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Modeling Cognitive Ability-Demand Gaps in Collaborative Sense-making and Designing Assistive Technology Solutions

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MODELING COGNITIVE ABILITY-DEMAND GAPS IN COLLABORATIVE SENSE-MAKING AND DESIGNING ASSISTIVE TECHNOLOGY SOLUTIONS

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To my family.

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ABSTRACT

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Sense-making is the ability to connect novel information to the familiar schema (or adapt to an unknown environment) and selection of actions. It can be viewed as a continuous effort to bridge the gap between human ability and agent's task demand in the context of human-agent (system) interaction. A range of the gaps can be considered in the context of human-agent interaction depending on the agent's role and functions. We focus on cognitive ability-demand gap for the sake of simplicity as it is critical in designing technology solutions that are adaptive, assistive, and can potentially enhance users experience through collaborative sense-making. The main goal of this study is to pursue new avenues in designing assistive solutions for people with varying degrees of disability. Every disability is unique and effective technology solution would require "assistive thinking" and "collaborative sense-making" between the user and the system (agent). The key idea is to develop a suite of techniques to model the ability-demand gap in order to have a deeper insight about human-agent interaction and leverage it in designing assistive technology solutions. The key objectives are to: (a) model the ability-demand gap in terms of cognitive ability using latent response theories, (b) establish the association of model parameters with cognitive resources and cognitive task demands in gap modeling, and (c) use the gap model for collaborative sense-making to design and develop novel assistive technology solutions. The proposed research connects psychometric ability and task difficulty parameters using the latent response model with the human ability and the task demand, respectively. This connection allows to model ability-demand gap using one parameter Item Response Model

(IRM). A natural extension for polytomous response using graded response model (GRM) was also used to evaluate performance on complex cognitive tasks. Pilot studies were performed to estimate ability parameter using simple cognitive task (e.g., simple mental multiplication). To further the understanding, two types of abilities (primary and secondary) a dual task scenario (e.g., complex collaborative task) was considered. Discrepancy in secondary task performance was found to be related to the gap. A variation of response latitude around the particular difficulty level (response attitude) was considered as gap value. With a combination of task response attitude, latitude and response time – we propose a 3D response model of gap estimation. To investigate the source of low cognitive performance in terms of mental resource allocation with task ability and demand multiple resource theory with dynamic shift of working memory resources was considered in precision of mental resource computation, which is considered as a direct correlation to mental workload. Thus, the range of score might represent the mental resource level gap. To study deeper analysis of cognitive task performance that reflects cognitive and collaborative ability-demand gap, Maximal Information Coefficient and Maximal Aasymmetry Score between ability and demand vectors are considered. Studies were performed to understand the effect of ability demand gap in collaborative sense making, cognitive dissonance and overload to advance the concept of assistive thinking in designing technology solutions for people with disability. This research expected to have an increased understanding of the parameters to have a deeper insight about collaborative sense making, provide effective feedback, classification of agent's roles in human-agent interaction and potentially transform assistive technology.

NOMENCLATURE

ECG: Electrocardiogram

HRV: Hart rate variability

EEG: Electroencephalogram

HCI: Human Computer Interaction

MINE: Maximal Information-based Nonparametric Exploration

MIC: Maximal Information Coefficient

MAS: Maximal Asymmetry Score

CDF : Cumulative distribution function

DIF : Differential Item functioning

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CHAPTER I: INTRODUCTION

"I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you can not express it in number, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of the knowledge, but you have scarcely, in your thoughts, advanced to the state of science, whatever the matter may be." - Sir William Thomson (Lord Kelvin) (1891, p.80)

"Blind Ambition" is an ongoing innovative research project at Computer Vision Perception and Image Analysis (CVPIA) lab at the University of Memphis. The main aim is to develop accurate, adaptive, affordable, effective and portable assistive technology solutions for the people who are blind or visual impaired. The key idea is to keep the design very simple so that the user can interact with the system effectively with minimal cognitive effort. The number of products and wide varieties of services were developed – such as, reconfigured mobile android phone application (RMAP) [159, 160], FEPS [161], iFEPS [162], iMAP [163], EmoAssist [164] and E-Glass [165] (Fig. 1).

Despite the advances and progresses, the assistive technology solutions remain inefficient, inflexible, and largely unnatural for many practical applications. In many instances, the system introduces errors in communication, cognitive overload/dissonance, inadequate feedback and ineffective interaction. It can be transformed by adopting ideas and strategies from human-human communications and interactions.

In general, human uses minimal cognitive resources, understand the context, identify gaps and quickly adjust for seamless communication or interaction. On the contrary, assistive technology systems are demanding more and more cognitive resources from the human. Also, human ability is latent, and random in nature, while the system's demand is fixed in most cases as it is programmed. This creates inconsistencies and dissonance in human-machine interaction [1]. More specifically, the gap between system's task demand and the human cognitive ability is widening, especially for people with a disability or limited abilities (in terms of cognitive, physical or social abilities). The increasing "ability-demand gap" is at the heart of inflexible, inefficient, slow, and artificial human-machine interaction systems. Modeling ability-demand gap has the potential to address some of the issues and help in collaborative sense-making [5-9], [94-98] and assistive thinking [10-13].

Designing an adaptive assistive technology solutions require an understanding of user's holistic need and ability to use the system to perform the task with minimal cognitive effort. Traditional designs focus on providing the functionalities without considering the adaptive behaviorism - a type of behavior that is used to adjust to another type of behavior or situation [1]. Using mobile devices in such technology solicitation is a challenging task [14 -19]. The research presented in this dissertation is a step towards

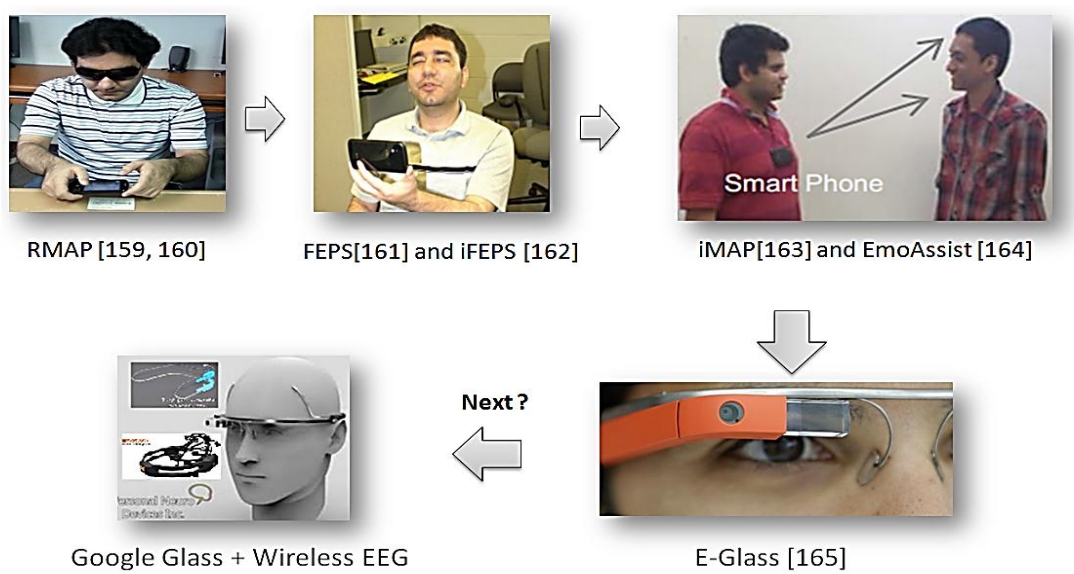


Fig. 1. Blind Ambition project in CVPIA lab

bridging the ability-demand gap in developing assistive solutions and collaborative sense-making.

Sense-making is the ability to connect novel information to a familiar schema (or adapt to an unknown environment), and selection of actions [5 - 7]. It can be viewed as a continuous effort to bridge the gap between human ability and agent's task demand in the context of human-agent (system) interaction. There are a number of different ways one can view the gaps in human-agent interaction depending on the agent's role and functions [2 - 4]. We focus only on the cognitive ability-demand gap for the sake of simplicity and also it is critical in designing technology solutions that are adaptive, assistive, and can potentially enhance users experience through collaborative sense-making.

The main goal of this dissertation is to pursue new avenues in designing assistive solutions for people with varying degrees of disability. Every disability is unique and effective technology solution would require "assistive thinking" and "collaborative sense-making" between the user and the system (agent). The key idea is to develop a suite of technique to model the ability-demand gap in order to have a deeper insight of human-agent interaction and leverage it in designing assistive technology solutions. The key objectives are to: (a) model the ability-demand gap using latent response model, (b) establish the association of model parameters with cognitive resources and ability-demand gap, and (c) use the gap model for collaborative sense-making to design and develop novel assistive technology solutions. Modeling and quantification of the ability-demand gap is critical in designing the next generation human-agent interaction system and assistive technology solutions. It is easy to note that a system capable of understanding and responding to the ability-demand gap will yield a system that is robust in error resolution, minimize the ability-demand gap, a personalized feedback and overall improved interaction experiences. This research pursued following specific aims (but is not limited to) to address the above mentioned problems:

A. Specific Aim 1 (SA1)

In a recent study [14] it was reported that, to be effective, the integrated on-device applications (mobile phone, iPad, etc.) should match the user's need and ability. In essence, it is critical to have a robust estimate of the ability-demand gap to have meaningful interaction with minimal cognitive resources. To estimate a user's ability, psychometric latent response theories and models are frequently used in educational psychology, medicine, nursing, political science and other disciplines [15-19]. Initially, one parameter logistic model (1PL) is examined over a benchmark dataset and two small experimental datasets (datasets are explained in Chapter III). Parameters of the model are linked to the ability of the user. The gap analysis facilitates in understanding the quality of communication between the collaborators. An acceptable gap motivates a user in seeking novel information and to connect him/her with familiar information – thereby, improves the sense-making process. In other words, lower ability-demand gap will motivate the learner to achieve collaborative sense-making [5]. Too much gap may cause cognitive overload, fatigue or techno-stress [82, 83]. How much gap can be considered as too much, still remains an open research challenge and will be explored as a function of individual's ability, agent's task demand, and context, types of communication/interaction. The proposed approach also will apply data mining and machine learning approaches, such as factorization techniques (non-negative matrix factorization, robust principle component analysis etc.), discriminant functions, nonlinear manifold learning and advanced regression techniques to find behavioral correlates (such as cognitive overload, dissonance etc.) with the model parameters [71-79]. Applying, response theories different ability attributes, such as – response attitude, response latitude, area under response curve, response principal component, differential item functioning (DIF) and item discrimination value can be computed [32-34]. Finally, robust and scalable models are aimed to estimate and quantify the ability-demand gap between the user and agent (system) [20-48].

B. Specific Aim2 (SA2)

Human performance has a direct relation to her mental resource utilization capability [54, 55-57]. In a complex cognitive task execution, the limited mental resources interfere her cognitive ability. A study of mental resources demand and its discrepancy with user's ability (computed from performance) is important and inline towards higher level gap identification [55-57].

To compute mental resource interference, multiple resource theory [55] precision of working memory resources [61] are adopted with a modification of limited ability concerns. The collection of this approach with the work presented in SA1 is that, latent logistic item response curve are considered similar to cumulative density function (CDF) with a constant of 1.702 [22]. Thus, CDF based analysis on mental resource associated task performance (in terms of precision score) are considered. In this proposed study, we apply Kolmogorov–Smirnov (K-S) [90-91] statistics on ability and demand vectors. Different parameters of K-S test and their correlation are considered as a gap and explored in Chapter IV (section C). We also aim to adopt signal flow directed graph [111 -114] based approach in robust cognitive gap identification and modeling. Once we have a graphical structure of instantaneous task evoked mental resource allocation, association rule mining and the frequent sub-graph mining will be applied in gap pattern identification. Together with the SA1 these results allow a dipper cognitive analysis of the gap in mental resource level.

C. Specific Aim3 (SA3)

Sense-making process bridges the cognitive gap that individuals experience when attempting to make sense of observed data (task) [6]. Ability based collaborative sense-making might require more insights (e.g., information flow dynamics analysis) in human-agent interaction. Information gain or information loss reflecting through bio-signals may help in deeper analysis of collaborative sense-making or sense-breaking (gap) in communication. In the same experiment with aim 1 and aim 2, behavioral (pupil size variation) [177] or physiological (ECG, HRV, EMG and EEG) bio-signals will be collected [177-179]. Entropy based approaches, mutual information, maximal differential entropy; transfer entropy will be adopted in computing collaboration or gap [101-104]. A new bi-variate measure of association, the MINE toolbox [102], is used to examine non-linearity, monotonicity, asymmetry, and non-functionality in uncovering and exploring relationships in ability-demand gap and collaborative sense-making. Hilbert analytic phase [117] will be computed using empirical mode decomposition [118] to illustrate the phase locking scenarios regarding gap or collaboration. This research will lead to an increased understanding of the parameters to have a deeper insight about collaborative sense making, provide effective feedback, classification of agent’s roles in human-agent interaction and potentially transform assistive technology.

The pilot study performed by this research on identification of the gap and its connection with assistive thinking and collaborative sense-making has laid the foundation to continue further investigations. In summary, Chapter II provides the background and context for the ability-demand gap quantification (section A), background of cognitive dissonance association with ability-demand gap (section B) and collaborative sense-making in (section C). Chapter III explains datasets used in this study. Chapter IV explains the confluence of ability-demand gap with cognitive dissonance and overload. Chapter V presents the study of gap influences in cognitive and collaborative ability. Ability-demand gap analysis application in assistive technology solution is explained in Chapter VI. Finally, Chapter VII concludes the dissertation with some lessons learned and possible future direction.

CHAPTER II: BACKGROUND

"Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?"   - T.S. Eliot (Eliot, 1934)

This chapter discusses operational definition of cognitive ability-demand gap and various measures that are used to quantify the gap (section A). It includes the brief review on item response modeling (Rasch model) with residue computation, response latitude and attitude computation. It also explains differential item functioning, kernel density estimation and Rasch tree analysis and how they are connected in ability-demand gap analysis (section B).

Limited capacity of working memory resources creates mental workload [50]. Study on cognitive load, cognitive dissonance and cognitive overload are imperative and aligned with ability-demand gap analysis. A brief description of cognitive dissonance and cognitive load types are explained with human working memory capacity measures (section C) [71-81].

To understand the effect of ability-demand gap in collaborative sense-making, a review on collaboration and sense-making are worked out, which is explained in section D. The concept of sense-making, collaboration and ability based collaborative sense-making are explained in sub-section [5-9], [94-104].

The measurement of ability-demand gap requires a non-parametric, scalable and scientific measure of similarity/difference analysis between ability and demand. In the final part, some related measurement techniques of human performance, human limited capacity of working memory resources and measures of collaboration are reviewed in section E.

A. Ability-demand gap problem

The discrepancy between user's ability and cognitive demand on the user by technology solutions remains the source of incoherence in human-machine (agent) interaction. This discrepancy is known as (dis)ability or ability-demand gap [1][5][6]. Modeling and quantification of the ability-demand gap is critical in designing the next generation human-agent interaction system and assistive technology solutions. It is easy to note that a system capable of understanding and responding to the ability-demand gap will help in error resolution, minimizes incoherent interaction, and facilitates meaningful and personalized feedback for overall improved interaction experiences. Figure 2 illustrates the ability-demand gap as the system (agent's) performance different roles and functions.

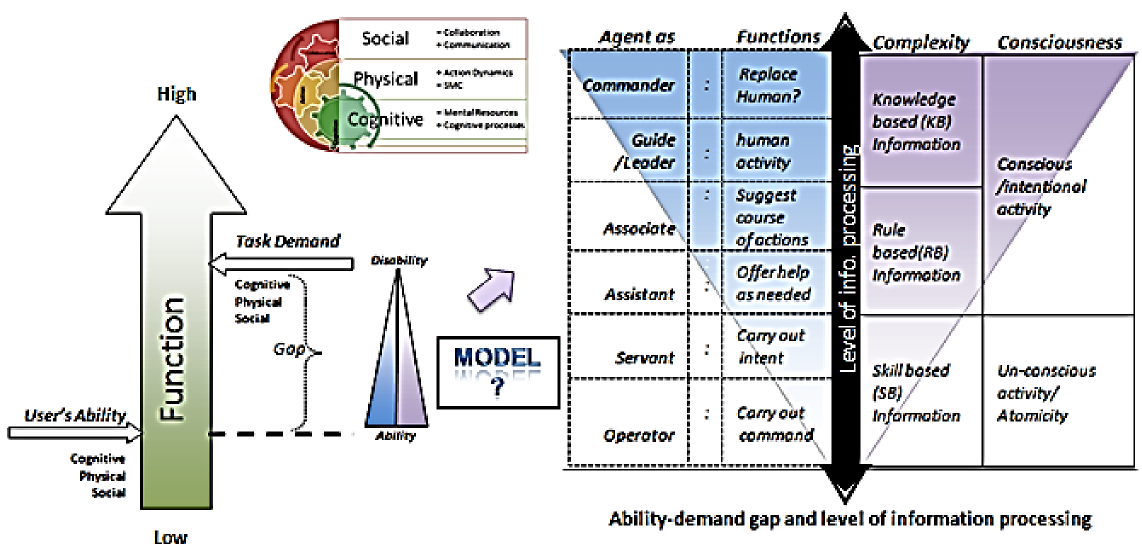


Fig. 2. Conceptual illustration of ability-demand gap (cognitive, physical, collaborative) [1], with connection of level of information processing [4] and consciousness [52]

Continuous monitoring of ability-demand gap can enable designing a multi-layer feedback system that is adaptive with the complexity of the cognitive task and consistent with user’s need. This research considers only the cognitive ability-demand gap in the context of human-agent interaction. A range of other types of gap can be considered from human-agent interaction depending on the agent’s role and cognitive functions [2 - 4]. Significance: This study seeks to analyze the deeper understanding of the ability-demand gap, formulate it in a cognitive perspective, validate with various applications including disabilities, adaptive authentication systems. The range of functions and agent role are shown in Table 1.

TABLE 1. Role of an agent in human-agent interaction. (modified from [4])

Gap	Agent’s Role	Functions	Example
No gap	Operator	Carry out command	Washing machine
Low gap	Servant	Carry out Intent (context dependent)	Smart Vacuum cleaner / automatic car
Moderate gap	Assistant	Offers help as needed	Intelligent Tutoring System (ITS)
High gap	Associate	Suggest courses of action	ITS with metacognition
Very high gap	Guide	Lead human activity	Autonomous bus driver
Highest gap	Controller	Lead a team	Automatic team leader

Some research questions related to cognitive gap are: How well do characteristics of human ability fit the demand or expected ability of the task? To what extent do task demands exceed or fall short of the abilities of the person? Are prior abilities of the employee met by actual task complexity? What is the degree of similarity between perceptions or beliefs in human and agent in their interaction? Does the ability of the person match the group ability in a team? Can novices provide performance evaluations that agree with expert ratings?

B. Assistive thinking

Assistive technology can be considered successful, if the user is able to perform expected activities with an increased level of independence. Designing an effective assistive technology requires a higher level of thinking, which can be accomplished by integrating (embedding) two popular thinking processes: system thinking and design thinking. System thinking starts with causal analysis and applies the system dynamics modeling techniques in building an optimal system [10 -11]. Steps in system thinking are: telling the story, drawing the graph, drafting a focus question, identifying the structure, applying the going deeper questions, planning and interventions. On the other hand, design thinking incorporates design-specific cognitive activities that designers apply during the process of designing. It can transform the way we develop products, services, processes - and even strategies. Design thinking is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of users, the possibilities of technology, and the requirements for business success [12-13]. Steps in design thinking includes understanding the problem consulting with experts, observing how people behave and interact with physical space, defining the problem properly, ideating the design by brainstorming, and design prototyping.

Shortly, system thinking helps us to understand the problems more fully before even jumping to a quick solution; design thinking helps us to create unique and often non-obvious solutions of that problem. An assistive thinking applies cognitive approach (understands users cognitive abilities and gaps) with the integration of system and design thinking. Based on user’s cognitive ability, assistive thinking provides the decision support to changes useful features in system operation as well as in user centric design process. The decision support embeds the quantitative (e.g., system components) and qualitative (e.g., design issues) attributes as part of hybridization. Such a thinking approach is incorporated in designing effective android application for the people who are blind or visual impaired [105-110]. Steps in assistive thinking include (but are not limited to): (i) effort to understand the user's intrinsic ability, (ii) estimate the ability-demand gap, (iii) use the ability-demand gap to generate multi-level feedback and resolving errors in interaction and (iv) bridge the gap through a collaborative sense-making process [13],[105] and (v) adopt hybrid of system and design thinking to implement the functionalities of the assistive solution that can be effectively managed with the given resources. Incorporating system and design thinking with the deeper understanding of ability demand gap, the assistive thinking creates a new paradigm of assistive technology design (detailed explained in chapter 6). Notably, assistive thinking mitigates shared understanding between the user and assistive technology tools (e.g., Mobile application).

C. Item response theory and models

Item response model predicts the probability of any response to a cognitive task given the true ability of the user. In general, users may have different levels of ability, and items (tasks) can differ in many respects—most importantly, some are easier, and some are more difficult. In a very simple item response setting, the subject x may only have dichotomous responses (1 = correct or 0 = incorrect), let us consider P_{ij} as the probability of a correct response, where i refer to the task, and the index j refers to the subject. Also, $P(\theta)$ to show that the probability of a correct response is a function of the ability θ. The simplest IRT model for a dichotomous task response has only one item parameter, the task difficulty parameter b_i. The probability of a correct response given the single task parameter bi and the individual ability level θ is known as item response function or logistic function which is shown in Fig. 3(a). The function shown on the graph is known as the one-parameter logistic function.

$$P_{ij}(\theta_j, b_i) = \frac{e^{(\theta_j - b_i)}}{1+e^{(\theta_j - b_i)}} \qquad (1)$$

This is known as one-parameter logistic (1PL) model or Rasch model [30-31], which predicts the probability of a correct response from the interaction between the individual ability θj and the task parameter bi. The parameter bi is called the location parameter or the difficulty parameter.

The logistic curve has its inflection point at X_{50} [22], the mean of the fitted (symmetric) function, at the point for which the predicted probability $P_{ij}(\theta j - bi)$ equals 0.5. This point determines the position of the curve along the scale of the amount of processing complexity. More difficult tasks are located to the higher or right end of the scale. Relatively easy tasks are located more to the lower or left end of the scale. The probability of incorrect response Q (θ) = 1- P (θ), is considered as the gap equation and is shown in equation (10). The probability of correct response P (θ) and the probability of incorrect response Q (θ) = 1- P (θ) have an interception point of 0.5, which is illustrated in Fig. 3(B) and Fig.3(C).

$$Q_{ij}(\theta_j, b_i) = \frac{1}{1+e^{(\theta_j - b_i)}} \qquad (2)$$

1) Item information function

In a cognitive experiment, any cognitive task should provide some information about the ability of the subject, but the amount of this information depends on how closely task difficulty matches the ability of the person and is known as item information function and expressed as –

$$I_i\,(\theta, b_i) = P_i\,(\theta, b_i) Q_i\,(\theta, b_i) = P_i\,(\theta, b_i)\{1 - P_i\,(\theta, b_i)\} \tag{3}$$

Where, P (θ) is the probability of correct response and Q (θ) is the P (θ) and the probability of incorrect response.

It is easy to see that the maximum value of the item information function is 0.25. It occurs at the point where the probabilities of correct and an incorrect response are both equal to 0.5 (Fig.3C).

As the ability becomes either smaller or greater than the item difficulty, the item information decreases.

This is clearly visible on Fig.3(D). Practically, an experiment requires a subject to interact with multiple test items or tasks. The test response function is thus the sum of the item response functions:

$$\mathrm{I_j}\left(\mathrm{\theta_j}\right) = \sum_{\mathrm{i}} \mathrm{I_{ij}}\ \mathrm{Q_j}(\mathrm{\theta}, \mathrm{b_i}) \tag{4}$$

Test as a whole is far more informative than each item alone, and how it spreads the information over a wider ability range. The information provided by each item is, in contrast, concentrated around ability levels that are close to its difficulty. The most important thing about the test information function is that it predicts the accuracy to which we can measure any value of the latent ability.

2) Precision and Measurement Errors

Precision is the opposite of error. Measurement error is expressed in the same units as the measurement itself—hence; we can compare it with the ability estimate, or use it to build a confidence interval around the estimate.

