases, Cambridge: Cambridge University Press.

Klein, G. (1993). A recognition-primed (RPD) model of rapid decision making. In Klein, G.A., Orasanu, J., Calderwood, R. &Zsambok, C.E. (Eds.) *Decision* *making in action: models, and methods* (pp. 138-147). Norwood, NJ: Ablex Publishing Corporation.

Kirlik, A. (Ed.). (2006). *Adaptive perspectives on human-technology interaction.* Oxford: Oxford University Press.

Stewart, T.R. (2001). The lens model equation. In K.R. Hammond and T.R. Stewart (Eds.), *The Essential Brunswik: Beginnings, explications, applications* (pp. 357-362). Oxford: Oxford University Press.

Zsambok, C.E. and Klein, G. (Eds.), (1997). *Naturalistic decision making*, Mahwah, NJ: Lawrence Erlbaum Associates, Inc.