The variance of the ability estimate $\hat{\theta}$ can be estimated as the reciprocal value of the test information function at $\hat{\theta}$:

$$\mathrm{Var}(\hat{\theta}) = \frac{1}{I(\hat{\theta})} \tag{5}$$

Again the standard error of measurement (SEM) is equal to the square root of the variance,

$$\mathrm{SEM}(\theta) = \sqrt{\frac{1}{I(\theta)}} = \sqrt{\frac{1}{\sum_i P_i\,(\theta,b_i)Q_i\,(\theta,b_i)}}. \tag{6}$$

t is noticeable that the SEM function is quite flat for abilities within the (-2; +2) range, and increases for both smaller and larger abilities (Fig. 3F).   The likelihood of a subject's ability can be estimated from the pattern of success and failure. Let, P (θ_j; b_1), P (θ_j; b_2), Q (θj; b_n) are functions of θj, the likelihood function is:

$$L(\theta) = \prod_i P_i(\theta, b_i\,)^{u_i} Q_i(\theta, b_i\,)^{1-u_i} \tag{7}$$

Where, ui ∈ (0; 1) is the score on item i, is called the likelihood function. It is the probability of a response pattern given the ability θ and, of course, the item parameters.

There is one likelihood function for each response pattern, and the sum of all such functions equals to 1 at any value of θ.

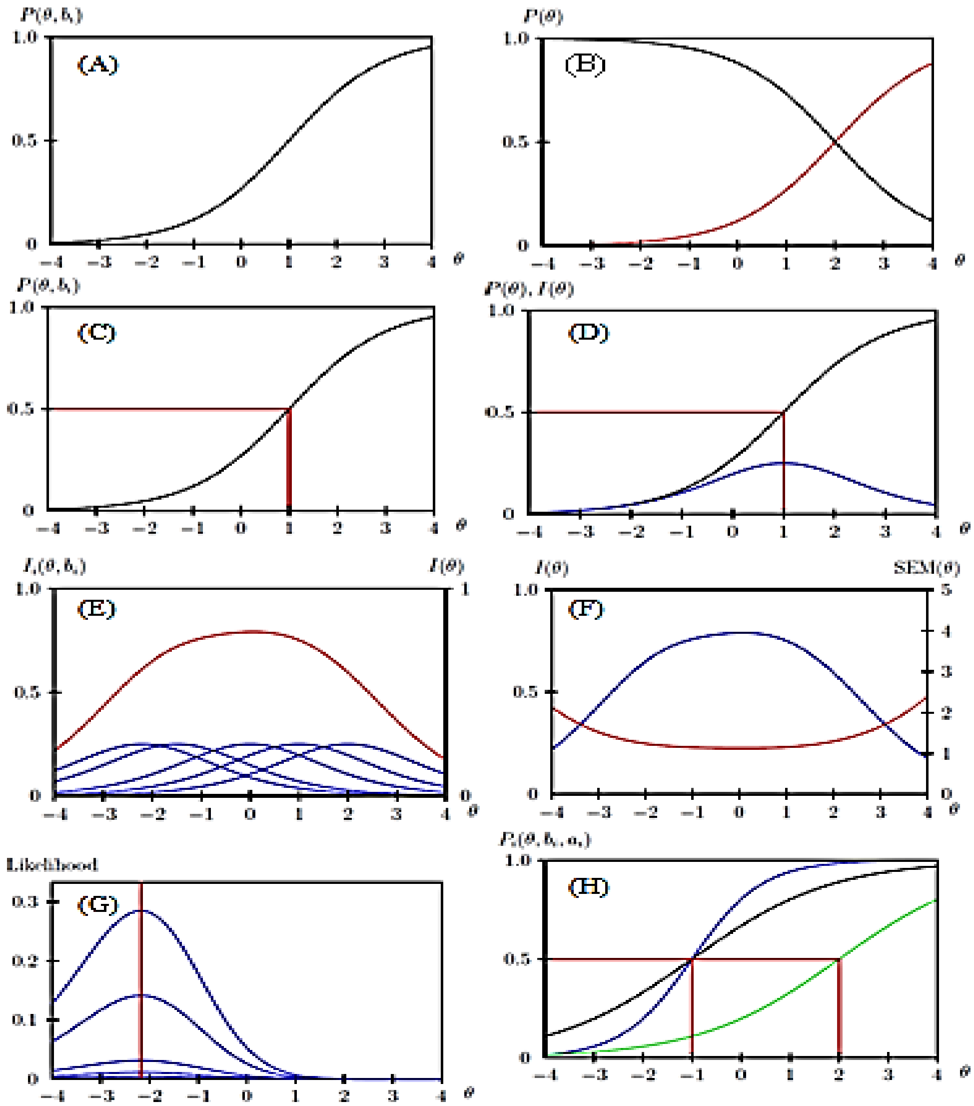


Fig. 3. Item Response Model, (A) The item response functions of the one-parameter logistic (1PL) model, (B) An IRT model for a dichotomous item, (C) Locating the difficulty of an item on the ability / difficulty axis, (D) Item information curve, (E) Item information functions and test information function for five items conforming to the 1PL model, (F) Test information function and standard error of measurement for a 1PL model with five items, (G) Likelihood functions for various response patterns having the same total score of 1 and (H)The item response functions of three 2PL items

3) Extended Rasch Model (Partial Credit Model)

Consider an integer random variable $X_{ni} = x \in \{0,1,\ldots,m_i\}$ with m_i as the maximum score of item i. The polytomous Rasch "Partial Credit" model [39-40], sometimes known as "extended Rasch model," is defined as the probability of outcome $X_{ni} = x$ is

$$\Pr\{X_{ni} = x, x > 0\} = \frac{e^{\sum_{k=1}^{x}(\beta_n - \tau_{ki})}}{1+\sum_{k=1}^{x} e^{\sum_{k=1}^{x}(\beta_n - \tau_{ki})}} \tag{8}$$

$$\Pr\{X_{ni} = 0\} = \frac{1}{1+\sum_{k=1}^{x} e^{\sum_{k=1}^{x}(\beta_n - \tau_{ki})}} \tag{9}$$

Where, τ_{ki} is the k^{th} threshold location of item i , β_n is the location and m is the maximum score for the item on a latent continuum. The model can be considered as the mathematical hypothesis that the probability of a given outcome is a probabilistic function of subjects (person) and task (item) parameters. A graph showing the relation between the probabilities of a given category as a function of person location is referred to as a Category Probability Curve (CPC). An example of the CPCs for an item with five categories, scored from 1 to 5, is shown in Fig.4.

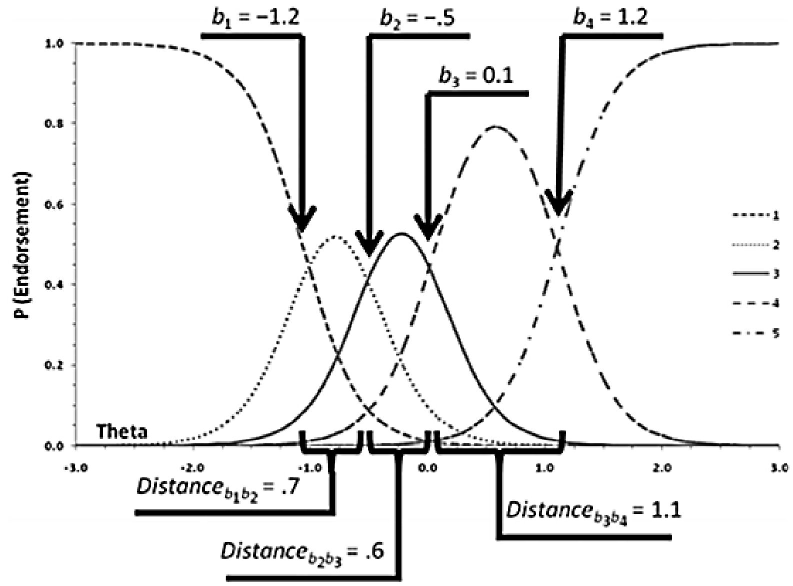


Fig. 4. Graphical representation of distance between graded response model b parameters [199]. Note: 1= Strongly disagree to 5 = Strongly Agree.

D. Sense and Sense-making

1) Sensation to cognition - Sensation is the process of receiving stimulus energies from the external environment and transforming those energies into neural energy. Perception is the process of organizing and interpreting sensory information so that it makes sense. Sensation involves detecting and transmitting information about different kinds of energy. The sense organs and sensory receptors fall into several main classes based on the type of energy that is transmitted. The functions of these classes include -

■ Photoreception: detection of light, perceived as sight

■ Mechanoreception: detection of pressure, vibration, and movement, perceived as touch, hearing, and equilibrium

■ Chemoreception: detection of chemical stimuli, perceived as smell and taste.

Fig. 5A. shows the general flow of sensory information from energy stimulus to sensory receptor cell to sensory neuron to sensation and perception [180].

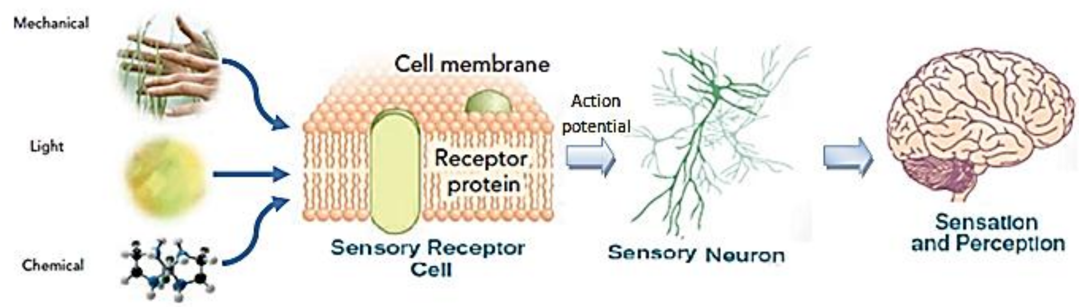
1) Thresholds - Any sensory system must be able to detect varying degrees of energy. This energy can take the form of light, sound, chemical, or mechanical stimulation. How much of the stimulus is necessary for you to see, hear, taste, smell, or feel something? What is the lowest possible amount of stimulation that will still be detected? (Fig. 5B)

2) Absolute Threshold - One way to think about the lowest limits of perception is to assume that there is an absolute threshold, or the minimum amount of stimulus energy that a person can detect. Absolute threshold is the minimum amount of stimulus energy that a person can detect. Absolute thresholds (Fig.5B) show the amazing power of our senses to detect even very slight variations in the environment [180]

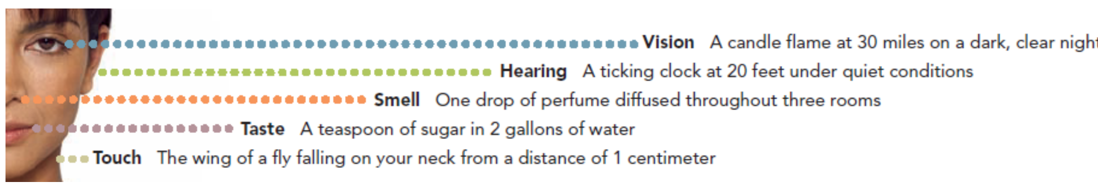
3) Cognitive Cycle Duration – Madl et al. [181] proposed that an initial phase of perception (stimulus recognition) occurs 80–100 ms from stimulus onset under optimal conditions. It is followed by a conscious episode (broadcast) 200–280 ms after stimulus onset, and an action selection phase 60–110 ms from the start of the conscious phase. One cognitive cycle would, therefore, take 260–390 ms (Fig. 5C).

E. Cognitive dissonance

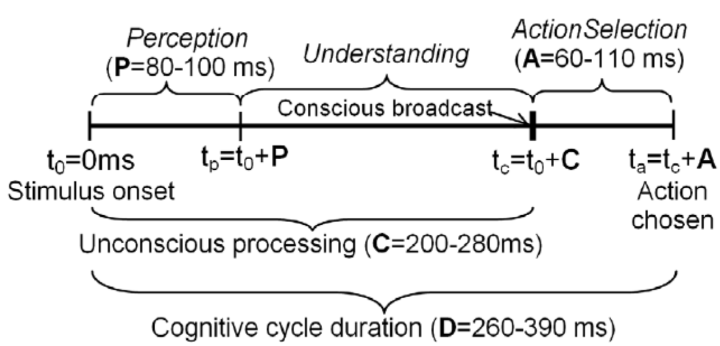
Most of the time people like to have control over their thoughts, feelings and desires. They often do experience an amount of yes/no or go/no-go situations. Sometimes they fail to filter all the contents in their mental activities that are inconsistent with intended states. Leon Festinger [71] termed this as cognitive dissonance. A clear example is, Aesop’s Fable “The Fox and the Grapes,” a fox tries to get some grapes that are hanging on a high, unreachable vine. After failing to reach them, the fox decides that the



(A)



(B)



(C)

Fig. 5: Sensation, perception and cognition process with timing; (A) Information flow in senses-making process [180]; (B) Approximate absolute thresholds for five senses [180], and (C) The timing of a single cognitive cycle (sense-making) [181]

grapes were probably sour anyway. An interesting aspect of this story is the idea that actions (e.g., giving up on the grapes) can change preferences. In considering such a mental workload involved with this process [296], it is conceivable why there may be such dissonance is just one of many biases that work in our everyday lives. Human don't like to believe that we may be wrong, so we may limit our intake of new information or thinking about things in ways that don't fit within our pre-existing beliefs. Psychologists call this "confirmation bias"[35, 36].

1) Cognitive Load and overload

The physical analogy of cognitive load is used by cognitive psychologists, instructional designers, and neurobiologists. The most commonly agreed upon definition of cognitive load is the mental states during cognitive task execution (problem solving) that is imposed by limited capacity of working memory resources [10, 11]. The cognitive overload and cognitive lock-up (in another word the cognitive dissonance) can be considered as the effects of cognitive tasks induced on the working memory of the subject.

Cognitive overload is a situation when user is loaded with too much information or too many tasks simultaneously, resulting being unable to process this information. In this situation, information processing demands go beyond user's processing limits. So, cognitive overload is considered as the ceiling of cognitive dissonance [80]. Fig. 6.

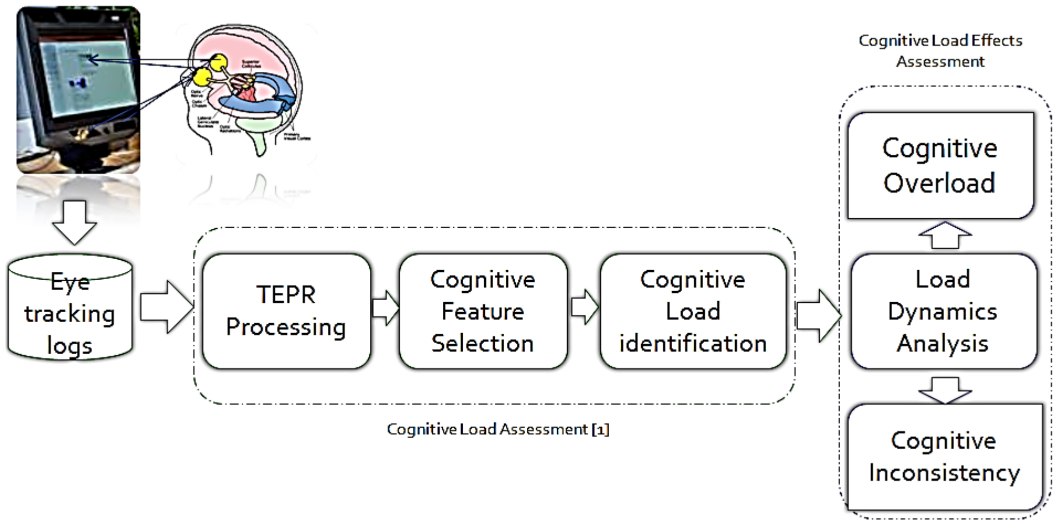


Fig. 6. Illustration of cognitive load effects: overload and dissonance with pupillary dynamics data.

illustrates cognitive load effect from pupillary responses with mental multiplication task [128] interaction. The Fig. schematically represents cognitive load effects as cognitive overload or dissonance. The cognitive task load model [67, 58] explains a way to measure cognitive overload from level of information processing, time occupied and number of task switches, which is shown in Table 2.

TABLE 2. Features of cognitive effort estimation [67]

Dimensions	Task Performance Periods		
	Short (<5min)	Medium (5-20min)	Long (>20min)
Time occupied = Low Info Processing = Low Task switches = low	No problem	Under-load	
Time occupied = High Info Processing = Low Task switches = low	No problem		Vigilance
Time occupied = High Info Processing = All Task switches = High	Cognitive lock-up		
Time occupied = High Info Processing = High Task switches = High	Overload		

2) Computing human working memory capacity: a brief review

According to Baddley's working memory model [49] central executive coordinates with mental resources and long term memory. What resources are free and which are allocated, to which process they are allocated, and a queue of processes waiting for this resource to become available can be a task list of the central executive. In the case of interruption management, central executive may signal some required process to wait.

In Fig. 7, the dark purple areas represent long-term or crystallized knowledge. The episodic buffer provides an interface between the sub-systems of working memory and long-term memory (LTM), Baddley have a new memory model with tactile, smell and taste sensation, which he states as speculative view of the flow of information from perception to working memory. He posted open questions with this new construct; a detail can be found from [50].

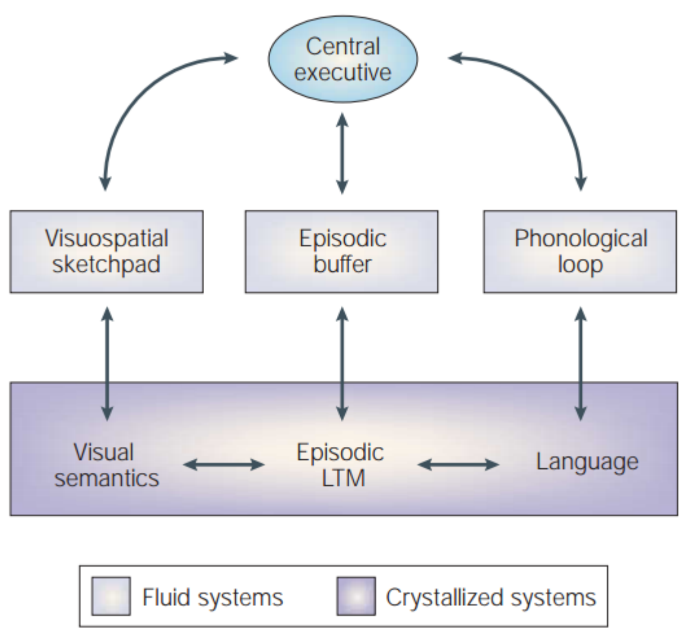


Fig. 7. Baddley's multi-component working memory revision [50]

In Fig. 8, we connected the new model combining Baddley's idea, Atkinson's information processing model and Grossberg's adaptive resonance theory [127]. VSSP - visuospatial sketchpad, processes visual and hepatic sensory information. Apart from the episodic buffer, and the new model attempt to provide considerably more speculative detail.

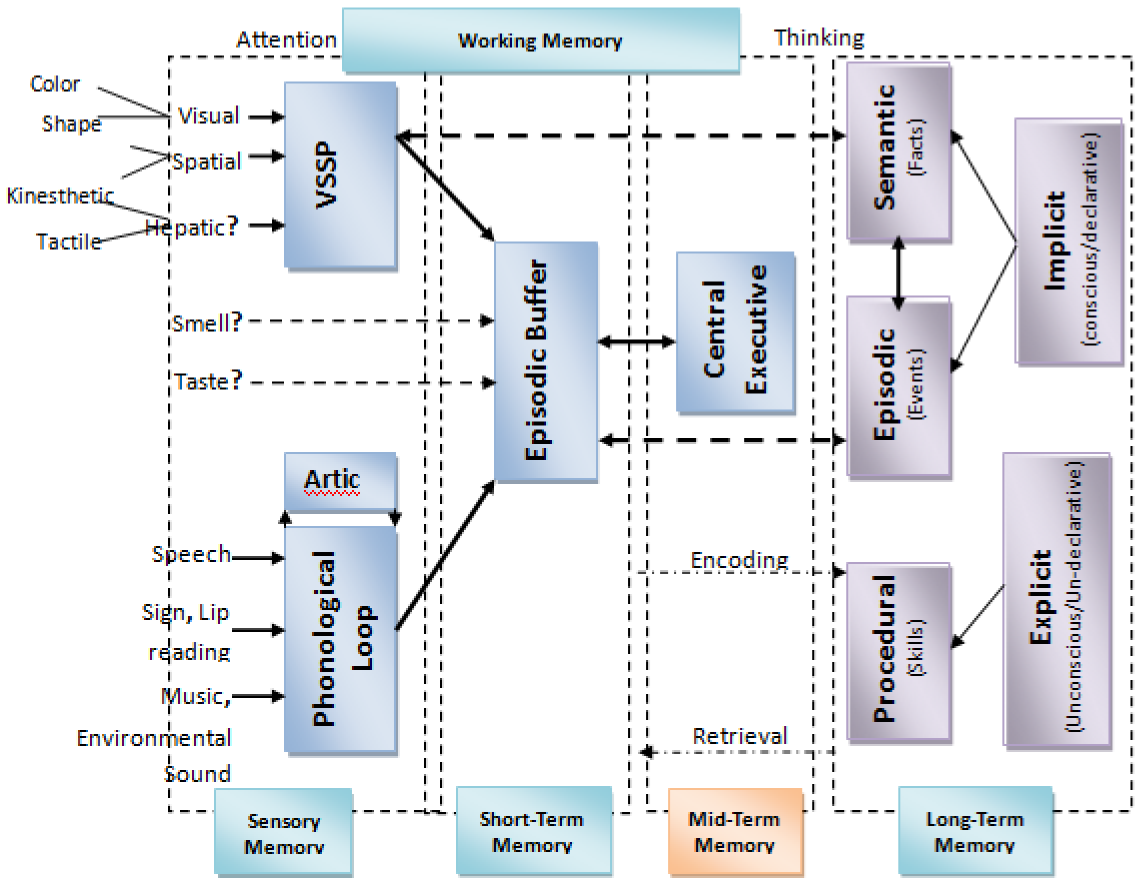


Fig. 8. Combination of Baddley's, Atkinson's & Shiffrin and Grossberg's models [50,53,127]

Cognitive gap analysis requires understanding of human cognition process (information processing), but human cognitive processing is bounded by human working memory capacity [54]. A challenging ongoing debate among cognitive scientists is whether working memory capacity is constrained by a limited number of discrete representations or an infinitely divisible resource. Miller [59] summarized evidence that people can remember about seven chunks in short-term memory (STM) tasks. Recently, Bays and Husain [61] claims this is inconsistent with their finding that precision continues to decrease with set size up to at least six items, even when they allow for the possibility that some items are not stored in working memory. Zhang and Luck's [182] model indicate that working memory capacity is limited to about two items (0.38 probability of storing any individual item in a six-item array). Earlier, Cowan [62] considers the central memory store is limited to three to five meaningful items in young adults and four in general with a number of experimental evidences. Breg et al. [165] introduced a model in which resource is not only continuous, but also variable across items and trials, which causes random fluctuations in encoding precision. Some studies have found evidence that precision decreases with set size, but others have reported constant precision. Mazyar el al. [183] found the concept of heterogeneity in test item set. They proposed that precision decreases with set size when the destructor are heterogeneous, regardless of whether short-term memory is involved, but not when it is homogeneous. Keshvari et al. [184] found no evidence of an item limit with a number of change detection experiments. According to Keshvari et al., human change detection performance was best explained by a continuous-resource model (i.e., mean precision decreasing with increasing itemset size) in which encoding precision is variable across items and trials even at a given set size. Luck and Vogel (2013) found the empirical evidence and neural network models currently favor a discrete item limit. Capacity differs markedly across individuals and groups and very recent research indicates that some of these differences reflect true differences in storage capacity whereas others reflect variations in the ability to use memory capacity efficiently. A recent nature paper Ma, Hussain, and Bays 2014 [61] revised on working memory and is widely considered to be limited in capacity, holding a fixed, small number of items, such as Miller's 'magical number' seven or Cowan's four. They recently proposed with behavioral and emerging neural evidence that, the working memory might better be conceptualized as a limited resource and the quality rather than the quantity of working memory representations determines performance. A time line of such evaluation is studied.

Among all recent work, we consider qualitative method of working memory capacity through precision of item retrieval. The information stored in LTS is comparatively weak and decays rapidly as succeeding items are presented. Information stored in the long-term memory increases linearly with time and the item resides in the buffer. Once an item leaves the buffer, the LTS trace is assumed to decrease as each succeeding item is presented for the study. According to Atkinson and Shiffrin memory model [53], the probability of retrieving the correct response from LTM depends upon the current trace strength, which in turn, depends on the amount of information transferred to LTS. Specifically, it is assumed that information is transferred to LTS at a constant rate θ during the entire period an item resides in the buffer; θ is the transfer rate per trial. Thus, if an item remains in the rehearsal buffer for exactly j trials, then that item accumulated an amount of information equal to $j\theta$. Also assume that each trial following the trial on which an item is knocked out of the buffer causes the information stored in the LTS for that item to decrease by a constant proportion r. Thus, if an item were knocked out of the buffer at trial j, and I trial intervened between the original study and the test on the item, then the amount of information in LTS at time of the test would be jθr i-j . Probability of correct retrieval of an item form LTS: If the amount of information in LTS at the moment of test is zero, then the probability of a correct retrieval should be at the guessing level, as the amount of information increases, the probability of a correct retrieval should increase towards unity. We define Pij as the probability of the correct response from LTS for an item that was tested as lag i, and resided in the buffer for extremely j trials. Considering the above specification of retrieval process,

$$P_{ij} = 1 - (1 - g)e^{-j\theta(\tau^{i-j})} \tag{9}$$

Where, g is the guessing probability. How to compute the length of time an item resides in the buffer was an open question.

Let, βj is the probability an item resided in the buffer for exactly j trials, given that it is tested at a lag greater than j. The probability of a correct response to an item tested at lag i can be written in terms of βj's. Let Ci represent the occurrence of a correct response to an item at lag i. Then,

$$\Pr(Ci) = \left[\mathbf{1} - \sum_{\mathbf{k=0}}^{\mathbf{i}} \beta_{\mathbf{k}}\right] + \left[\mathbf{1} - \sum_{\mathbf{k=0}}^{i} \beta_{\mathbf{k}}\, \mathbf{p_k}\right] \tag{10}$$

The first part of the right side indicates the probability that the item is in the buffer at time of the test. The second part contains a sum of probabilities, each term representing the probability of correct retrieval from LTS of an item which remained in the buffer for exact k trials and was then lost. So there are four parameter in the model, r – buffer size; N – item into the buffer; θ - the transfer rate of information to LTS and τ = the decay rate of information from LTS after an item has left the buffer. One final process must be considered before the model is complete. This process is the recovery of information from STS which is not in the buffer. It will be assumed that the decay of an item which has entered and left will be rapid, so rapid that an item which has left the buffer cannot be recovered from STS on the succeeding test. The only time in which recovery is made from STS, apart from the buffer, occurs if an item is tested immediately following its study (i.e., at a lag of 0). The recovery probability can be assumed as one. The probability of correct retrieval is one when lag is zero.

3) Summary of research on workload, mental workload and cognitive load

Review on the number of research articles which are related to workload, mental workload and cognitive load, found using Microsoft academic search are summarized in Table 14 (Appendix A).

4) Performance –resource function

According to Norman [54], performance is monotonically nondecreasing function of the amount of processing resources that are allocated, with the upper limit on available resources given by *L*. Performance within the data limit region of operation is independent of the expenditure of processing resources. In the resource-limited region, performance-resource relationship depends upon the detailed operation of the processes

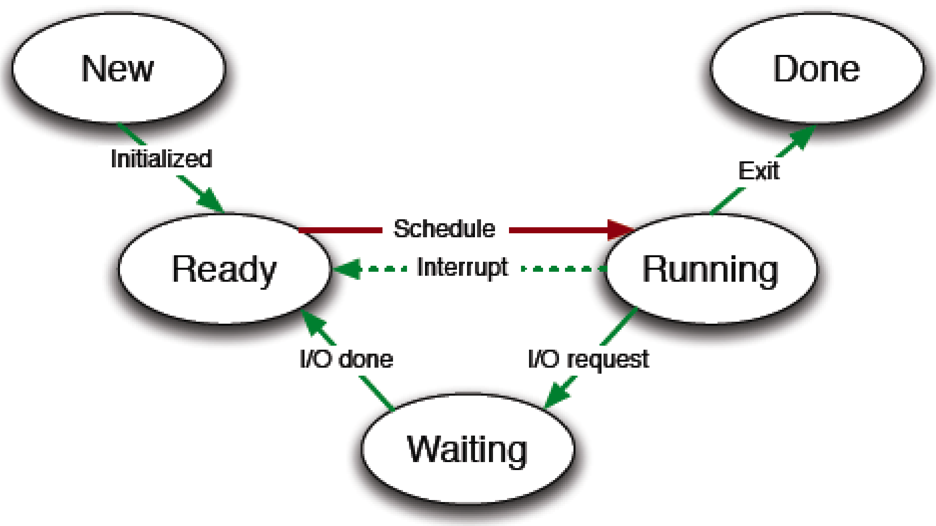


Fig. 9. States of cognitive processes [88]

which are involved (Fig. 9).

Mental resources are the working memory resources used in cognitive processing. Mental resource categories may include visual, auditory, tactile, or other related to action (Fig. 10). By definition, all mental resources within a category are equivalent, and a request of this category can be equally satisfied by any one of the resources in that category.

It means that the resources are unique in nature. Some categories may have a single resource.

a) Cognitive processes - cognitive psychology explains the cognitive processes as the performance of some composite cognitive activity or an operation that affects mental contents; "the process of thinking"; "the cognitive operation of remembering". In information processing, cognitive process may be in any of the five states. As a cognitive process executes, it might changes the following states:

(1) New state: The process is being created.

(2)Running state: Instructions are being executed.

(3) Waiting state: The process is waiting for some event to occur.

(4) Ready state: The process is waiting to be assigned to a processor

(5) Terminated state: The process has finished execution.

Cognitive psychologies think about two broad category of process: data-limited processes and resources-limited processes.

(1) Resource-limited process - in a complex cognitive task, task performance relates to cognitive effort up to some limit. An increase in mental resources can result in improved performance; the process is known as resource-limited.

(2) Data-limit process : task performance sometimes only depend on the quality of the data. Whenever the performance is independent of processing resources, we say that the task is data-limited [54].

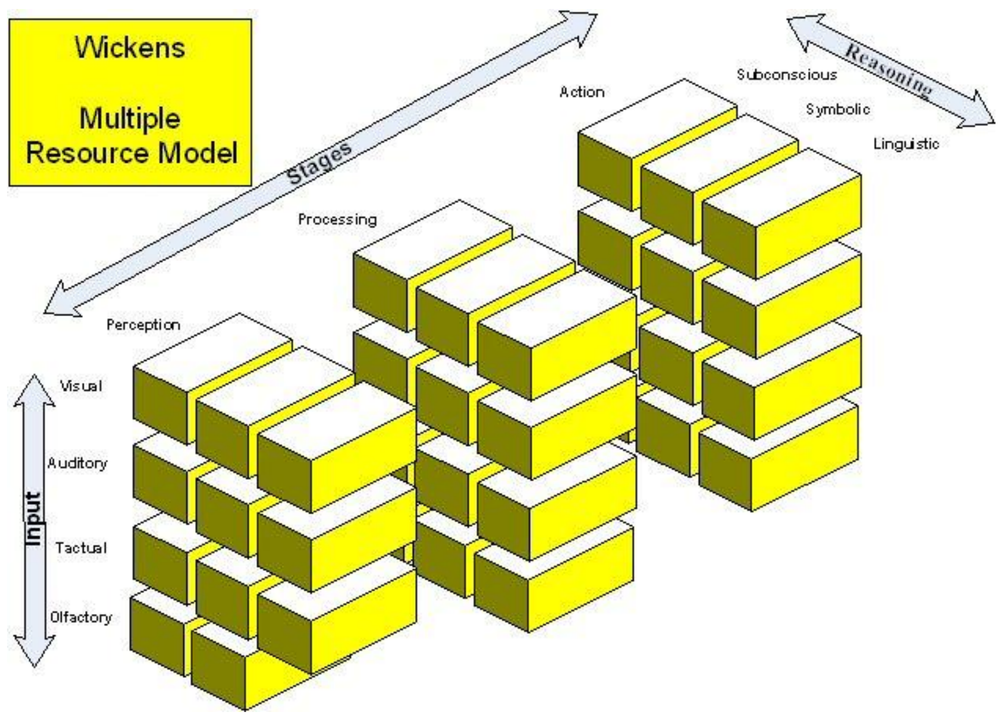


Fig. 10. Multiple-resource theory and computational modeling - Wickens [55]

5) Multiple Resource Theory

In complex information processing, human use several different pools of resources that can be tapped simultaneously. According to Wickens [55-57] humans have limited capability for processing information and performance decrement occurs as a shortage of these different resources. Cognitive resources are limited, and a cognitive ability-demand gap occurs when the individual performs two or more tasks that require a single resource (as indicated by one box on the diagram). The gap should be lower than individual available mental recourse limit, or it causes mental workload. In cognitive task execution, the excess mental workload is termed as cognitive overload. A task using the same resource can cause problems and result in errors or slower task performance, causing cognitive ability-demand gap, cognitive overload and finally disability.

Workload (WL) is defined as the time required (performing the tasks) over time available to perform the task. A value greater than 1 indicates overload situation. WL value range 0.30 – 0.80 indicated average (acceptable) load and WL less than 0.30 associates to the under load situation.

According to Wicken's multiple resource model [55, 57], each task can be represented as a vector of its processing demands, both at a quantitative and qualitative level. Qualitative level explains 'which resources' whereas quantitative level explains 'number of resources'. Example – Resources demand in the task of vehicle control in automobile driving:

$$D = V - S_a + M \tag{11}$$

Where , D= resource demand, V = Visual resources, S_a = Spatial ambiant resources and M = manual, physical or action.

The amount of load within each of these resources will be task dependent. Example : Visual/special resources demand will increase on dimly illumination highway at night, whereas manual resources demands will increase in icy roads. Both will increase as vehicle speed increases, as long as some maneuvering is required.

The model computes a loss of performance on one or both tasks from its single task level by a formula that penalizes performance in the extent that: The total demand on both task is high, and both tasks compete for overlapping resources (common levels on one of the dichotomous dimension) within the four dimensions of the multiple resource model (or within the dimensions of whatever other model is selected). The extent to which one or the other of the two tasks loses performance can be established by the allocation policy. If both tasks have equal priority, each task will share equally in the performance decrement.

A task analysis shell, useful in constructing resource vector, contains task demand values as input at different resources on each task. Value '1' for some demand and '0' for no demand. Conflict matrix represents the amount of conflicts between resource pairs across tasks. If two tasks cannot share a resource, the conflict value is 1.0 (e.g., two task simultaneously demanding voice resources). If two tasks can perfectly share the resource, the conflict value is 0. Heuristic: the amount of conflict is proportional to the number of shared resources within 4D model. Task demand (resources) can be computed from the conflict matrix and can be processed using normalized conflict score and can be compared with the response latency.

6) Memory research timeline

Timeline of memory, working memory, encoding, and cognitive assessment is shown as Fig.11.

7) Cognitive cost analysis

When we try to learn something we sometimes feel burden in interior steps or at the very beginning. This burden of understanding, recalling, or memorizing requires memory cost - named as cognitive cost [185-187]. Understanding and analyzing causes of cognitive costs may help us to reduce the overall costs during cognition.

In this section, we perform a brief review on factors (antecedents) of cognitive costs. A cause effect diagrams with these ten costs are shown in Fig. 12.

1.) Learning willpower – factor that indicate learner is willing to learn or not. Willpower is regarded as the battery of doing things.
2.) Background/Knowledge – factor regarded as the common ground or background knowledge of before starting the learning process.
3.) Task activation energy – factor related to the cost of energy required to start and continue a learning task.
4.) Opportunity Cost – factors accounts for the cost for a bad decision to select a subtask/sub goal. Time wasting cost for bad sub-goal selection.
5.) Cognitive Inertia – factors related to cost for delaying to actively doing task in all steps.
6.) Sensory Impairment - Health of sensory organs also impart in cost of spontaneous task perception.
7.) Hormonal Balance – Hormonal change in body may cause people pleasant to be consistent in the cognitive task. Example –Cost impact for gender differences.
8.) Neurosis/fear – Fear or in general neurosis may impart in higher cognition cost. Example – during driving the task, a new driver may fear have different things, like highway traffic, speeded etc.
9.) Maintenance cost –Bad maintenance of brain capacity or over feeding the brain may cost in cognition.

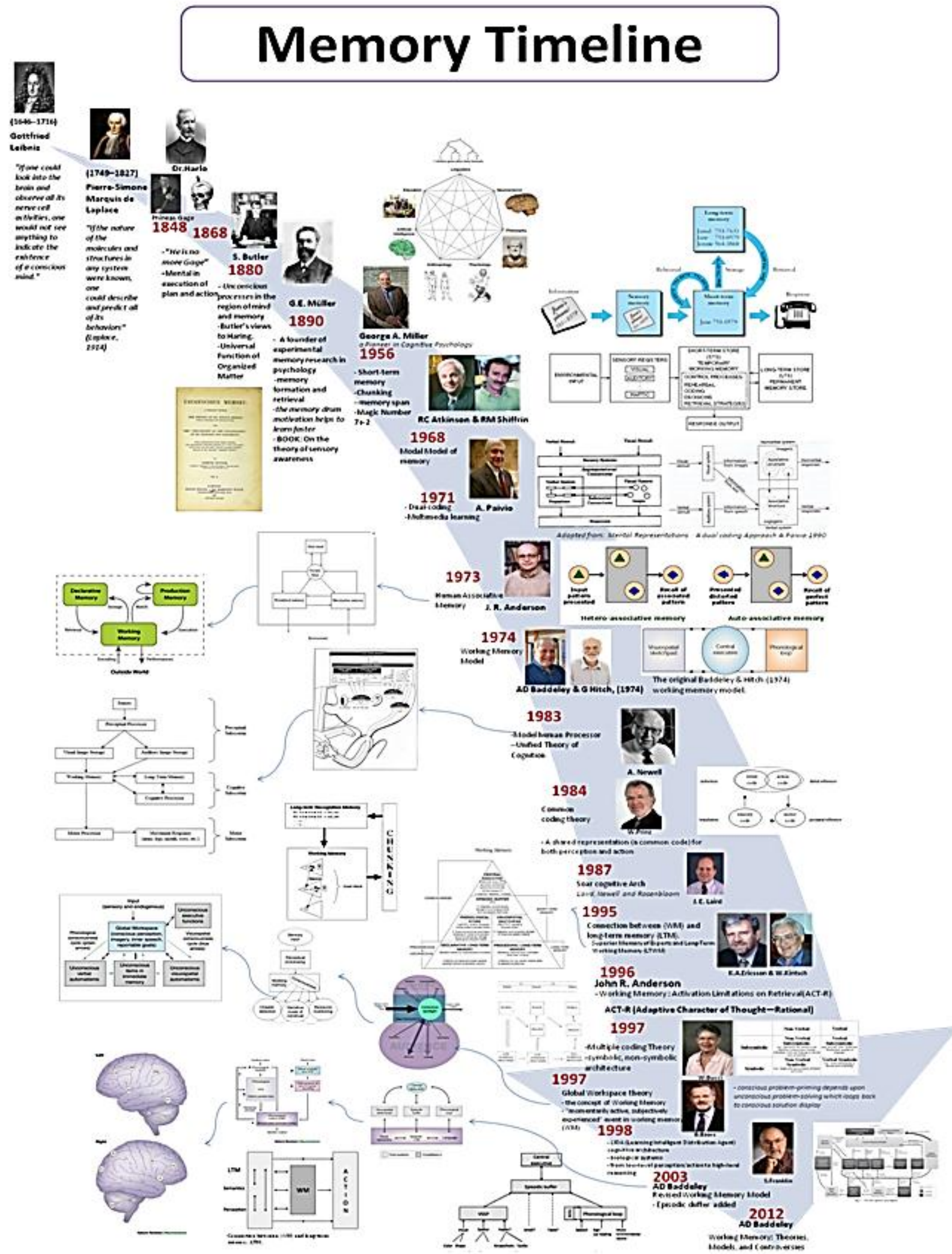


Fig. 11. Human memory, coding and models - Time line

10.) Age - Human cognitive system has a lifetime. The child, young or old is not able to use their sensory, primary and secondary memory in the same way.

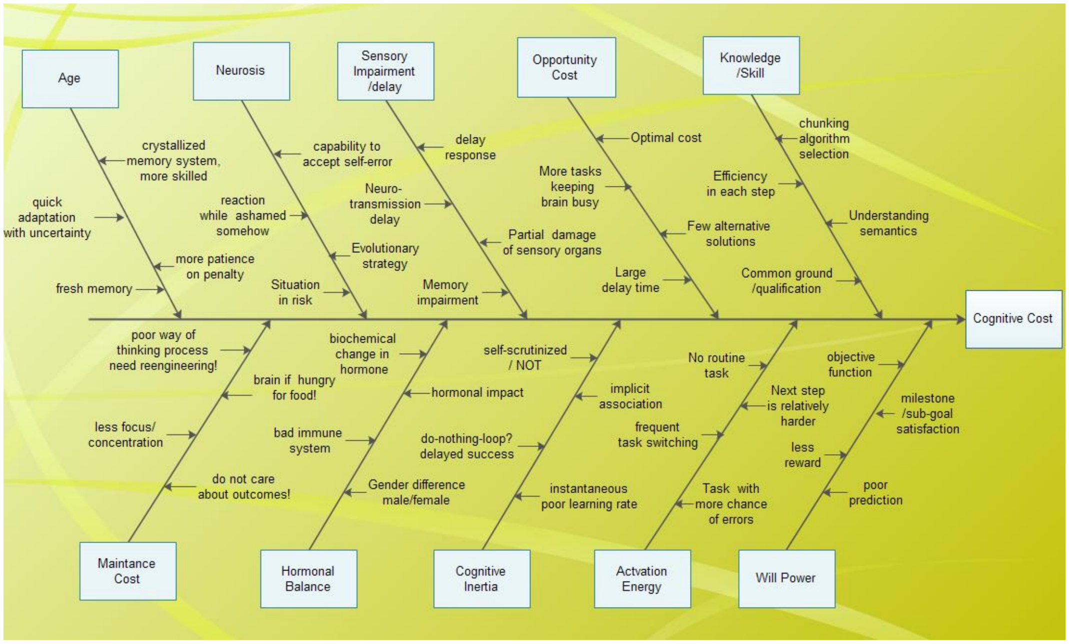


Fig. 12. Cognitive cost analysis cause-effect diagram (proposed - Hossain and Yeasin, 2014)

Details of Fig. 11 and Fig. 12 can be found from author's future work.

E. Collaborative sense-making

Humans seek information, sense and share this information with others as a social need. For instance, information seeking behavior may include finding and linking information, listening, or even observing and studying. The sensing may include, igniting passions, creating and converging, and by testing opinions. Humans also share information by mutual engagement, shared understanding and working with collaborators. In human-centric model development, sense-making concept first appeared through the Dervin's communication research. Dervin's triangle model [4] explains how individually trying to make sense of a complex situation steps through a space-time context. Beginning with the current situation, individual moves through the space to have expected outcomes (effects, consequences, hindrances, impacts). He recognizes gaps in understanding (questions, confusions, muddles) that must be "bridged" via resources (ideas, cognitions, beliefs, intuitions) to meet expected demand. Dervin's work aligns with Human-Computer Interaction (HCI) research and aims to design and implement human-centric communication systems including system debugging [5]. Following Dervin's "bridge" aspect of sense-making a series of sense-making models began to appear. Among them, Russell et al. [7] defines sense-making as how people make sense of information around them, and how they represent and encode that knowledge, so as to answer task-specific questions. Russell et al.'s cost structure of sense-making model includes the core part of sense-making known as learning loop complex. The learning loop complex seeks suitable representations of the problem, instantiates those representations, shift the representations when faced with missing data (terms as residues) and finally consume the instantiated schemas (i.e., encodons). A more detailed version of Russell's cost structure of sense-making model reflects through Pirolli and Card (2005) cognitive task analysis and verbal protocols with intelligence analysis as an example of sense-making.

Like other sense-making model, Pirolli and Card pointed out that sense-making is a process that involves planning, evaluating, and reasoning about alternative future steps. Pirolli/Card model can make sense of the change of users' representations in sense-making processes. The Pirolli/Card model can be viewed as a model with a low-level focus on Dervin's "bridge" component and Russell et al.'s learning loop complex, and this low-level focus made it a good fit for our interest in investigating end-user debugging in a fine-grained way.

A Cynefin domain for sense-making is identified by Kurtz and Snowden (2003). Sense-making represents a complete cognitive cycle, in combination of "action and cognition together" (Weick, 1995). It bridges the cognitive gap between the expected technological advances made it possible for people with disabilities to collaborate among themselves using smart phones. Collaborative sense-making can be thought as drawing from individual level cognitive processes up to social interaction processes. More specifically, sense-making in collaboration signifies meaningfully retrieved information by collaborative information seeking.

Collaboration sense-making is illustrated in Fig.2.5, (A) illustrates Dervin's sense-making model, (B) shows the relation of collaboration sense-making with other terms, (C) and (D) explains collaboration as the higher level of communication. Collaborative sense-making is factored with six rubrics, interaction, intent, trust, symmetry of belief and level of awareness [8]. Collaborative sense-making (Table 3) aims to support a group people, who are explicitly working together to make a successful communication or sense-making task. In collaborative sense-making, collaborative systems should provide collaborators capability "to infer some idea what they have, what they want, why they can't get it, and why it may not be worth getting in the first place" (Weick, 1995). Collaborative sense-making can be thought as a driving force of individual's cognitive processing towards social interaction processes.

TABLE 3. Collaboration structure [187]

Process	*Structure*	*Information Integration*
Communication	Network, round table	Very Low
Contribution	Support group	Low
Coordination	Task Force, council, alliance	Average
Cooperation	Partnership, coalition, consortium	High
Collaboration	Collaboration	Very High

A collaborative system should satisfy some requirements to better support collaborative sense making activities including interpersonal social communications. Some essential requirements are summarized in Table 4.

TABLE 4. Summary of essential requirements in collaborative sense-making [188]

	Requirements : Support for
1.	Creating explicit representation
2.	Co-existence of different representations
3.	Developing shared representation
4.	Creating representation using templates
5.	Providing workspace for developing shared representations
6.	Consensus building and reaching agreement
7.	Facilitating and moderating interactions
8.	Exchanging documents
9.	Retrieving and visualizing information

Individual sense-making should satisfy 1, 2, 4 and 9; the collective sense-making should satisfy 3, 4, 5, 6, 7, 8 requirements [189]). She also identified that, as a prerequisite, requirement number 2 dependents on 1; the requirement 3 depends on 1, 5 and 6.

F. Performance measurement techniques

To have an accurate measure of ability-demand gap, ability and demand should have to be in the same scale, and common measurement technique should be adopted. Table 6 summarizes pros and cons of some behavioral measures used in human performance evaluation.

TABLE 5. Major behavioral measures used in cognitive engineering [26]

Measure or Method	*Example*	*Advantages*	*Limitations*
Accuracy (% correct, % error)	Memory recall	Objective measure of processing effectiveness	Ceiling effect (No difference – because the task is too easy); floor effect (No difference – because the task is too hard); speed-accuracy trade-off;
Response time (RT)	Time to answer a specific question	Objective and subtle measure of processing, including unconscious processing	Sensitive to experimental expectancy effects and to effects of task demands; speed-accuracy trade-off
Judgments	Rating on a seven point scale	Can access subjective reaction; easy and inexpensive to collect	Participant may not aware about the scale; may not have concise access t the information; may not be honest;
Protocol collection (Speaking aloud one's thought about a problem)	Talking thought	Can reveal a sequence of processing steps	Cannot be used for most cognitive processes, which occur unconsciously and in a fraction of a second

Similarly, measures of cognitive ability are classified in direct or indirect and subjective or objective as stated in Table 6.

TABLE 6. Categorization of Cognitive Ability Measurement

Objectivity	*Causal Relationship*	
	Indirect	Direct
Subjective	Self-reported invested mental effort	Self-reported stress level Self-reported difficulty of materials
Objective	Physiological measure Behavioral measure Learned outcome measure	Brain activity measure (e.g., fMRI) Dual-task performance

With all these categorization, the measurement also depends on data distribution, size and types.

G. Cognitive Load Types and Assessment

Instructional designers consider three types of cognitive loads associated with the learning process. These are (1) The Intrinsic cognitive load - represents the inherent difficulty associated with any problem. Example: “2+2” or “solving a differential equation”. (2) The extraneous cognitive load - considers how the information is presented to the learners. It is under the control of instructional designers. For example: Defining a “square shape” literally or showing a picture takes different cognitive load. (3) The germane cognitive load - cognitive load devoted to the processing, construction and automation of schemata. The cognitive load theory suggests increasing the germane load while decreasing intrinsic and extraneous load. Mayer [153, 171] identifies, in multimedia learning cognitive outcomes with ten different effects. These are summarized in Table 7.

TABLE 7. Summary of different effects during cognition

Cognitive Load	*Effects*	*Example*
Extraneous cognitive load (Design and Management)	a. Goal free effect	Given that: If y = x + 6, x = z + 3, and z = 6, find what you can. Attention would focus on "z = 6" as this is the only variable specified as a numerical value.
	b. Worked example effect	Step by step demonstration of how to perform task or problem
	b. Problem completion effect	Some problems take more time to complete than it is expected.
	c. Split attention effect	Split attention occurs whenever a learner needs to attend to more than one source of information, or more than one activity. A common source of split attention is the need for the learner to perform a search.
	d. Redundancy effect	The graphic contains labels to indicate parts of the heart, and arrows to indicate the flow of blood.
	e. Modality effect	The graphic is presented visually, but the text is only presented auditory.
Germane Load (Maximizing)	f. Variability effect	Example: variability used in an user interface
	g. Self-explanation effect	Example: picture tales something,
	h. Imagination effect	Example: easy to guess
	i. Interactivity effect	Example: next step is deducible from previous steps
Intrinsic Load (Minimizing)`	j. Sequencing effect	Flow of learning is sequential
	k. fading support effect	Missing partial information; practicable but takes time

H. Ability-demand gaps with assistive technology solution

Traditionally people with disability use hand-over-hand or hand-over-face for communication (e.g; hand-over-face Fig. 13). Hand-over-hand sign language is also called tactile signing. It can be used by people who are either deaf and blind (DB). It requires the blind to have previously been sighted so as to have knowledge of what he/she says. It requires the interpreter to put his hand on the client's hand and ride along the signing up. Helen Keller, an American author who was deaf-blind and Anne Sullivan who was her tutor, also visually impaired. Anne was able to teach Helen to speak using the 'Tadoma' method which involved touching the lips and throats of others (Fig.13) as they spoke [190].

Fig. 13. Hand over face - Helen Keller (left) “hears” her teacher Anne Sullivan by reading Sullivan’s lips with her fingers. Source: AP/Wide World Photos Helen Keller/ Anne Sullivan

Later on, TTY (TeleTYpe), TTD (Telecommunication Device for the Deaf), and TT (Text Telephone) all refer to the text-based telecommunications device that the deaf, hearing impaired, and deaf-blind use to communicate on the telephone. The sighted person types a message on a small keyboard and the deaf-blind user receives the message on a Braille display. The deaf-blind responds by typing on a standard or Braille keyboard and the sighted person reads the message on the screen.

Presently, TTY and TTD based communication system supported android apps are also available in the smart phone (Google play [195]). In this work, such apps are demonstrated to see whether it makes sense in future communication design.

At this point, we review some useful android apps that might be useful in bridging the gap and provide a sense of solutions that have the potential in addressing some of the challenges.

1) Blind Ambition Project

As mentioned earlier in chapter 1, the “blind ambition” is one of the signature projects at the CVPIA Lab, The University of Memphis. The main goal of the project is to develop a suite of assistive technology solutions to improve the quality of life and enhance the interaction experience of people who are blind or Visually Impaired or Deaf. The goal is to design enabling technology solutions that will assist them to efficiently perform their day-to-day activities with a relative ease. The key objectives are to develop solutions that are light weight, low cost, un-tethered and have an intuitive and easy to use natural interface that can be reconfigured to perform a variety of tasks. Also of importance is to make the technology available at zero cost to one who cannot afford and provide affordable, efficient, scalable and reliable services.

The project “Blind Ambition has been developing Assistive technology solutions to provide a number of key services through Smart Phone using Cloud Computing and Cyber Physical systems as the backbone of application development. Among a number of applications developed under the blind ambition project, we will explain RMAP, iFEPS and emoAssist. Here we review some useful android application blind people are using nowadays, and some applications can be useful in cross-disability communication.

Meanwhile, a number of applications are found through google apps market, google play. A few of them are explained later on:

2) Virtual Voice and Electric Ears

With the text to speech (TTS) and Speech recognition of your Android device, the deaf can communicate with others without the need for sign language or lip reading. It has a remarkably simple 3 button interface useful for visually impaired. Text To Speech App with Pitch, Speed Control and Multiple Languages [195]. A snapshot of virtual voice and digital ears are shown in Fig. 14.

Some recent study revealed that there has been neither subsequent research to update the exact estimates of the prevalence of signing nor any specific study of ASL use.

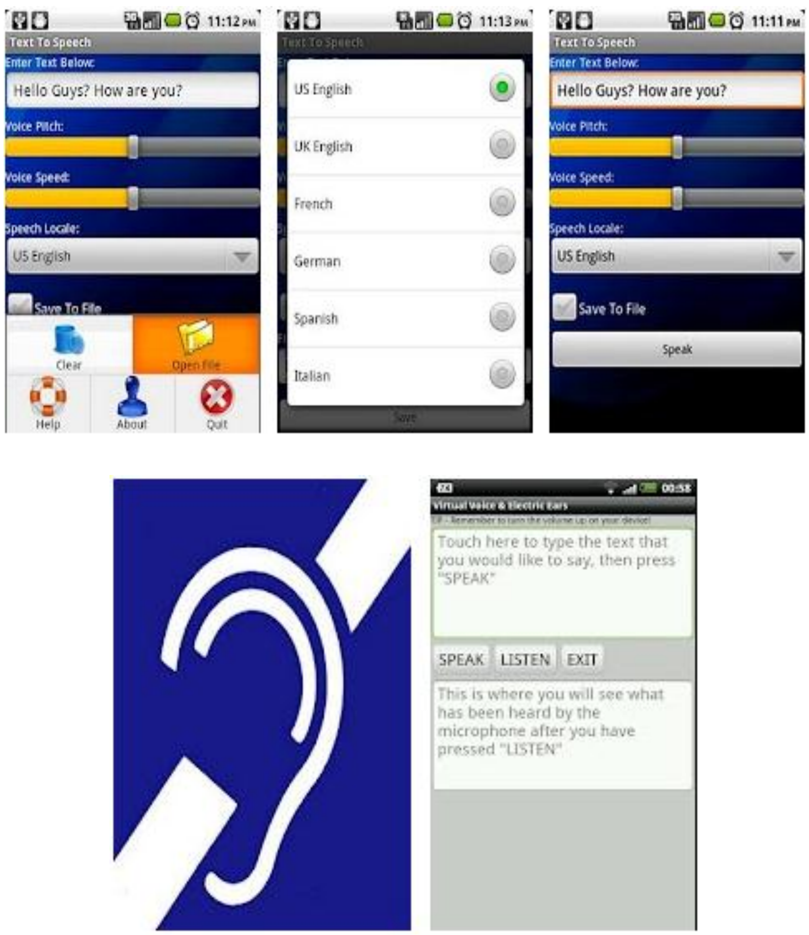


Fig. 14. A screenshot of virtual voice and digital ears apps. Sign Language to Speech Conversion and applying over Avatar.

An estimated population size is stated greater than 500,000 and appears to use ASL (Klein, 2006). Some new instrumented approach for translating ASL into sound and text and a combinational method with hardware and software interface are proposed in [196, 197]. In disability studies, it is revealed that the blind or deaf are less fans of the use of instruments rather than a cell phone [198]. Android Apps based ASL or Braille and related apps to translate them seems to be a promising research. “Sign Language!”, another app, is the most downloaded Sign Language app in the world now (over a million). Features include: how to fingerspell words, numbers, express basic sentences, idioms and learn about Deaf Culture. This app is free and is based on demography of deafness estimates. Following are two such research (SiSi, Mimix.me) that work on British sign Language (BSL) and American Sign Language (ASL) respectively.

3) SiSi

This application is an innovative 'speech to sign language' translation system demonstrated by IBM research in 2007 and works for BSL. It has potential to make life easier for the deaf community. An example is shown in Fig.15.

4) Mimix.me

This application translates spoken and written words into American Sign Language (ASL) and text into speech (Hernandez-Rebollar et al. 2004). The mimix engine translates speech to text and then animates a 3D avatar with the equivalent sign language. The avatar is ergonomically positioned on the screen, and as a first phase it translates English to ASL (American Sign Language).

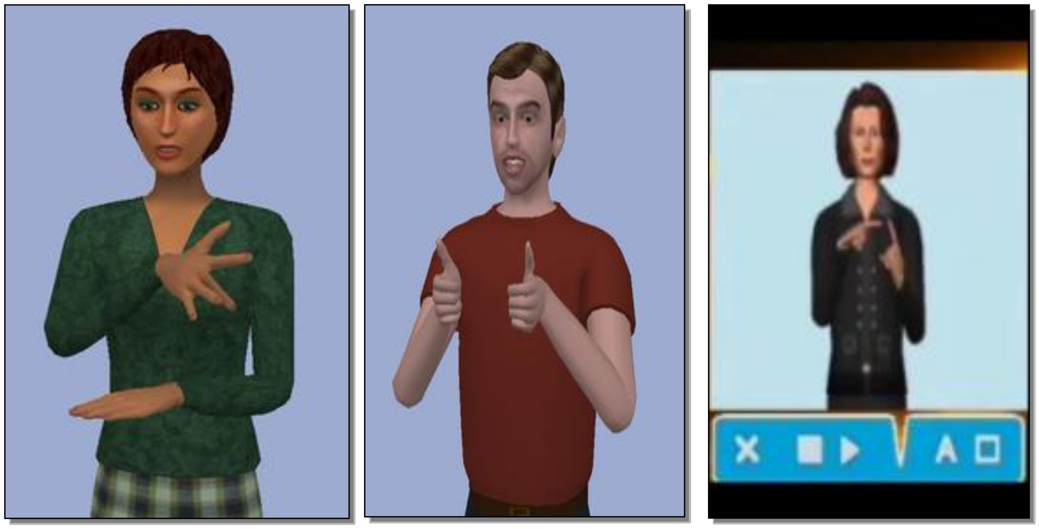


Fig. 15. snapshot of avatars (left two: IBM avatar in BSL, right c: Mimix with ASL) [195]

It is compatible on Android mobiles and Desktop and hopefully good for the deaf-blind communication. Among a number of research, this study conducts a theoretical basis for deaf-blind communication through Android apps in collaborative sensemaking perspective.

In Fig. 15 (left), an avatar translates the spoken word 'performance' into the corresponding sign from British Sign Language. The new technology -- which can be adapted for any country specific sign language -- allows a person giving a presentation in business or education to have a digital character projected behind them signing what they are saying. (Fig.15 -middle) An avatar translates the spoken word 'good' into the corresponding sign from British Sign Language. The new technology, which can be adapted for any country specific sign language, allows a person giving a presentation in business or education to have a digital character projected behind their signing displaying what they are saying. (Fig. 15 - right) mimix me avatar, display ASL, "Nice to meet you".

We have research with search categories, "speech to text conversion", "speech based texting", "speech based browsing/navigation" ,"text to speech conversion", "text to Braille conversion"," sign to speech conversion", etc. A summary is shown in Table 15 (Appendix B).

CHAPTER III: DATASETS

This chapter explains details of the datasets used in this research. Most of the analysis are performed on two benchmark datasets, mental multiplication [128] and team shared mental model (Human Agent Pair - HAP) [129], which are reviewed by the institutional review board (IRB – APPENDIX C) for secondary evaluation. The mental multiplication dataset is used in item response theory based analysis of cognitive task interaction illustration. Task performance scores are compared with pupil size variation to understand cognitive demand. Additionally, task response time is also computed from the task completion and the maxima of pupil dilation in task facing stage. Details of mental multiplication data are given in section A. To see gap confluence and effects in social coordination, complex team shared mental model dataset is considered. HAP data is explained in B. Other data sets are small, collected through CVPIA and clover nook [154] collaboration.

A. Benchmark datasets

The first dataset is the mental multiplication dataset [128] which is obtained from the Department of Computer Science at Stanford University. The second dataset is the team shared mental model dataset - known as human agent pair (HAP) dataset [129] obtained from Pennsylvania State University.

1) Mental Multiplication Data

Mental multiplication data is one of the three data instances in cognitive papillary dataset [110]. The dataset consists of pupillary logs during mental multiplication experiment. Participants were 24 undergraduate students from a large public university in North America. All the participants had normal or corrected-to-normal vision. All participants were compensated by Amazon.com gift certificates with a value ranging from $15 to $35 based on their task performance. Details can be found in [128]. Materials used were: Tobii 1750 remote eye tracker (Tobii Technologies, 2007) 50Hz is used in data collection. This remote-camera setup enables pupil measurements without encumbrance or distraction. A very good room lighting condition also considered for better tracking performance. Eye tracker was placed on a desk with the top of the screen approximately 140 cm from the screen in a relatively bright room.   A snapshot of pupillary dilation with multiplicand, multiplier, is shown Fig. 16 (left) the effect of task difficulty is shown in Fig.16 (right). Figures are copied with email permission from the author. The log file gendered by the Tobii software includes different scrap values.

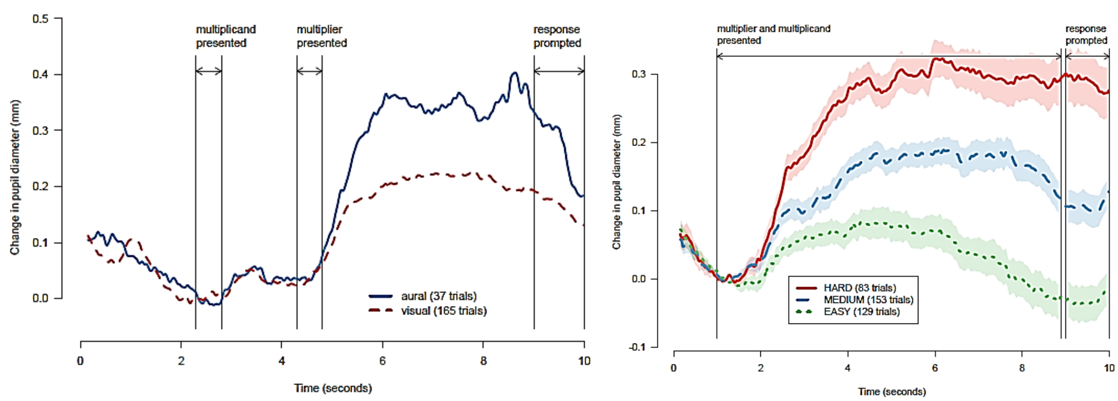


Fig. 16. Average pupil dilation evoked by visually and aurally presented mental multiplication problems. A. Aural and visual task with illustration of multiplicand and multipliers. B. Pupillary dilation with task difficulty [128] (picture copied with email permission)

For instance, the value marked with "-1" in pupil size means that the person is either looking away or typing or is not at the computer, meaning the tracker is not able to detect pupil size. Some of these values are interpolated from other values preceding the current value and following values. More specifically, the interpolated pupil size is calculated as

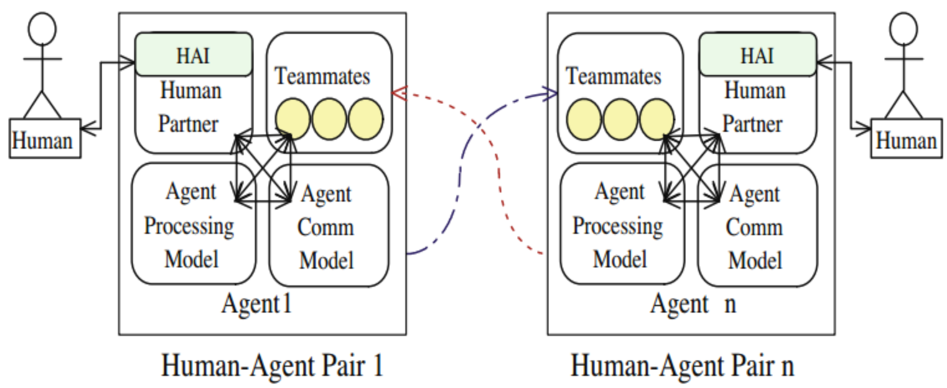
$$\mathbf{y} = \mathbf{x_0} + \frac{(\mathbf{x_1} - \mathbf{x_0})(\mathbf{t_1} - \mathbf{t_0})}{(\mathbf{t_c} - \mathbf{t_0})} \quad (12)$$

Where tc is the time for the corresponding pupil diameter recording, x0 is preceding value of expected pupil diameter y and x1 is the following value of the expected pupil diameter. Data validation is considered from Tobii's validation values (0-4). Where, 0 represents the eye is found, and the tracking quality is good. In the case of eye out of the range, validation code is logged as 4.

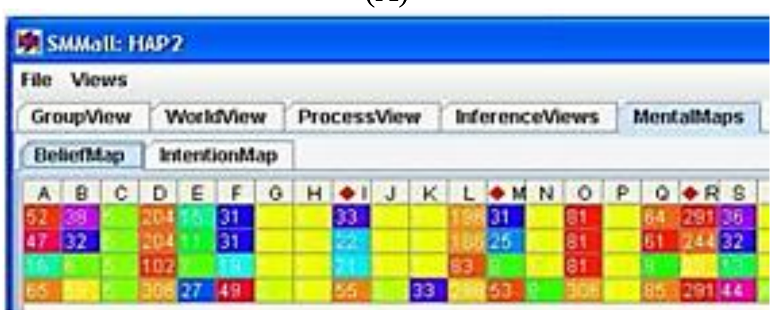
2) Shared Mental Model dataset [129]

The data were collected from a controlled experiment where users share information while interacting with agents through GUI known as shared-belief-map. Their clicking information (number of click) is recorded valid/invalid click also compared for performance. There are 12150 rows of data, including 270 (3 * 3 * 3 * 10) sequences of 45 human observations. We can sequentially separate the 12150 rows into sequences of length 45 to do our analysis. A collaborative setting was simulated as a dynamic battlefield infosphere. A team can have several team members (in this case, three team members); each of them has limited observability (say, covering only a portion of the battlefield). The goal of the team is to selectively share information among members in a timely manner to develop global situation awareness (e.g., for making critical decisions).

Team members share information through a GUI, called shared belief map (Fig. 17), a table with color-coded info-cells, with cells associated with information. Each row captures the belief model of one team member, and each column corresponds to a specific information type. Thus, info-cell Cij of a map encodes all the beliefs (instances) of information type j held by agent i. Color coding applies to each info-cell to indicate the number of information instances held by the corresponding agent.



(A)



(B)

Fig. 17. Human-Agent Pair (A) and shared belief map (B) [127] (picture copied with email permission)

Semantically related information (e.g., by inference rules) can be closely organized in the map using similar colors. The change of indicates overlapping degrees.

In addition, the perceptible color (huge) difference indicates the information difference among team members, and hence visually represents the potential information needs of each team member.

The Dual task scenario: The primary task of human subject is to share the right information with the right party at the right time. Every 15 seconds (time step) simulated spot reports (situational information) was generated and randomly dispatched to team members. An info-cell on a person's belief map flashed 2 seconds with new information represented by that cell. To share the information associated with an info-cell, a human subject needs to click the right mouse button on the cell to pop up a context menu, and select the receiving teammate(s) from the pop-up menu. Because the information is randomly dispatched to team members, to each participant, the flashed info-cells vary from time to time, and there can be up to 12 info-cells flashed at each time step. To choose an appropriate secondary task for the domain problem at hand is not trivial; although the general rationale is that the secondary task performance should vary as the difficulty of the primary task increases. The secondary task of human subject is to remember and mark the cells being flashed (not necessarily in the exact order). Secondary task performance at step t is thus measured as the number of cells marked correctly at t. The number of cells marked correctly, the lower the subject's cognitive load. While the experiment is designed in a collaborative setting with a meaningful primary task, the secondary task performance is only considered for cognitive load estimation.

Thirty undergraduate students were recruited and randomly formed 10 teams of size 3. The simulation run was passed nine times for each team and the secondary task performance of each team member was collected as the number of info-cells marked correctly at each time step. Each run of the experiment has 45 time steps. Thus a total of 10 x 3 x 9 = 270 observation sequences of length 45 (Total 12150) were collected. We also controlled an agent's outgoing communication capacity by varying the maximum number of communication messages from 6, 8 to 10 (queue size). Together with team type and load sensitivity level 9 (=3 team types × 3 queue size) treatment design. Each run of the experiment had 45 time steps; each time step lasted about 15s.

At each time step, the human subject has to carefully go through three cognitive decisions: whether sharing the information under consideration is right (i.e., whether it is associated with an info-cell just flashed), whether a team member is the right party to share the information with (i.e., does it really need the information), and whether this is the right time to share (i.e., is the team member already overloaded). A snapshot of the dataset is shown Fig 18.

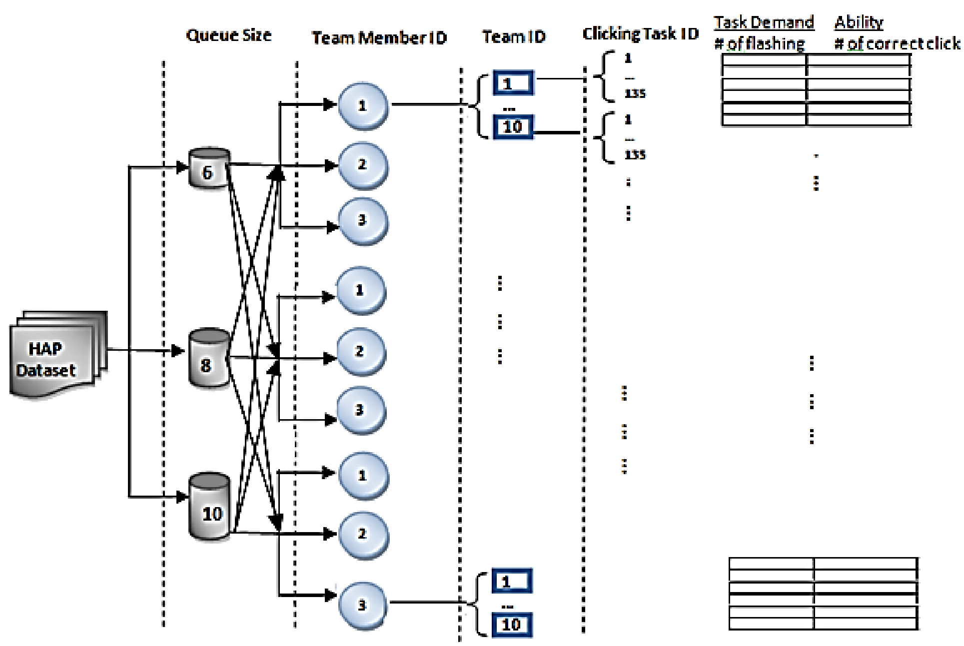


Fig. 18. Snapshot of collaboration in HAP dataset (HAP dataset) [127]

B. Experimental datasets

In CVPIA and Clovernook [154] collaboration, we collected two datasets: Reconfigurable mobile android phone (RMAP) dataset [159] and cross-disability communication [149] datasets. These are explained later on.

1) RMAP interaction (usability and cognitive load rating) dataset

R-MAP subjective rating dataset uses the concept of the NASA Task Load Index [205] with six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Table 8 shows the description of NASA-TLX dimensions. Five step graded response scales are used to obtain ratings for these dimensions. A score from 0 to 10 is obtained on each scale. The six individual scale ratings are combined using a weighting procedure.

TABLE 8. NASA-TLX used in subjects' cognitive load computation

Scale	*Description*
Mental Demand	How much mental and perceptual activity was required (e.g., thinking, deciding, calculation, remembering, looking, searching, etc.)? Was the task easy or hard, simple or complex, extracting or forgiving?
Physical Demand	How much physical activity was required (e.g., pressuring during tapping interface, tapping in different locations, double-tapping, position the camera, positioning your hand, positioning the item etc.)? Was the task easy or hard, slow or fast, slack or strenuous and restful or laborious?
Temporal Demand	How much time presser did you feel due to the rate or pace at which the task or task element occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task set by experimenter? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

A cumulative workload score from 0 to 1is obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by individual average score we normalized the score. The usability measures questioners are followed from Nielsen's five usability metrics (Table 9).

TABLE 9. Usability measures quantitative

Question category	*Question*
Memorability	How difficult was the experiment instruction content for you?
Learnability	How difficult was to learn with the instruction format?
Efficiency	How much did you concentrate during experiment?
Errors	What do you think about the chances of errors during the experiment?
Satisfaction	How pleasant are you to participate in this experiment and to use the design?

2) Cross-Disability Dataset

This is a subjective rating dataset using the concept of the NASA Task Load Index [205] uses six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Table 8 shows the description of NASA-TLX dimensions for cognitive load assessment. A score from 0 to 100 is obtained on each scale to fit seven step graded response model (Very high to Very Low). This is a weighted version of NASA-TLX scale rating. Weight (1-5) is considered based on their perceived importance on the rating. The workload score from 0 to 100 is obtained for each rated task by multiplying the weight with original (20 from NASA-TLX method) by the individual dimension scale score, summing across scales, and dividing by individual average score we normalized the score. To assess the collaborative load we followed a modified version of NASA-TLX [206]. The index is explained in Table 10.

With subjective rating, this dataset also recorded conversation and rating video and critical incidence report by the facilitator –a multi-dimensional data set. Fig. 19 shows the schematic of the processes followed in such type of data collection.

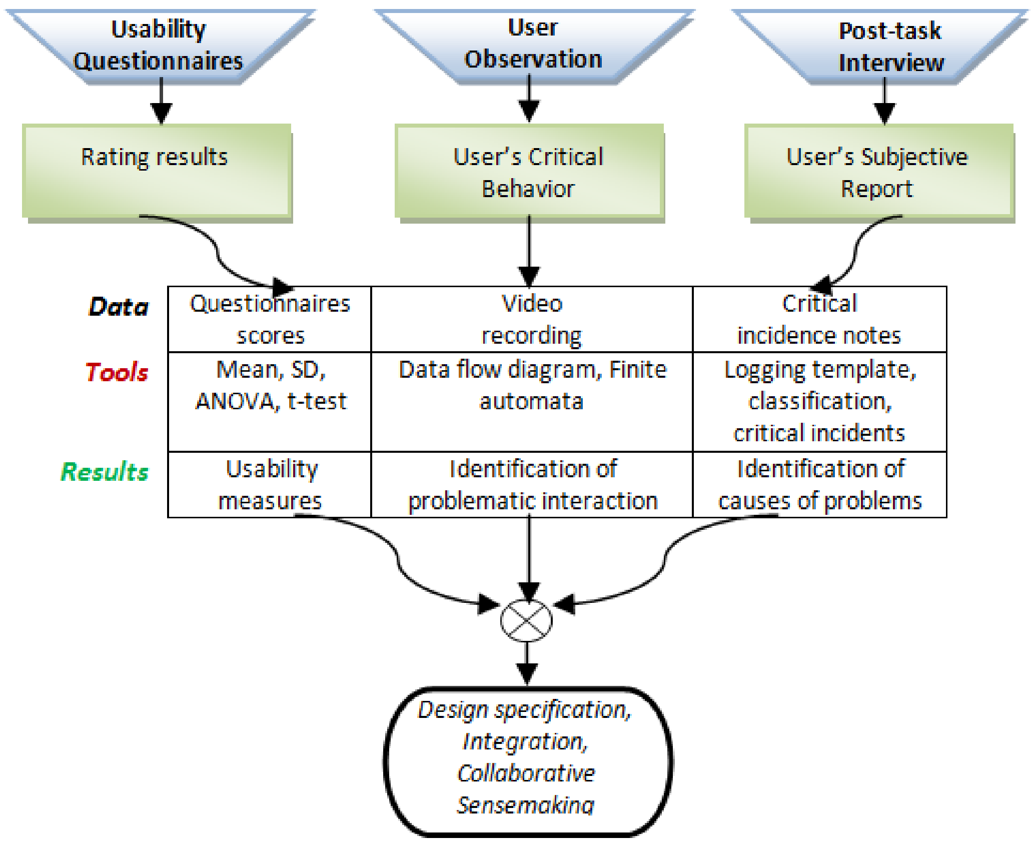


Fig.19. Schematic of cross-disability multi-dimensional data collection

TABLE 10. NASA-TLX used in subjects' collaborative load computation [206]

Scale	*Description*
Coordination Demand	How much coordination activity was required (e.g., correction, adjustment)? Were the coordination demands to work as a team low or high, infrequent or frequent?
Communication Demand	How much communication activity was required (e.g., discussing, negotiating, sending and receiving messages)? Were the communication demands low or high, infrequent or frequent, simple or complex?
Time Sharing Demand	How difficult was it to share and manage time between task work (work done individually) and teamwork (work done as a team)? Was it easy or hard to manage individual tasks and those tasks requiring work with other team members?
Team Effectiveness	How successful do you think the team was in working as a team? How satisfied were you with the team related aspects of performance?
Team Support	How difficult was it to provide and receive support (providing guidance, helping team members, providing instructions, etc.) from team members? Was it easy or hard to support/guide and receive support/guidance from other team members?
Team Dissatisfaction	How emotionally draining and irritating versus emotionally rewarding and satisfying was it to work as a team?

CHAPTER IV: MODELING COGNITIVE ABILITY-DEMAND GAP

This chapter describes ability-demand gap analysis method with item response model and its variants. Rasch model [30] and extended Rasch models [31] (rating scale model and partial credit model) are used in gap measurement. Mental multiplication [128] and RMAP datasets [159] are considered as dichotomous and polytomous datasets, respectively. Rash model [30] and extended Rash [31] are applied. We also performed item difficulty effects with DIF and item/person maps. All related analyses are shown in subsequent sections. Section A describes the analysis method of cognitive ability-demand gap with latent response model, section B illustrates some results and the section C summarizes the findings.

A. Ability-demand gap analysis method

The gap analysis method explained here encompasses, ability-demand gap computation, difference computation with item and response parameters of latent response theories. These are explained later on:

1) Ability-Demand Gap Computation

(Dis)ability can be viewed as the difference between the cost demanded by environment and individual's ability [1]. In new technology adaptation, a user starts with ability-demand gaps that are reduced with an increase of skill and experiences. Users with physical or sensory disability will always have some gaps (in their ability) to be considered with holistic design. The ability-demand gap can be formalized as a latent response analysis as illustrated in Fig. 20, with subject's ability vs. task demand parameterized with task difficulty (β), task discrimination (α), subject's ability (θ), performance (x) and the probability of success ($P_{j)}$. Intuitively, the cognitive demand on the user can be written as [27]:

$$Demand\ (D) = f(P_d, Ph_d, S_d) + D_A \qquad (12)$$

where, P_d is the physical demand; P_{hd} is the psychological demand; S_d is the sociological demand, and D_A is demand with ignored ability. The function on the right side of the equation is the demand function. Similarly, the ability can defined as [28]

$$Ability(A) = f(P_a, Ph_a, S_a) + A_D \qquad (13)$$

where, Pa is the physical ability, P_{ha} is the psychological ability; S_a is the sociological ability and A_D is the ability with ignored demand. The function on the right side of the equation is the ability function. The ability demand gap can be formalized as"

$$Ability\_demand\ gap = K(D - A) \qquad (14)$$

where, K can be considered as a normalizing constant (e.g., the power constant 0.74+-0.06, 95% confidence limits [29])

2) Difference Computation

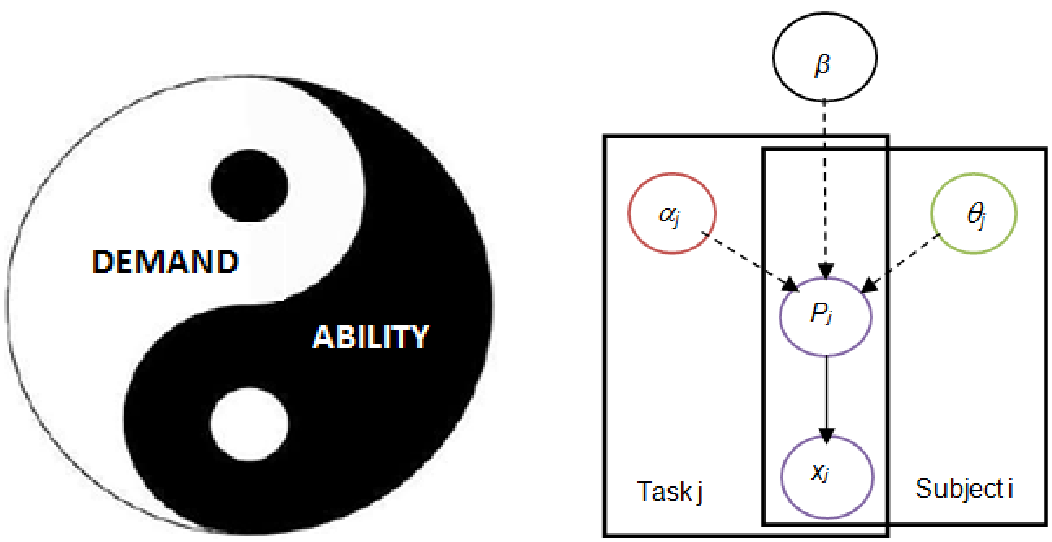
Given the subject's ability A and cognitive task demand D, the ability-demand gap can be defined by Coombs theory of difference [20]. If A is greater than D, say, A- D > 0 and the subject make some error. With probability of error the equation can be written as,

$$p(A > D|A, D) = f\ (A - D) \qquad (15)$$

Alternatively, A is close to D if the absolute difference between them, is less than some threshold, δ.

$$p(|A - D| < \delta|A, D, \delta) = f\ (|A - D|, \delta) \qquad (16)$$

This distinction are shown graphically by considering the probability of being greater as a function of the distance A -B (Fig. 20), or the absolute difference between A and B. Ordered difference considers the probability of observing A > D as a function of the difference between A and D. The greater the signed difference, the greater the probability that A will be reported as greater than D. The three lines represent three different amounts of sensitivity to distance. The proximity relationship considers the probability of observing A is the same as (close to) D as a function of the difference between A and D. The less the absolute difference, the greater the probability they will be reported as the same. Given a data matrix D with features $d_{ij,}$ we try to find model values m_i and m_j such that some function f when applied to the model values best recreates d_{ij}. For data that are expressed as probabilities of an outcome, the model should provide a rule for comparing multiple scale values that are not necessarily bounded 0-1 with output



(A) (B)

Fig. 20. Ability-Demand gap Illustration, (A) Interplay of ability and demand, (B) latent diagram [30]

values that are bounded 0-1. That is, we are interested in a mapping function f such that for any values of m_i and m_j

$$0 \leq f(mi, mj) \leq 1 \tag{17}$$

In order to fit it to model, we need to find scale values that minimize some function of the error. Applying f (m_i,m_j) for all values of i and j produces the model matrix M. Let the error matrix E = D - M. Because average error will tend to be zero no matter how badly the model fits; median absolute error or average squared error are typical estimates of the amount of error. A generic estimate of goodness of fit in terms of errors becomes

$$GF = f(D, M) \tag{18}$$

3) Item Response Model and Gap Computation

The item response theory (IRT) model predicts the probability that a certain subject gives a certain response to a certain item. In a very simple item response setting, let the subject *x* may only have dichotomous responses (1 = correct, or 0 = incorrect), let P_{ij} as the probability of a correct response, where i refer to the task, and the index j refers to the subject. The function shown on the graph is known as the one-parameter logistic function.

$$P_{ij}(\theta_j, b_i) = \frac{1}{1+e^{-(\theta_j - b_i)}} \tag{19}$$

This is known as one-parameter logistic (1PL) model, also known as the Rasch model [23], which predicts the probability of a correct response from the interaction between the individual ability θ_j and the task parameter b_i. The parameter b_i is called the location parameter or the difficulty parameter. Cognitive ability experiment conducts picking a cognitive task of average difficulty (b about 0).

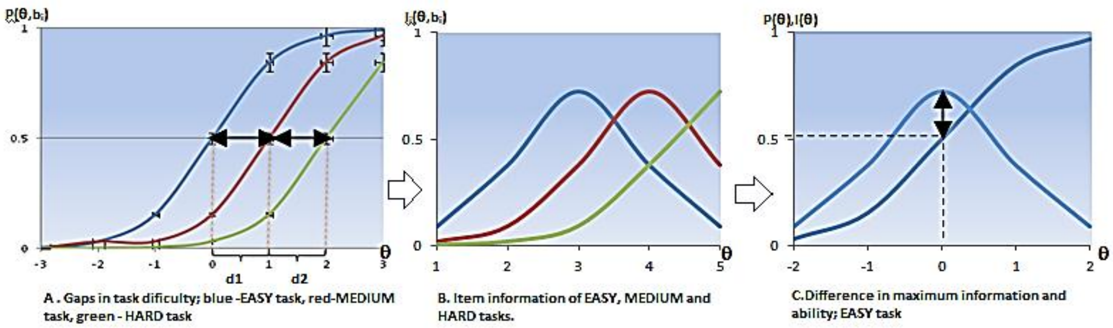


Fig. 21. Residual computation of ability-demand gap

If the subject gets it right, the system might select a more difficult task. The system will continue making the experiment more difficult until the student performs a task incorrectly. If the subject makes a mistake in the first task, system gives an easier task. Keep making the tasks easier until he/she gets a task correct. As soon as at least one task is correct and at least one task is incorrect, the system computes a maximum likelihood estimate of the subject's standing on the trait. As soon as the system has a point estimate, it can compute a confidence interval, that is, a local standard error of measurement for the subject.

Latent response model, namely the Rasch model [17] predicts the probability of any response to a cognitive task given the true ability of the user.

In general, users may have different levels of ability, and items (tasks) can differ in many respects—most importantly, some are easier, and some are more difficult. In a very simple item response setting, the subject x may only have dichotomous responses

(1 = correct, or 0 = incorrect), let us consider P_{ij} as the probability of the correct response, Where *i* refers to the task, and the index *j* refers to the subject. Also, *P(θ)* to show that the probability of a correct response is a function of the ability θ. The probability of incorrect response Q(θ) = 1- P(θ) with Rasch modeling might show the disability, specifically the ability-demand gap[1].

$$Q_{ij}(\theta_j, b_i) = 1 - P_{ij}(\theta_j, b_i) = \frac{1}{1 + e^{(\theta_j - b_i)}} \tag{20}$$

We consider the equation (20) as the gap equation. Where $(\theta_j - b_i)$ is considered as residue of expected ability (difficulty) and observed ability.

4) Response latitude computation

Fig. 22B and C illustrates category response functions [199], which are estimated to describe the likelihood that a person at a given level of the latent attitude selects a given response option.

The x –axis in the Fig. represents the attitude towards performing the correct action (valid click or answering correctly), which is represented by value ranging from -4 to +4.

The y-axis represents the probability that subjects at various locations along the attitude range selecting a given response option. Each response option is represented by logistic curve function running along the attitude range. The higher values along these functions indicate a higher probability of respondents selecting that particular response option.

Let, there are four b parameters associated with five point response scale. The lowest b_1 =-8.5 and the highest b_4 = 1.15 represent the locations at which there is 50 percent probability of respondents selecting the lowest (strongly disagree) and highest (strongly agree) response options. The average b value, (.85+.25+.5+1.25)/4 = 0.7125 is considered as response latitude of the test [199]. The middle b parameters, b2 and b3, represent the intersection of middle response options. The distance between bs' are shown in bracketed regions of the attitude range in the bottom of the Fig.23B. The low distance between choices may indicate the subjects are in low load and are selective in their choice of response option.

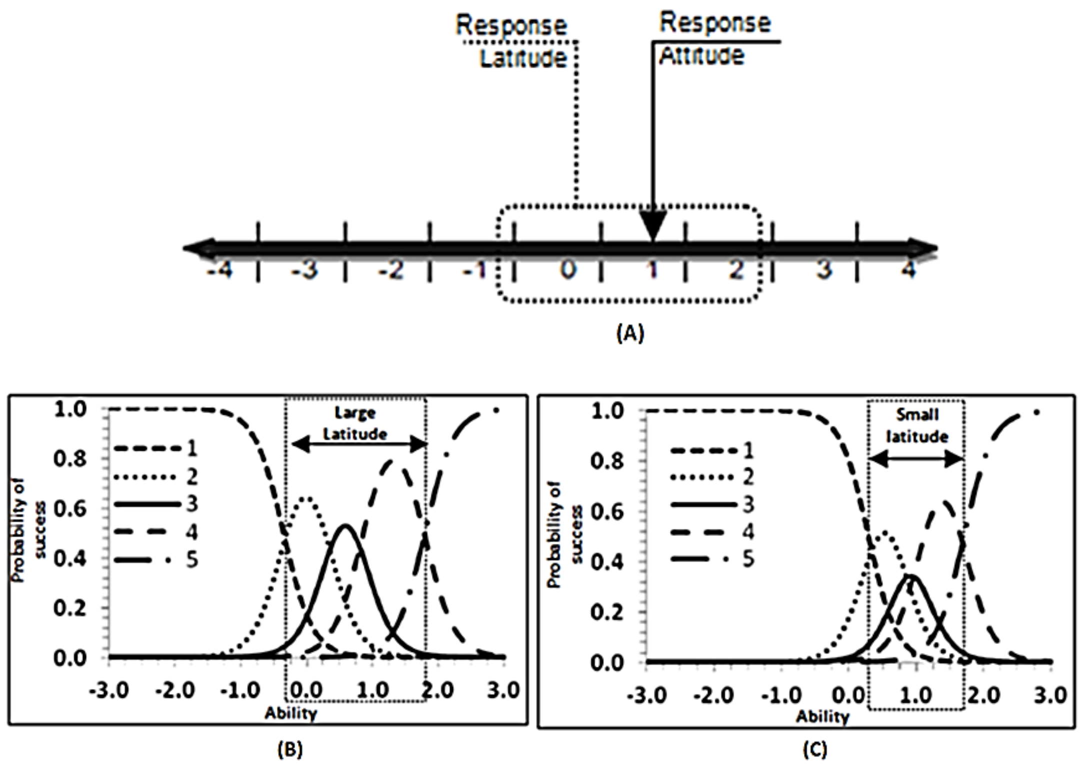
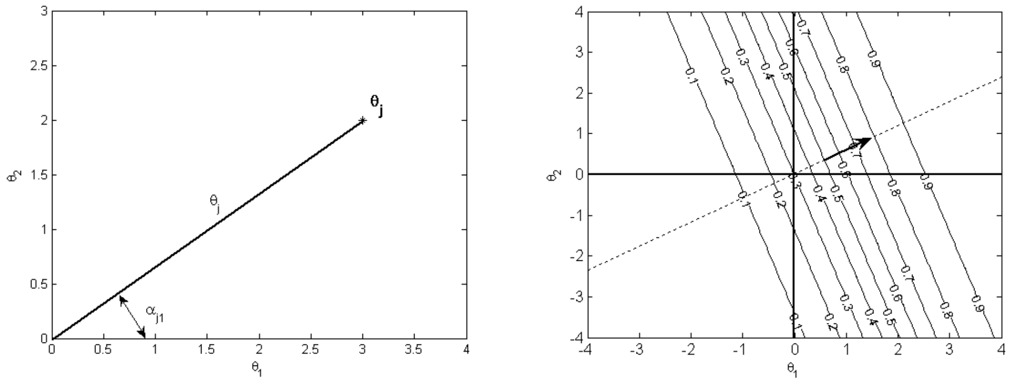


Fig. 22. Response latitude (RL) computation – (A) response attitude and latitude, (B) Large latitude, (C) Small latitude [199]

Another important characteristic of a test item is how well it differentiates between two subjects or items located at different points in the θ-space. If the probability of the correct response to the item for the locations of two subjects is the same, the item provides no information about whether the subjects are at the same point or different points. However, if the difference in probability of the correct response is large, then it is very likely that the subjects are located at different points in the d-space. Differences in the probability of the correct response for an item are largest where the slope of the item response surface is greatest, and when points in the space differ in a way that is perpendicular to the equiprobable contours for the item response surface. In this two dimensional case, $\theta j_2 = 90 - \theta j_1$. More generally, the relationship among the angles between the coordinate axes and the line connecting the origin of the space to the θj-point is given by

$$\sum_{k=1}^{m} (\cos \alpha_{jk})^2 = 1 \qquad (21)$$

This relationship is a general property of the relationships of angles with a line represented in an orthogonal coordinate space. An example of this vector representation of an item is given on the contour plot of an item response surface in Fig. 23. Further discussion of the development of these measures can be found in [35].



(A) (B)

Fig. 23. Vector representation of subject or item – (A) Polar coordinate representation of subject or item location θj, (B) Item vector representing the direction of best measurement of an item. (a_1 = 1.2, a_2 = .4, d = -.84)

B. Ability-demand gap analysis result

The first specific aim in ability-demand gap analysis was to examine the latent response models as gap identification model along with the ability estimation process. The key assumption underlying was that, human inherent ability and task complexity both are related to human task performance. Similarly, the ability-demand gap might be related to human task performance, which can be identified with the same framework. Moreover, the reliability and accuracy of the identification process should not vary with fit statistics (infit/outfit). As an exploratory data analysis, we performed non-metric multidimensional scaling (MDS) to infer the dimensions of the perceptual space of subjects. The raw data entering into an MDS analysis are typically a measure of the global similarity or dissimilarity of the stimuli or objects under investigation. A monotonic transformation of the proximities is calculated with stress function [57]. It is considered that the lesser the stress value (in the range of 0.10 - 1.0), the better the fit of the data .

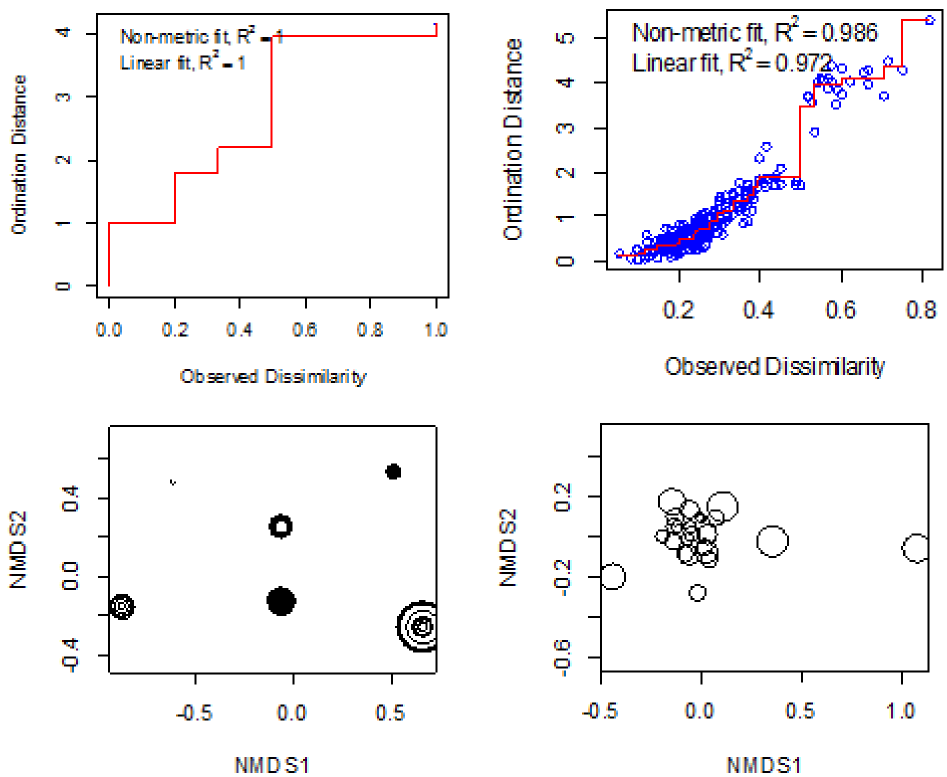


Fig. 24. Shepard plot of mental multiplication (top - left) and RMAP dataset (top - right). metaMDS plot of mental multiplication (bottom - left) and RMAP dataset (bottom- right)

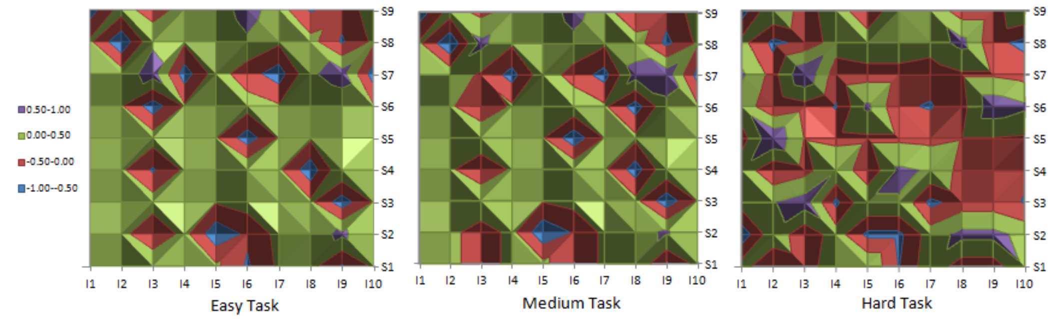
Because of the nonlinear relationship between ordination and original dissimilarities, the iterative searches sometimes have sometimes become very difficult in NMDS. The iteration easily gets trapped into a local optimum instead of finding the global optimum. Rotating solutions to principal components are showed from the dispersion of the points which are highest on the first dimension, using metaMDS (Fig. 24). To show amplified points, Fig. 25 clearly distinguishes the dichotomous (mental multiplication) and polytomous (RMAP dataset) responses.

1) Ability-demand gap computation from residual analysis

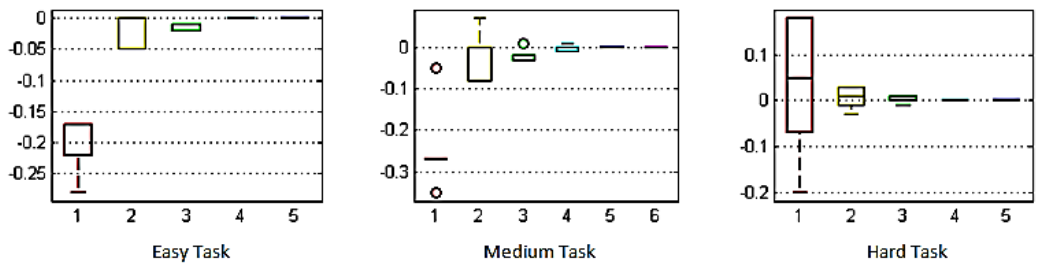
In latent response model based, ability-demand gap analysis, dichotomous and polytomous datasets are processed with Rasch one parameter (1PL) item repose model and extended Rasch model, respectively.

Ability-demand gap is computed from average residues of endorsement in dichotomous responses. An example analysis is shown in Fig. 26, which illustrates Rasch model residual analysis of easy, medium and hard tasks processed by nine subjects. Rasch analysis identifies users' inherent ability from dashing point of conversing the residuals (ability-demand gap) – which is considered a value very close to zero. Such residual plots are shown in Fig. 25A. Hard task (right most top panel) shows larger residue than others. The medium task shows more different residue values, which is good in discriminating subjects. The medium task took relatively more iterations to converge. In Fig. 25B, the box plots shows that after the fifth iteration the sum of average residual converges. Fig. 25C illustrates the five iterations.

Item characteristic, test information, item parameter, standard error of measurement and kernel density estimation of easy, medium and hard task interaction are



(A)



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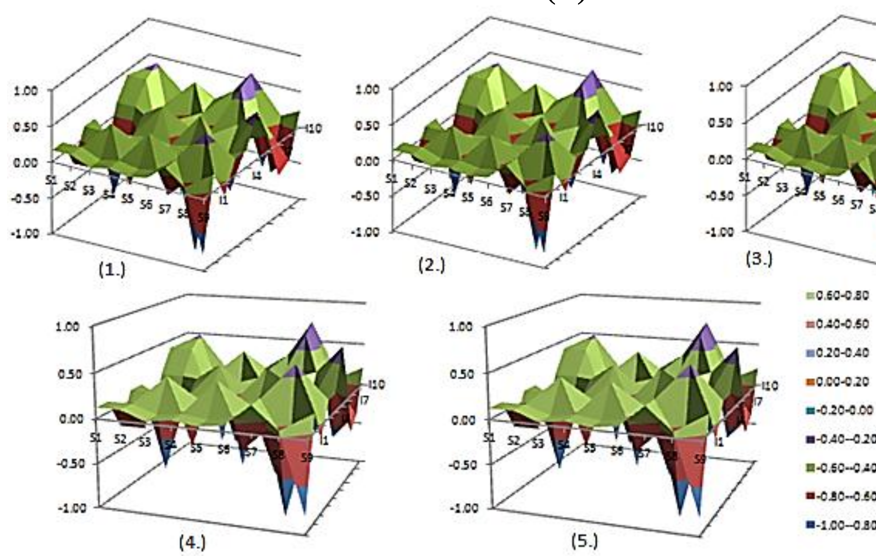
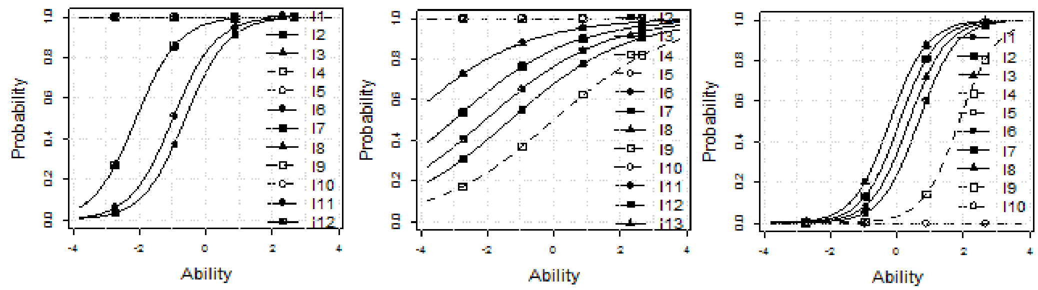


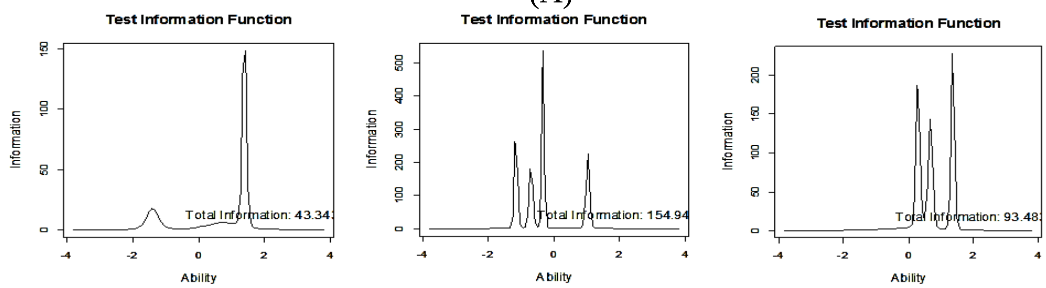
(C)

Fig. 25. Ability-demand gap (residuals) identification in cognitive experiment (Rasch modeling), (A) 2D surface plot of nine subjects ten tasks, (B) Rasch model convergence in easy, medium and hard task and (C) Gap convergence details in medium task

shown in Fig. 26. ICCs of all easy, medium, and hard (left to right) mental multiplication tasks performed by all 12 subjects are presented in Fig. A. Subjects are given more medium tasks (14) then easy (12) and hard task (10). Example, of an easy task (8 x 12), a medium task (7 x 13) and a hard task (14 x 17). ICCs in the left part of A explain 12 subjects easy task interaction. Subjects correctly performed most of the easy tasks except task 1 (5 x 19), task 6 (7 X13) and task 12 (9 X 17). In terms of difficulty, task 12 (19 X 13) was felt most difficult, then the task 6 (13 X 17), task 1(11 X 13) and all rest of the tasks. In terms of discrimination, easy tasks have two discrimination values 0.87 (task 1, 6, and 12). Subjects are good in guessing the outcome of other tasks, then the task 12, then task 16 and then task 1. Similarly, in ICCs of medium task (in the middle column of Fig. 26), task 8, 3,7,2,4 have chronologically higher discrimination values. Except these five tasks, subjects correctly performed most of the other tasks. An overturn picture is observed in the case of the hard task; almost half of the tasks are incorrectly performed by the subjects. Among five successful tasks, a few of them correctly performed the task 4. Thus, it is clear that ICCs are good to represent suitability of tasks in cognitive experiment. Standard error measurement (SEM) and Kernel density (KD) plots are also carried out to see error sensitivity and item distribution which are shown in Fig. 26B and C, respectively. Although SEM plots are looks same, KD plots differentiate item density in terms of subjects' ability. The b, value in the overall ICC plot (Fig.26E) measures the differences. The correct responses are plotted in red whereas incorrect responses are plotted using black color.



(A)



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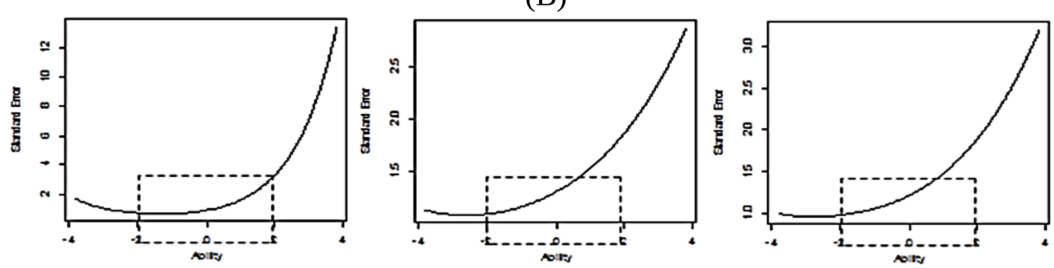

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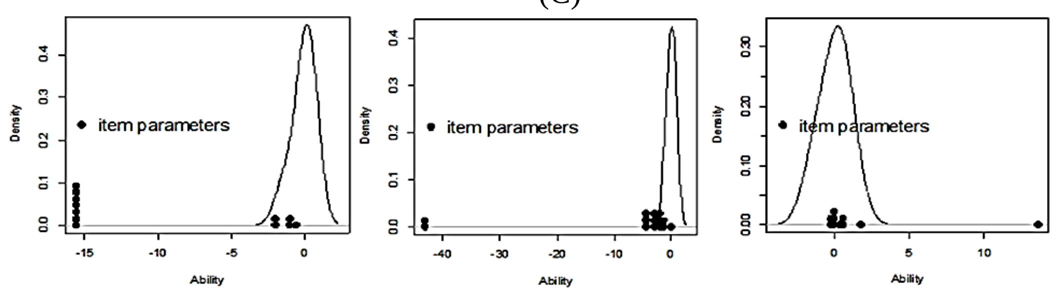

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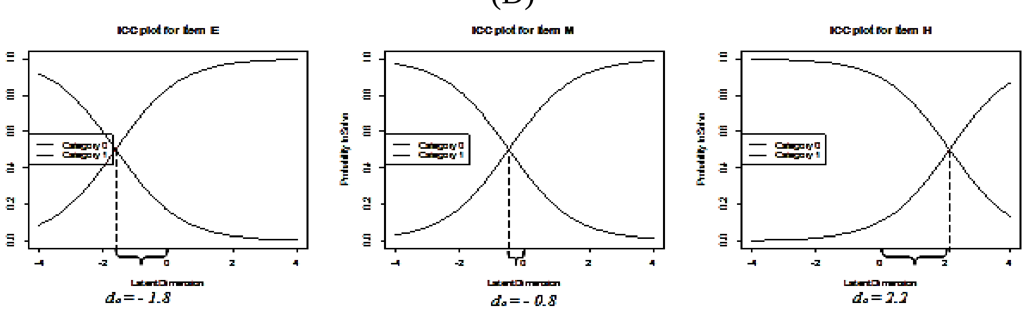


(E)

Fig. 26. Rasch analysis plots for mental multiplication tasks - (A) Item Characteristic Curves (ICCs), (B) Test information curves: (A) Standard Error Measurement (SEM) plot; (B) Kernel Density Estimation (KDE) plots, and (C) overall ICC plot

2) Ability-demand gap analysis in polytomous responses

In polytomous responses (RMAP dataset [159]), the ability-demand gap computation is performed with extended Rasch modeling. The confidence interval (item-person map) and response attitude are considered as an indicator of ability-demand gap. The average value of response latitude (e.g., response latitude in mental load using absolute difference [(|0.2-0.1|+|1.0-0.2|+|2.25-1.0|)/3 = (0.1+0.8+1.25)/3 = 0.716] which represents subject's average involvement, is equally important in gap computation process. Average response latitude greater than .05 indicates low involvement and higher gap. Fig. 27 shows the item response curves of all six NASA-TLX load indexes. All load indexes shows similar average response latitude (= 0.716).

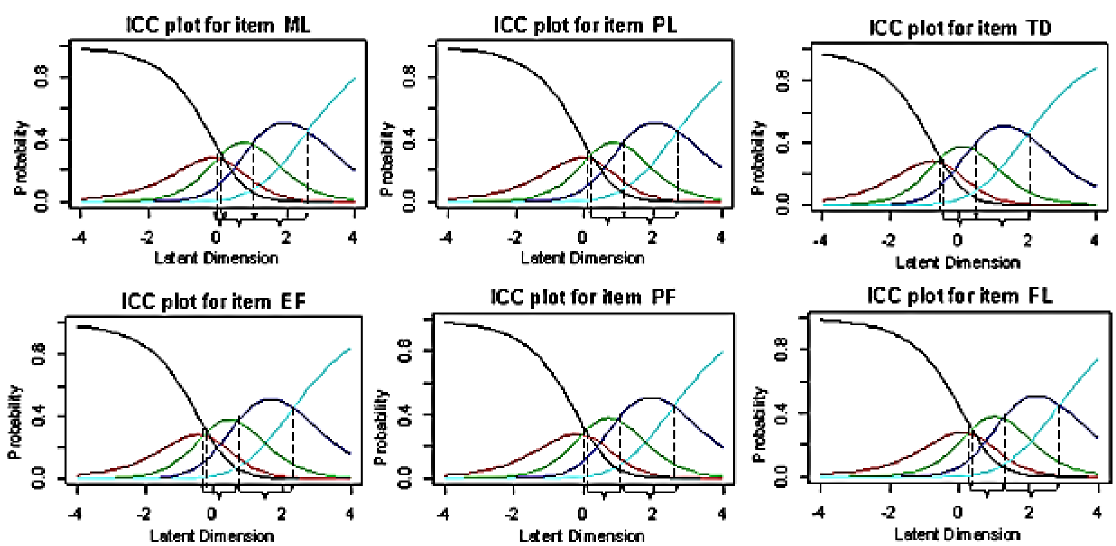
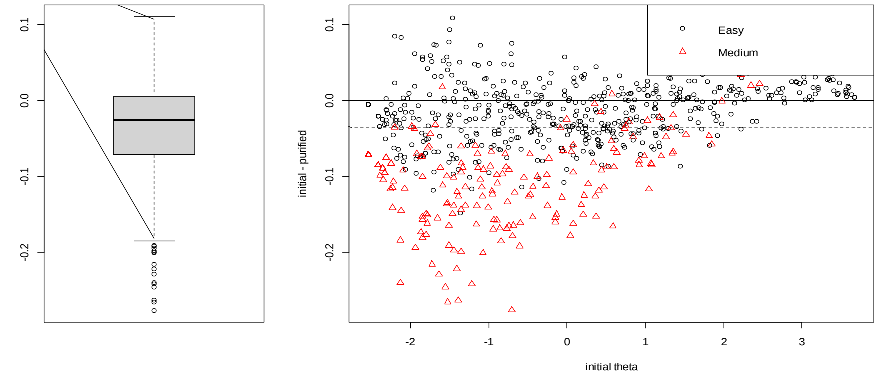


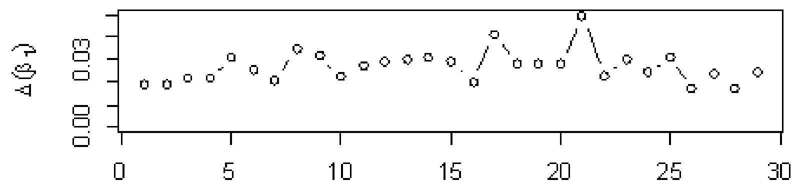
Fig. 27. Response latitude computation from partial credit ICC plot. Top row (from left) Mental load (ML), Physical load (PL), Temporal Load (TL), Effort Factor (EF), Performance Factor (PF) and Frustration Level (FL)

The temporal load has a different orientation [(|-(0.45)-(-0.55)|+|-(-0.55)+0.75|+|2.00-0.75|)/3 = (0.1+0.8+1.25)/3], but same (0.716) response latitude score. Therefore, subjects have unacceptable ability-demand gaps in technology interaction.

3) DIF analysis and category related ability-demand gap observation - Rasch model necessaries that item difficulty does not change between groups. For instance, subjects need more cognitive effort in medium task execution then easy and medium task. In Fig. 28A, guidelines are placed at 0.0 solid lines, i.e., no difference, and the mean of the differences (dotted line). The positive values to the left of the graph indicate that in almost all cases, according for DIF led, to slightly lower scores (i.e, naive score ignoring DIF minus score accounting for DIF>0, so accounting for DIF score is less than the naive score) for those with lower levels of anxiety, but this appears to be consistent across easy and medium tasks. The negative value to this graph indicates that for those with higher levels of anxiety, according for DIF led to slightly higher scores, but this again was consistent across easy and medium tasks. Higher order gap can be identified with 3D response modeling and robust principal component analysis. To show a prediction on large volume of data, Monte Carlo (MC) simulation is applied, which is shown in Fig. 28B. In addition, Fig. 28C illustrates higher level classification of response tasks in terms of response time (another dimension considered with Rasch tree).



(A)



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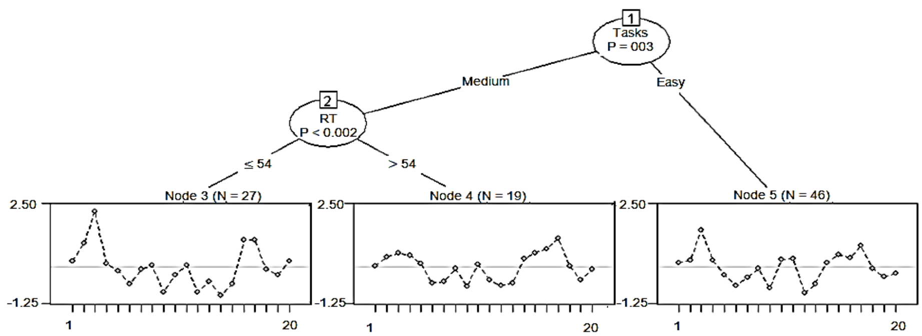


(C)

Fig. 28. DIF plots, (A) DIF of easy vs. medium task; (B) DIF with Monte Carlo (MC) simulation, (C) DIF tree - Rasch tree plot

4) Person-item map

A person-item map displays the location of item (and threshold) parameters as well as the distribution of person parameters along the latent dimension. Person-item maps are useful to compare the range and position of the item measure distribution (lower panel) to the range and position of the person measure distribution (upper panel). Items should ideally be located along the whole scale. Fig. 29 shows a person-item map in terms of response latitude. The upper panel describes the distribution of persons' abilities and the lower panel explains item measure distributions. The black circle in the lower panel indicates mean difficulty and the white circles represent category thresholds.

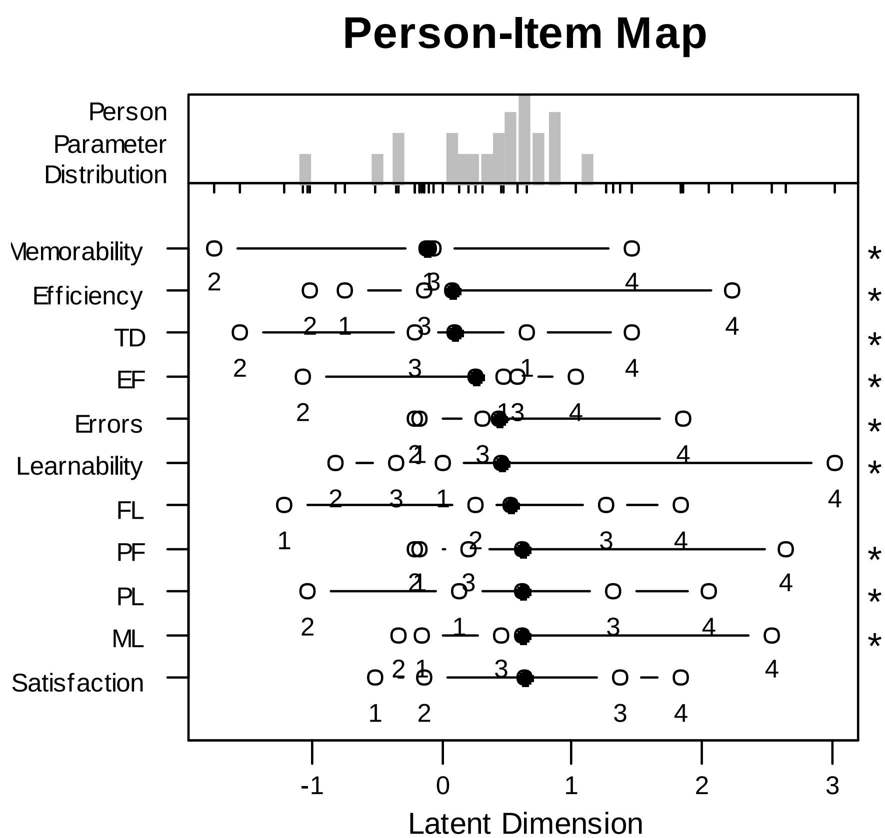


Fig. 29. Person-Item maps with response latitude

The monotones of a person's ability can be illustrated with his or her row scores vs. ability parameters (Fig. 30)

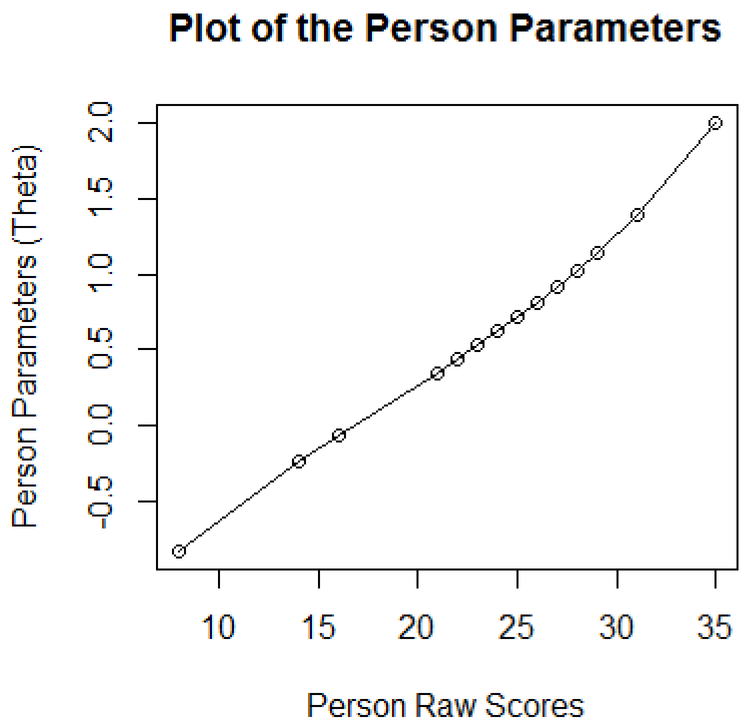
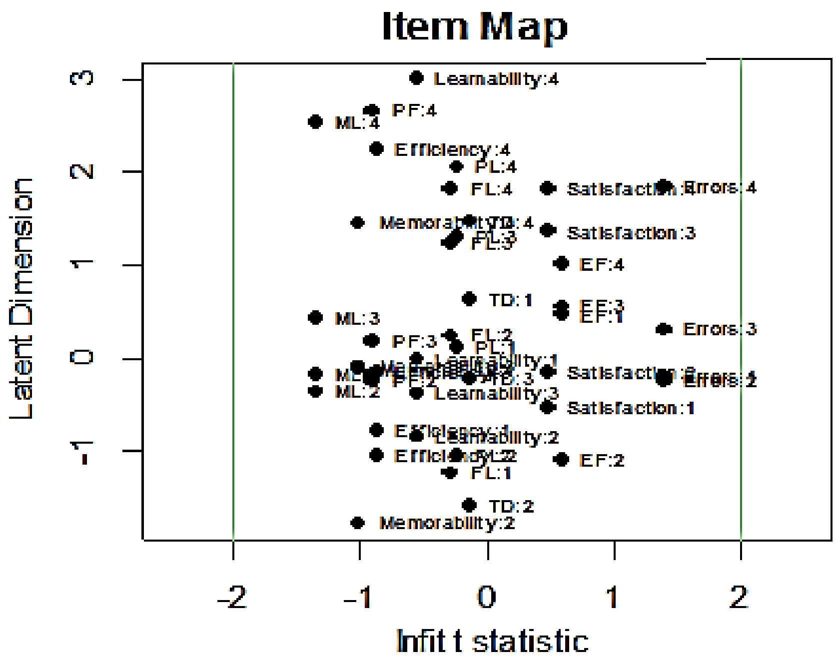
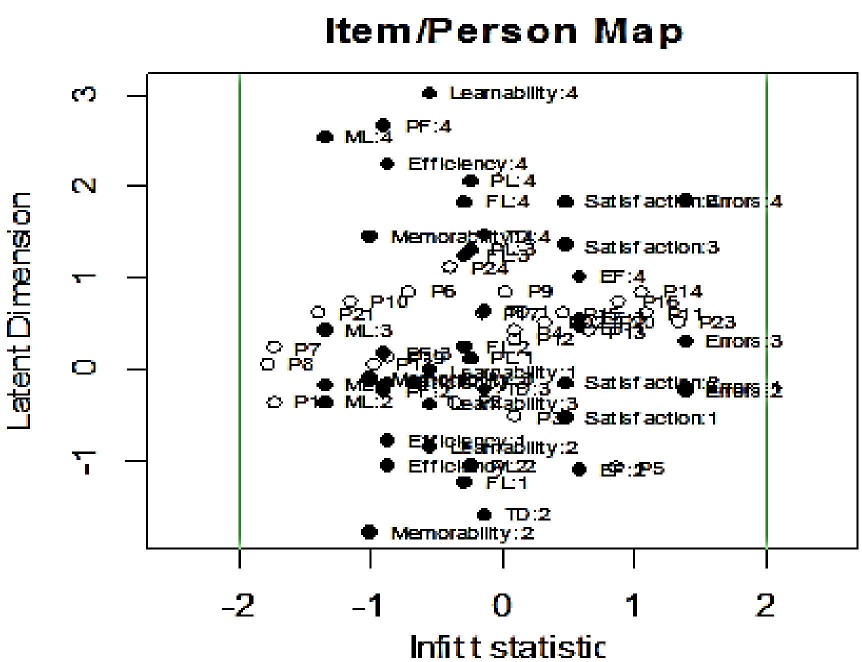


Fig. 30. Plot of Person parameters

Figure 31 illustrates item map and item/person with Bond and Fox pathways. The acceptable boundary is shown in green lines (-2 to +2). It is observed that although items are scattered all over the map regions, the person are clustered close to zero latent dimension due to the ability.



(A)



(B)

Fig. 31. Person-Item maps- with Bond-and-Fox pathway : (A) Item map only, (B) Item-person map

C. Summary

A better understanding of human cognitive ability-demand gap is critical in designing assistive technology solution that is accurate and adaptive over a wide range of human-agent interaction. However, the latent structure and relationship between human ability to respond to cognitive task (demand on human by the agent) remains unknown. Robust modeling of ability-demand gap will be a paradigm shift from the current trends in assistive technology design. The main goal of this research is to model ability-demand gap based on human-agent cognitive task interaction. In particular, latent response model was adopted to quantify the ability-demand gap. The key idea is to quantify ability-demand gap so that the system can adapt with the user's abilities and needs over a wide range of cognitive task. It will also enable the system to provide feedback consistent with the situation. We adopted one parameter (1PL) Rasch model and extended Rasch model (rating scale model, partial credit model) with dichotomous and polytomous responses, respectively to model ability-demand gap. Residues between expected and observed ability scores are considered as gap parameter in case of dichotomous response. In extended Rasch modeling, response latitudes are considered as an indicator of the ability-demand gap. Additionally, we tested the model fit comparisons, standard error measurement (SEM), Kernel Density Estimation (KDE) and Differential Item Functioning (DIF) to see applicability of Rasch model in various items and responses. Empirical analyses on a number of data set shows that proposed analytical method can model ability-demand gap from dichotomous and polytomous responses. In dichotomous case, the model better fits for mixed responses (combination of easy, medium and hard) dataset rather than monotonic (e.g., only easy) data. Residues score shows the gap in interaction. In general, ability-demand gap scores showed a negative correlation between ability, which is illustrated in result section. Our results demonstrated Rasch approach of the ability-demand gap modeling with different cognitive task types and application to disabilities. To have better performance with response model, we need large disability dataset to have an adaptive system.

CHAPTER V: COGNITIVE GAP CONFLUENCE ANALYSIS

This chapter describes the confluence of cognitive ability-demand gap with cognitive dissonance. The confluence, which is the feedback loop between gap and cognitive states (load or dissonance), can be compared with the cognitive cycle [181] in cognitive processing. It was argued that using precision of memory recall, one can estimate the cognitive state [61]. In this study, the precision of memory recall is fitted over cumulative density function (CDF) to see the right-left shift through the inflection point. Two datasets are used in the analysis. The mental multiplication dataset [128] is used in the maximum ability-demand gap computation in simple task interaction. The HAP dataset [129,158] is used to compute gaps in complex task interaction. In both cases, easy, medium and hard tasks are considered to study cognitive load confluence with variable task difficulties. The Kolmogorov–Smirnov (K-S) test is used to describe a sample coming from a population with ability-demand gap or not. The statistics are based on the empirical cumulative distribution function (ECDF).

Section A address as the analysis methods of different gap parameters and their association with human mental resources, section B illustrates some results with simple and complex cognitive task interaction and section C summarizes the findings.

A. Ability-demand gap confluence with cognitive dissonance

It is argued that error [200], confusion [201], noise/uncertainty [202] (Ability-demand gap) motivates humans to learning new information. On the other hand, excessive cognitive gap creates cognitive dysfunction or failure [77,203]. This back and forth situation in the cognition process we call confluence of ability-demand gap. The situation is illustrated in Fig. 32.

The figure illustrates that the cognitive load, bias and demand may cause a gap in information processing that might effect cognitive dissonance, overload or failure. But, in

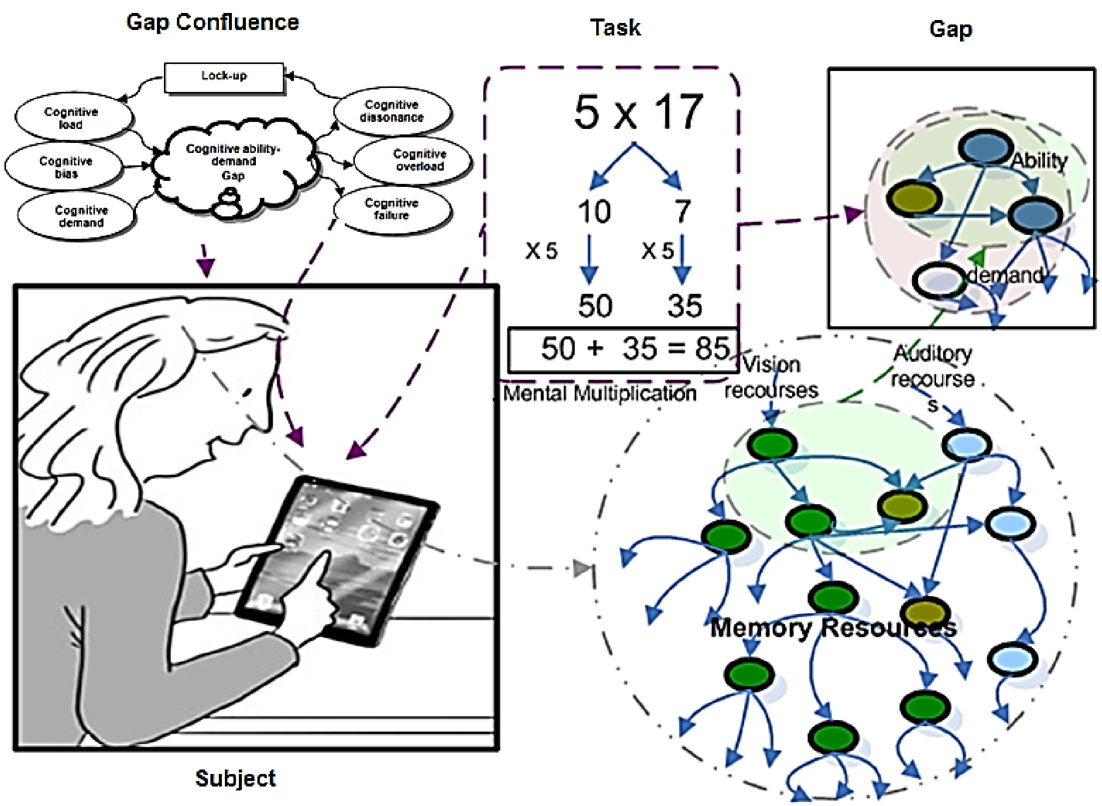


Fig. 32. Cognitive ability-demand gap and cognitive load confluences in terms of mental resources, the top left directed ovals constructs the confluence between cognitive load and dissonance which might created from confusing (gap enabled) mental multiplication task

case of dissonance (confusion), it might reinstate to cognitive load state, through a cycle known as *lock-up/in* or sometimes 'do-nothing-loop'. The loop is shown in Fig. 33.

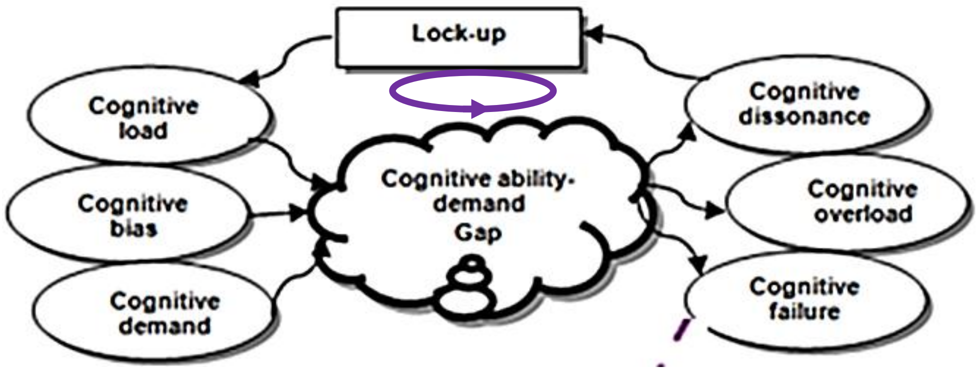


Fig. 33. Cognitive confluence with lock-up

As noted earlier in chapter II, the 80-20 rule [42, 43] are adopted with item response model to scale difference values. In 80-20 rule fitting, the 80 percent is considered from 10 to 90 percent (Fig. 34). The cognitive cycles, or cognitive loops, are considered in the middle (the lock-up) part. Both tails of the response curve show un-acceptable states (overload or underloaded).

To have a connection with the level of information processing and cognitive lock-up, the cognitive task load model of Neerincx [67, 68] is adopted with three response parameters (response latitude, response attitude and response time), which is shown in Fig. 34.

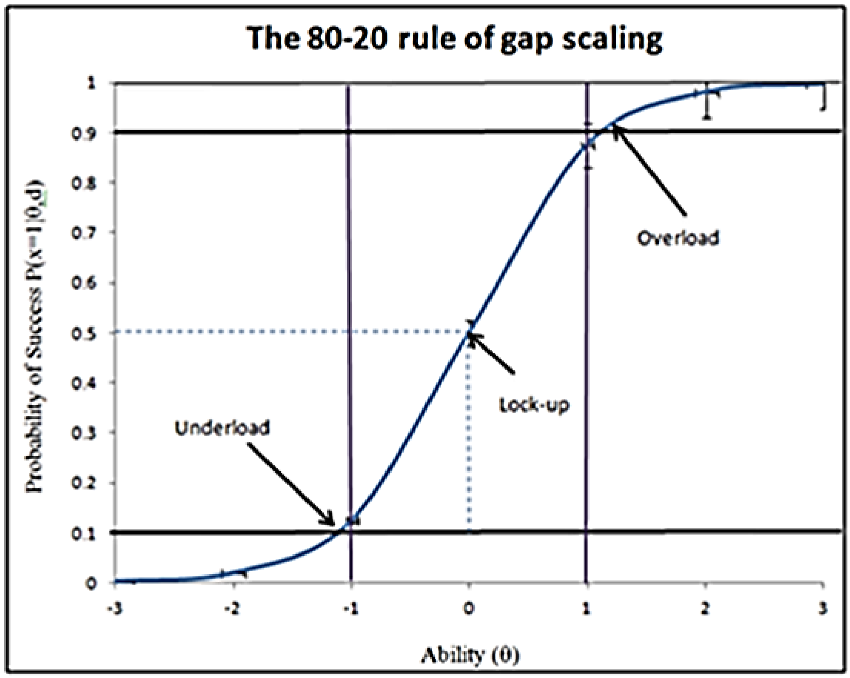


Fig. 34. The 80-20 rule in dichotomous unimodal data (one ability parameter) [42]

Relating to the cognitive lock-up term in 3D task cognitive load model, we introduced a way to measure the threshold of ability-demand gap and its different variants: vigilance, under load, lock-up and overload. Fig. 35 illustrates the relation with 3D response surface. The response latitude is considered as dependent variable with inputs of the ability functions by response time and response attitude. The multi-dimensional difference of these ability functions with task demand might associate to the complex representation of cognitive ability-demand gap. The model is considered compatible with a 3D response model in the sense that the level of information processing is comparable to the response latitude, the response time with task completion time, and the number of task set switch with the response attitudes.

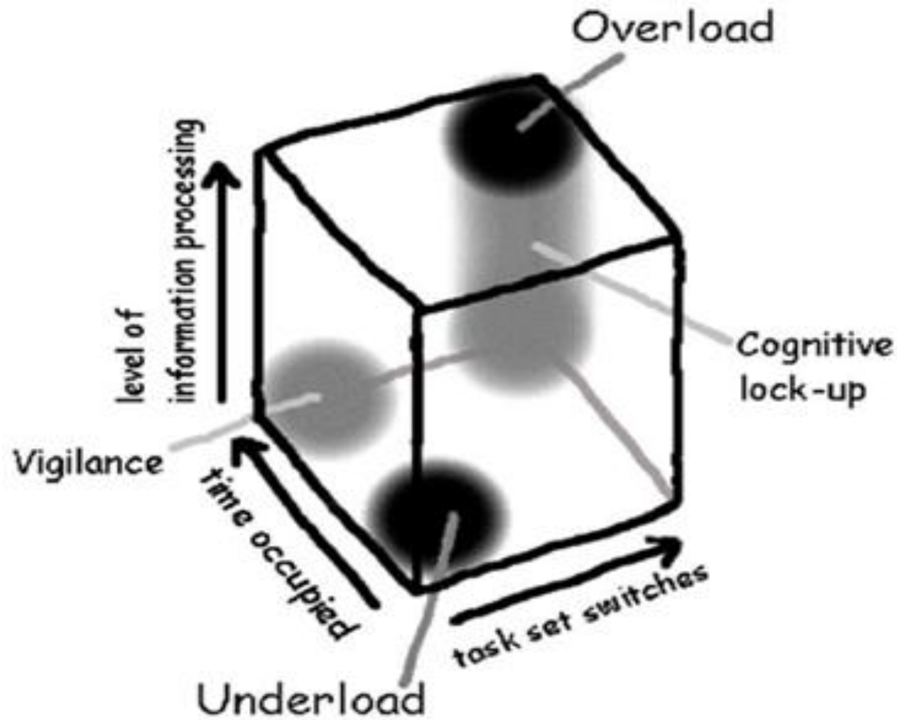


Fig. 35. Cognitive task load model [67, 68] with cognitive lock-up

1) The 3d Response Model

The response data that follow the simple item response function is plotted in a semi-log plots. The ability concentration corresponds to the inflection point of the curve considering the identical parameters task difficulty, cognitive load to the x-axis. Moving an order of magnitude down in ability concentration from the inflection point, one can reach an ability concentration point equal to 1/10th of the equilibrium disassociation constant (k_d). Moving an order of magnitude up in ability level above the same midpoint, equal to 10 times the k_d, equal at the 90% of the maximum response. Over these two orders of magnitude of ability concentration level with the midpoint k_d, the responses can be categorized to whether they were highly demanded or acutely negligible performed.

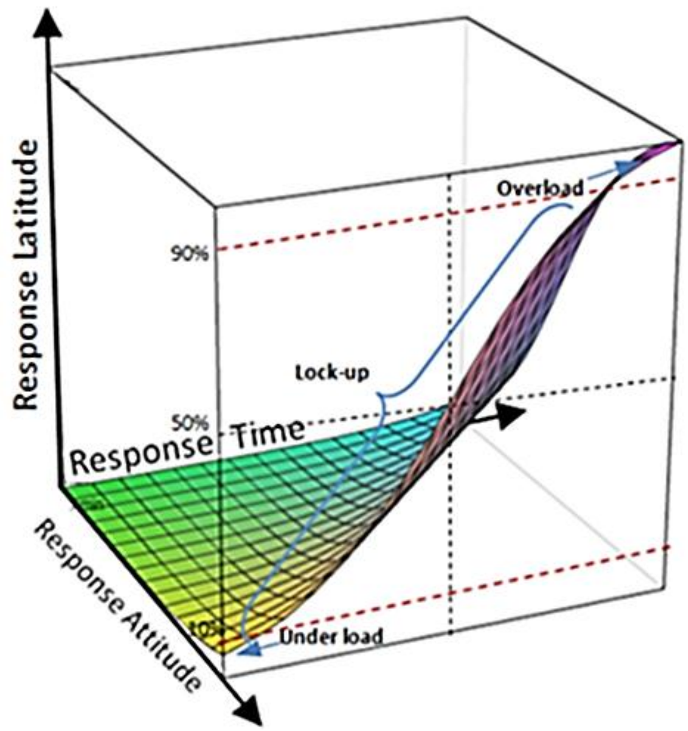


Fig. 36. 3D response model of gap scaling with multimodal (response latitude, response attitude and response time) gaps

This form of 80% rule of absolute change in response is proposed to use cognitive gap scaling with item response theory.

$$\text{Response latitude} = \frac{\mathbf{1}}{\mathbf{1+e^{1.702(d-\theta_{RA}-\theta_{RT})}}} \tag{22}$$

where, d = task difficulty, RA = response attitude, RT = response time, $\boldsymbol{\theta}_{\mathbf{RA}}$ = ability of response, $\boldsymbol{\theta}_{\mathbf{RT}}$ = ability by response time.

Response latitude is a function of task difficulty, response attitude and response time. Probability of response latitude given other parameters forms a statistical model, named as 3D response model in this study. 3D response model might include 80-20 rule to differentiate different stage of response latitude. The response latitude may be analogous to the cognitive gap. Different distance measures can be adopted in the gap computation. A useful way we propose is the Mahalanobis distance of a matrix $X = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}^T$ where m is the number of variables and n is number of data from a group of values, with mean $\mu = (\mu_1, \mu_2, \mu_3, \dots, \mu_m)^T$ and common (nonsingular) covariance matrix $S = T\Lambda T^T$, where Λ are the principal loading and eigenvalues of S and $U = [T \quad \tilde{T}]$, is defined as[11]

$$\Delta^2(x) = \left(f_j - \mu_j\right)^T T\Lambda T^T \left(f_j - \mu_j\right) = \left(f_j - \mu_j\right)^T S \left(f_j - \mu_j\right) \quad (23)$$

where, f_j is the row j of matrix x.

Mahalanobis distance is obtained through the rows of matrix **X** and ability scores through columns. With Mahalanobiz distance the response latitude can be modeled as below

$$\text{Response latitude} = \frac{1}{K}\, e^{-\left(RA_j - \mu_j\right)^T T\Lambda T^T \left(RT_j - \mu_j\right)} \quad (24)$$

K can be considered as a normalizing constant (e.g., the power constant 0.74+-0.06, 95% confidence limits [29])

2. Types of ability-demand gaps

Ability-demand gap can be classified as similar to the mental workload classified by Xie and Salvendy [203]. These are as follows:

Instantaneous Gap $G_i(t)$ – this is the basic measure and is important as the gap can vary from moment to moment in the process of event.

Maximum gap (or peak gap), $G_p(t)$ – is the maximal value of instantaneous ability-demand gap detected when performing a task. It is calculated by computing magnitudes of all instantaneous gaps. A threshold in peak load can indicate whether they exceed human resource limit.

$$G_p(t) = Max\{G_i(t)\} \tag{25}$$

Accumulated gap, $G_{ac}(t)$ - the total amount of gap experienced after completion of the cognitive task. The accumulated gap is defined by the area below the instantaneous cognitive gap carves.

$$G_{ac}(t) = \int_0^t G_i(x)\ dx \tag{26}$$

Average gap, $G_{avg}(t)$ – is the intensity of the gap, the average value of all instantaneous gaps that equal to the accumulated gap in per unit of time.

$$G_{avg}(t) = \frac{1}{t} G_{ac}(t) = \frac{1}{t}\int_0^t G(x)\ dx \tag{27}$$

Overall Gap, $G_{all}(t)$ – in fixed time interval, it is same as the average gap or accumulated gap that states the overall gap during the cognitive processing.

$$G_{all}\,(t) = F_1[G_i\,(t)] = \ F_2\left[G_{ac}\,(t), G_{avg}\,(t)\right] \tag{28}$$

Where, F_1 and F_2 are individual or task dependent mapping functions. As of now, there are no unified measures of cognitive ability-demand gap.

Cognitive gap is necessary task and person specific. Expert people can perform the difficult task effortlessly. Similarly, for lack of skill (ability) a very simple task may become complex to the novice people. Person specific issues are hence very important to consider during gap measurement.

Effective Cognitive gap, G_{eff} - need less attention- is the gap that people must bear while working, even if they act efficiently and accurately. This is the acceptable gap generated by task requirement for motivation of the work.

Ineffective Cognitive gap, $C_{in\text{-}eff,}$ -need more attention- is the gap generated internally by individuals. It requires more extra attentional mental resources. Different people may experiences different amount of ineffective cognitive gap for the same task. In action dynamics and information processing, effective cognitive gap relates to fast, and accurate action whereas ineffective cognitive gap relates to error and inaccuracy. Learning is only affected by ineffective cognitive gap for a given learning task. Using definition of effective and ineffective gap that can be redefined as accumulated cognitive gap as,

$$G_{ac}\,(t) = K + \left(\mathrm{G}_{eff}\ + \mathrm{G}_{in-eff}\,\right) = \ \int_0^t G_i(x)\ dx \tag{29}$$

K is the degrading factor (0 - fully concentrated, 1 –DNC – do-not-care)

Again average cognitive gap is defined as,

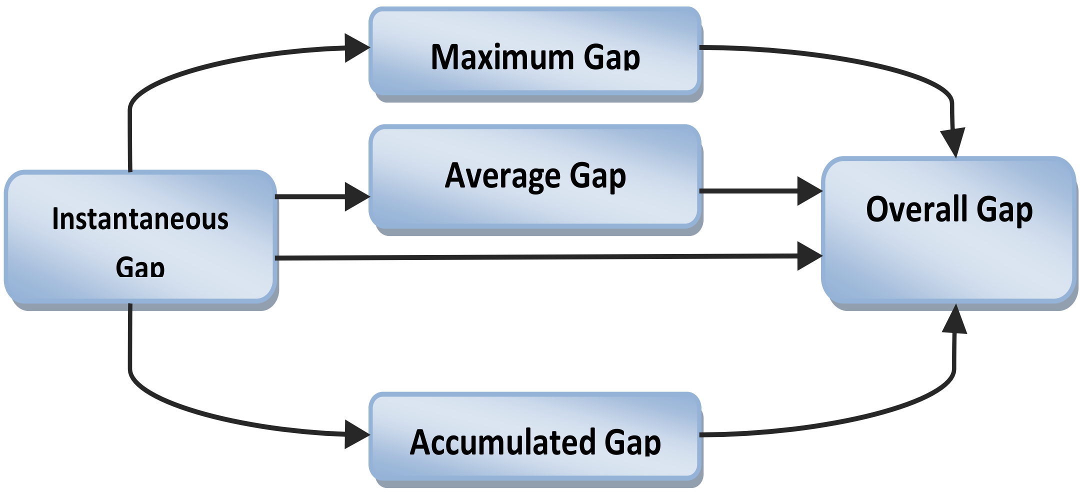


Fig. 37. Relationship flow diagram of various ability-demand gap types

As task complexity (T_c) and task type (T_t) are task related factors, selection of only these two for cognitive load measurement considers only effective cognitive load. Considering individual factors, personal knowledge (P_k) and physical skills (P_p) such as typing and mouse movement abilities can be considered as an ineffective load.

3) Cognitive Dissonance/ Lock-Up Computation

The probability of response attitude switch is considered as a way to compute 'Do-nothing-loop' – the dissonance/lock-up situation. In a complex task environment, let, n be the number of response options a user is switching in-between. Let p be per-option switching probability that some response delay associated for mental overload within the current activity. If the responses are considered independent to each other, then the probability that no task is delayed on any node is $(1-p)^n$. Therefore the probability that the task is delayed within the current computation phase is

$$d_p\,(n) = 1 - (1-p)^n \tag{30}$$

If p is considered as a small number then

$$d_p\,(n) \approx \overline{d_p}(n) = p_n \tag{31}$$

(2) can be used for a reasonable approximation. The difference between (3.18) and (3.19) is

$$\Delta = \overline{d_p}(n) - d_p\,(n) = p_n - 1 + (1-p)^n \tag{32}$$

It is easy to compute that; Δ is a non negative number. According to the binomial theorem,

$$(1-p)^n = 1 - (p)^n + \frac{n(n-1)}{2}\,p^2 + \sum_{k=3}^{n}\binom{n}{k}(-1)^k(p)^k \tag{33}$$

Here the right most summation has the negative value.

From (30) and (34) we have,

$$0 \le \Delta \quad < \frac{n(n-1)}{2}p^2 < \frac{n^2p^2}{2} \tag{34}$$

Which means that Δ is bounded by some small ε if $p < \frac{\sqrt{2\varepsilon}}{2}$.

$$\text{So, } \frac{\Delta}{\overline{d_p(n)}} < \frac{n^2p^2}{2np} = \frac{np}{2} \le 0.05 \tag{35}$$

Which holds, if $p \le \frac{1}{10n}$.

$$\text{Another way, } \overline{d_p}(n) \le 1 - (1 - \frac{1}{10n})^n \approx 1 - e^{-\frac{1}{10}} \approx 0.1 \tag{36}$$

4) Cognitive cost in dissonance situation

Let us consider the sequence of colored cells (or any visual stimuli) visited by a subject to complete a task is,

$$S_c = \{S_{c_1}, S_{c_2} \ldots S_{c_n}\} \tag{37}$$

The probability that the subject switches between n of tasks T until $t = t'$ and choose cell sequence j is

$$P(j, t'|T_n, S_{c_n}) = P(j|\, t', T_n, S_{c_n})\, P(t'|S_{c_n}) \tag{38}$$

$P(t'|S_{c_n})$ is the probability of continuing the visit between cell until t'or equivalently stopping the switching task at $t' + 1$:

$$P(t'|S_{c_n}) = \left(1 - P(S_{c_n,t'+1}|S_{c_n})\right) \prod_{t=1}^{t'} P(S_{c_t}|S_{c_n}) \tag{39}$$

Where, the switching probability at stage 1 is 1 for any task. Whether the subject visit the particular cell is $P(S_{c_1}|S_{c_n}) = 1$ and stopping probability beyond the final stage is 1, that is

$$P(S_{c_n,t'+1}|S_{c_n}) = 0 \tag{40}$$

Since t' is latent, we have

$$P(j|T_n) = P(j|\, t', \mathrm{No-switch})\, P(\mathrm{No-switch}) + \sum_{n} \sum_{t'}^{T_n} P(j|\, t', T_n, S_{c_n})\, P(t'|S_{c_n})\, P(S_{c_n}) \tag{41}$$

$P(S_{c_n})$ is the probability of a subject visiting a colored cell.

Specifically at each stage a binary logic function is used to all attentive cells or stopping. So the systematic activities

$$\bigcup S_{c_n} = \beta_{cognitive\ cost} + \beta_{benifit}\beta_{c_t}(GO)$$

$$\cup(stop) = \beta_{benifit}\beta_{c_t}(Stop) \quad (42)$$

$\beta_{c_t}(GO)$ means average expected maximum utility of switching at stage t for a student n for task Ti. $\beta_{c_t}(Stop)$ is the expected maximum utility stop switching between cells.

5) Gap scaling

Mental workload can be defined with the dynamics right/left shift of the precision of working memory resources [62], [63]. Dynamic right shift represent difficult task. Reversely, the ability based mental resource dynamics is computed in the same way. Kolmogorov–Smirnov (K-S) statistics is practical in this case. In K-S statistics, the K value is considered as the maximum gap index between ability and demand vector and the H=1 or 0 indicate the significance of the gap as like 80-20 rule. The two-sample K-S test compares the distributions of values in the two data vectors of ability and demand. The null hypothesis for this test is that ability (θ) and demand (δ) have the same continuous distribution. The alternative hypothesis is that they have different continuous distributions. The result H is 1 if it the hypothesis can be rejected that the distributions are the same or 0 if we cannot reject that hypothesis. We reject the hypothesis if the test is significant at the 5% level.

The K - S statistic [12] is considered as a nonparametric test for the equality of continuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution

$$\mathrm{d} = \mathrm{Max}|\mathrm{F(x)} - \mathrm{G(x)}| \quad (43)$$

Where, F(x) and G(x) are the theoretical and empirical distribution functions evaluated at x, respectively. These two functions are evaluated at xi are defined as

$$F(x_i) = P(X \leq x_i) \tag{44}$$

and $$G(x_i) = \frac{\text{Number of } X's \leq x_i}{n} = \frac{i}{n} \tag{45}$$

Where, i=1,2,…,n. If the observed maximum departure d is small, then the assumed F(x) may be reasonable as that distribution that generated the data. But if this d is "large" then it is unlikely that F(x) is the underlying data distribution. Individual's cognitive effort to bridge cognitive gap might drive her will power.

According to mental health research [65, 66, 70], cognitive ability-demand gap effects in cognitive overload. Logically, the cognitive gap can be associated with the "cognitive-lock" and can be scaled as: vigilance, (low) cognitive load, lock-up, overload. Neerinx [67, 68] assumed 80-20 rules [42] for lock-up vs. overload computation over the level of information processing capability and scaled cognitive load as Table 11.

TABLE 11. Features of cognitive gap estimation

Response Dimensions	Task Performance		
	Low	Medium	High
Time = Low Latitude = Low Attitude = low	No cognition	Under-load	
Time = Medium Latitude = Low Attitude = low/Medium	Cognition		Vigilance
Time = low/Medium Latitude = Medium/High Attitude = Low/Medium/High	Cognitive lock-up		
Time = High Latitude = High Attitude = High	Overload		

In this research, we only computed maximum and overall cognitive gap with K-S statistics and showed whether subjects are in cognitive lock-up (caused by dissonance) or overload situation.

B. Gap Confluence Analysis Result

The specific goal was to identify a subject's cognitive dissonance or overload situation form maximum ability-demand gap or overall gaps computed from demand and ability distributions. With this goal, the maximum cognitive ability demand gap is computed from the K parameter of K-S test between ability and demand distribution. Task evoked pupil dilation is considered as demand and the task response time (action) as the ability. The task response time is computed as the time difference between the peak (maxima) of the pupil dilation and the task completion (click) time. Both are normalized before the non-parametric K-S statistical analysis. The K value is then compared with task difficulty scores to see the effect of gap over cognition process.

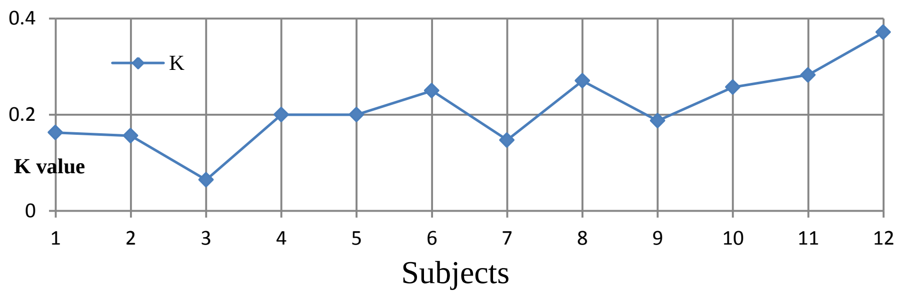
Table 12 shows twelve subjects' cognitive task (mental multiplication) interaction performance. It is observed that subject number four was given the highest number of hard tasks and performed most of them successfully and is shown with a relatively low K value (0.10).

TABLE 12. Ability demand comparison in mental multiplication task

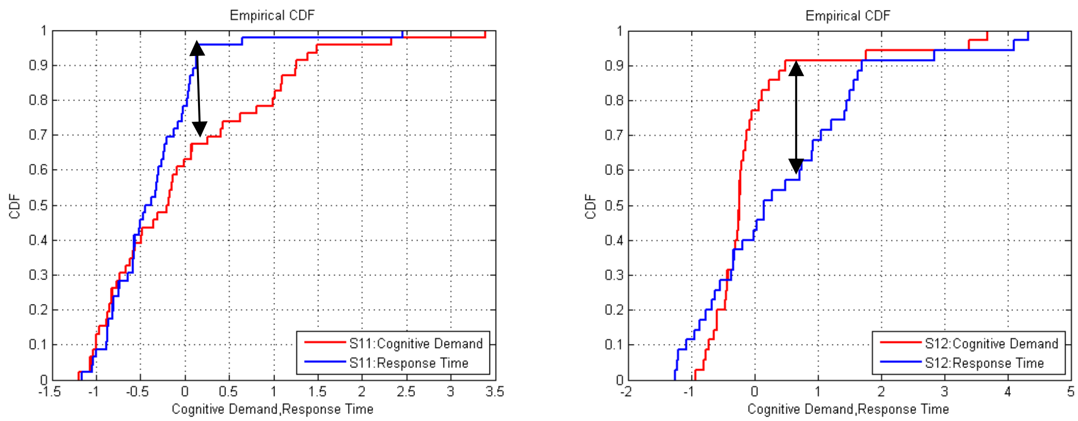
Subject	Cognitive Tasks			Cognitive Performance			Task Demand (Wavg.)	Task Performance (Wavg)	K-S Statistics		
	Easy	Medium	Hard	Easy	Medium	Hard			H	p-value	K
S1	16	17	10	15	16	3	1.86	1.65	0	0.58	0.16
S2	12	11	9	12	9	5	1.91	1.73	0	0.80	0.16
S3	11	13	7	11	11	5	1.87	1.50	0	1.00	0.06
S4	8	13	14	8	13	10	2.17	2.06	0	0.44	0.10
S5	12	14	9	12	11	6	1.91	1.79	0	0.44	0.20
S6	13	14	9	12	13	3	1.89	1.68	0	0.18	0.25
S7	12	14	8	12	12	5	1.88	1.76	0	0.83	0.15
S8	13	14	10	13	10	5	1.92	1.43	0	0.11	0.27
S9	13	12	7	12	10	6	1.81	1.45	0	0.58	0.19
S10	9	12	7	9	14	6	1.93	1.90	0	0.17	0.26
S11	16	17	13	13	9	0	1.93	1.70	1	0.04	0.28
S12	11	17	13	11	13	0	2.05	1.83	1	0.01	0.37

Meanwhile, subjects who failed to perform a hard task showed a relatively higher cognitive ability-demand gap in terms of K value. For instance, subject 11 and 12 have relatively higher gaps (.37 and .28, respectively) and failed to perform hard task. Whereas, subjects (6, 8, 10) with a gap score $> .25$ performed some hard task. This indicates that, there was a marker between subjects who performed well on all types of tasks and who failed some task with a higher gap score. More specifically, this sore works as the threshold between cognitive dissonance and cognitive overload. In this case, the value is .26. Fig. 38 illustrate the findings.

Fig.38A shows the comparative score with a line plot, and Fig.38B shows CDF plots of subject 11 and subject 12.



(A)



(B)

Fig. 38. K-S statistics in cognitive overload assessment, mental multiplication task , (A) K value comparison and (B) CDF plot of subject 11 and 12, having cognitive overload

When subject ability meets task demand, then both the curved red and blue should become identical.

To show confluence of gap in complex cognitive and collaborative task, we choose the HAP dataset. Ability-demand gap hampers subjects to select right colored flushing cells resulting cognitive dissonance or cognitive overload. The maximum gap score represents whether the task participant is in cognitive dissonance or cognitive overload state. In complex cognitive task interaction, there may be multiple states of task difficulty. For instance, a primary cognitive task given to the subjects in the HAP dataset was to click the right colored cells. The secondary cognitive task was to click the valid cells. Fig.39 shows such distribution with the difficult task (Q =6).

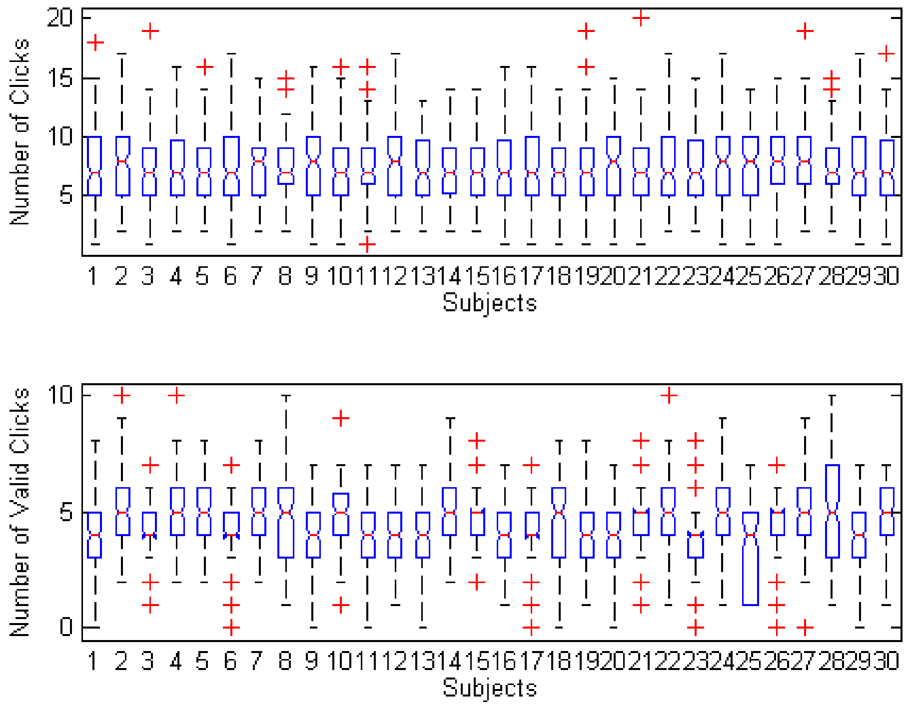


Fig. 39. Comparison of number of clicks and number of valid clicks by thirty participants in HAP task interaction

The gap score with team performance illustrates the maximum, average and minimum gaps, which is illustrated as the ability-demand gap three (Fig.40).

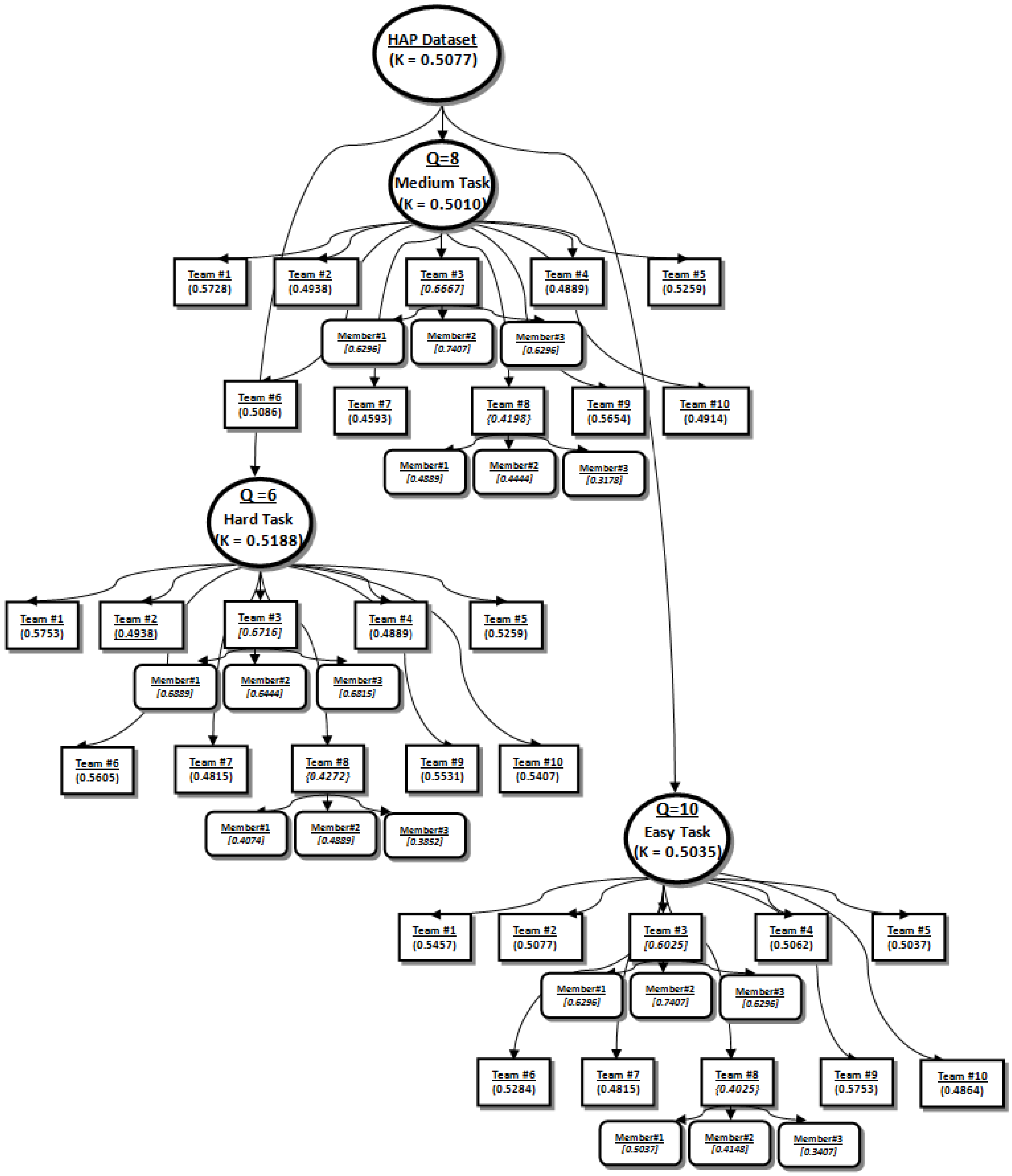


Fig. 40. Ability-demand gap tree in complex HAP task interaction

The circle in the Fig. 40 shows the demand types by queue size, and the external nodes shows team level gap. Only maximum and minimum team level gaps are shown as leaf node (e,g., team three and team eight).

Such a tree might be useful to distinguish cognitive dissonance and overload situation. The maximum ability-demand gap identified through ability and demand CDF distribution indicates team members overload status [61]. Accordingly, in Fig. 38 the highest gap is observed in the hard task (Q =6) interaction, than medium (Q =8) or easy task (Q =10). It is observed that, team 3 shows highest k value (gap) and team8 shows lowest k value (gap).

Team members' primary and secondary activities are shown in Fig. 41. It is observed that most of the team members in team eight have spread median distribution than that of team three.

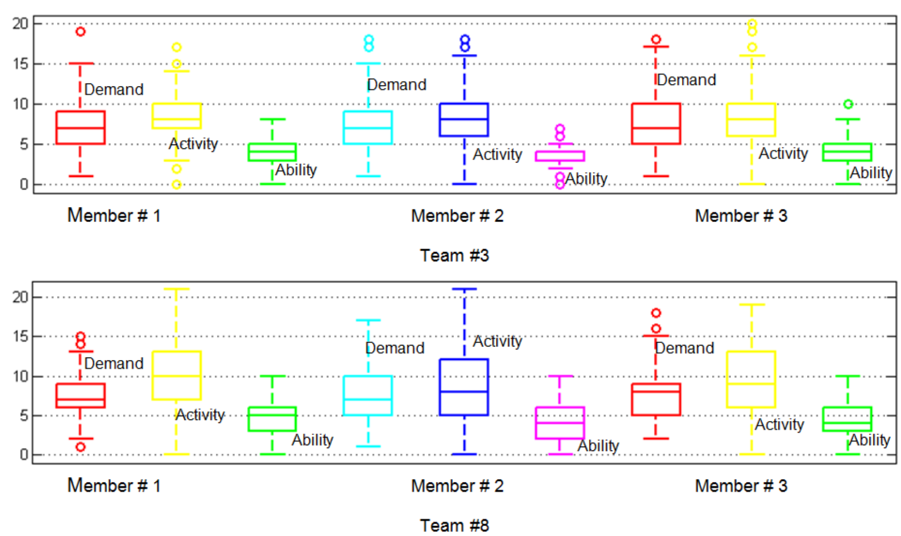


Fig. 41. Team members’ cognitive demand, clicking activity and correct performance (ability) comparison

To have more insights on team members' gap confluence, the bi-variate plots are performed (Fig. 42 and Fig. 43). The reason of choosing bag plot is their distribution free, multivariate properties. The bi-variate median (the orange central region) in team members' bag plots shows the clear picture between team three and team eight. The area of 50% most central data points are larger in team eight than team 3, signifying the spread of ability-demand data. The light region 'the fence' contains the points that are further away (but not enough that they would be considered outliers.). No data points are observed in the outside the fence signifies that no clear outliers.

C. Summary

This chapter contributes empirical findings on the confluence of ability-demand gap with cognitive dissonance and overload in complex collaborative task interaction. The study summarizes how statistical analysis techniques can be used to add value and insight into the nature of cognitive ability-demand gap types, especially in maximum gap identification and application as a threshold between dissonance and overload. K-S statistics and bi-variate analysis (bag plot and box plots) were practical to reliably report team individual's ability-demand gap and were found effective in terms of quantitative and qualitative analysis. Our empirical results show that team and members' maximum ability-demand gap can be identified through the maximum K value (with K-S statistics). Having team or team member's ability demand gap, individual's similarity/dissimilarity with their team mates can be observed thought median distribution and bag sizes. Our research offers novel techniques to analyze the relationship of ability-demand gap with cognitive load effects - dissonance or overload. The 3D response model with 80-20 rule, which is theoretically explained with gap threshold identification and cognitive load classification, further enriches the way that researchers can evaluate cognitive task load and effects. In this study the probabilistic difference between ability and demand vectors with CDF, represents the gap score. Further analysis will be done with the ability based demand vector and conflict metrics analysis with multiple resource theory and cognitive signal flow graph – a similar concept of resource allocation graph. Next analysis will be applied to interference computation, signal flow graph mining and gap pattern identification. Connection of cognitive lockup and cognitive resources interference will also be accomplished in future studies.

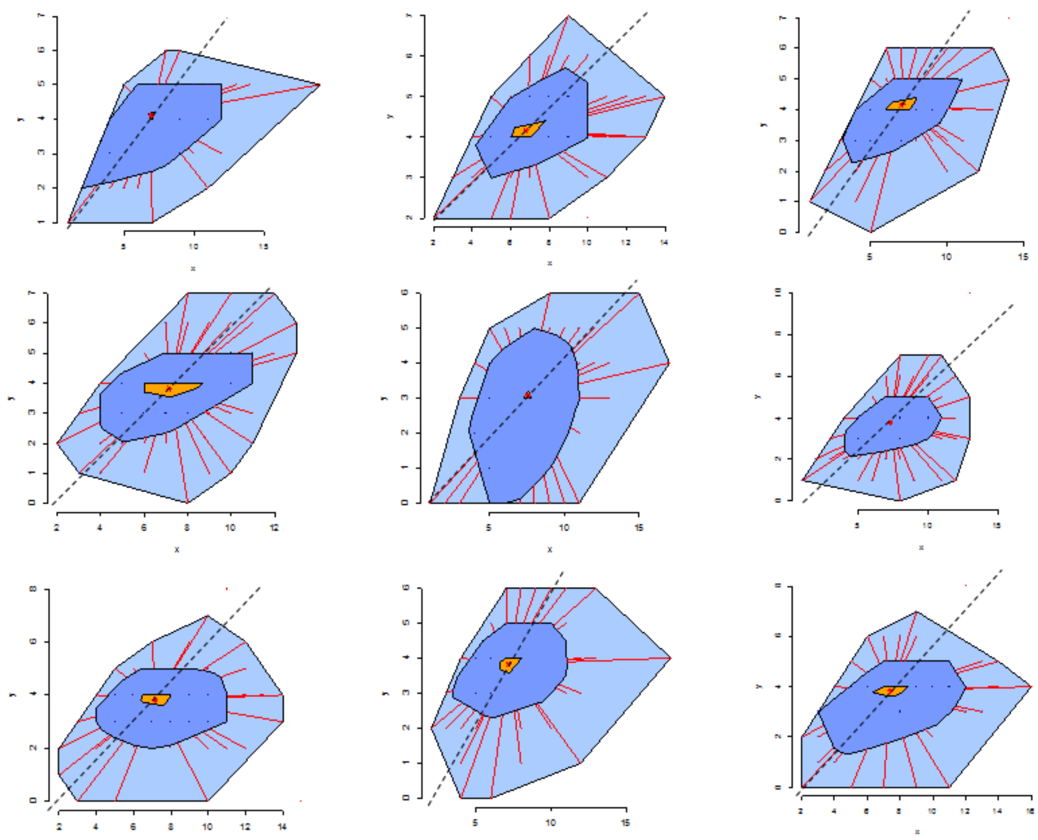


Fig. 42. Team members demand vs. ability comparison with the (3 x 3) bag plot matrix - of team members (row) and task difficulty (column) - Team3

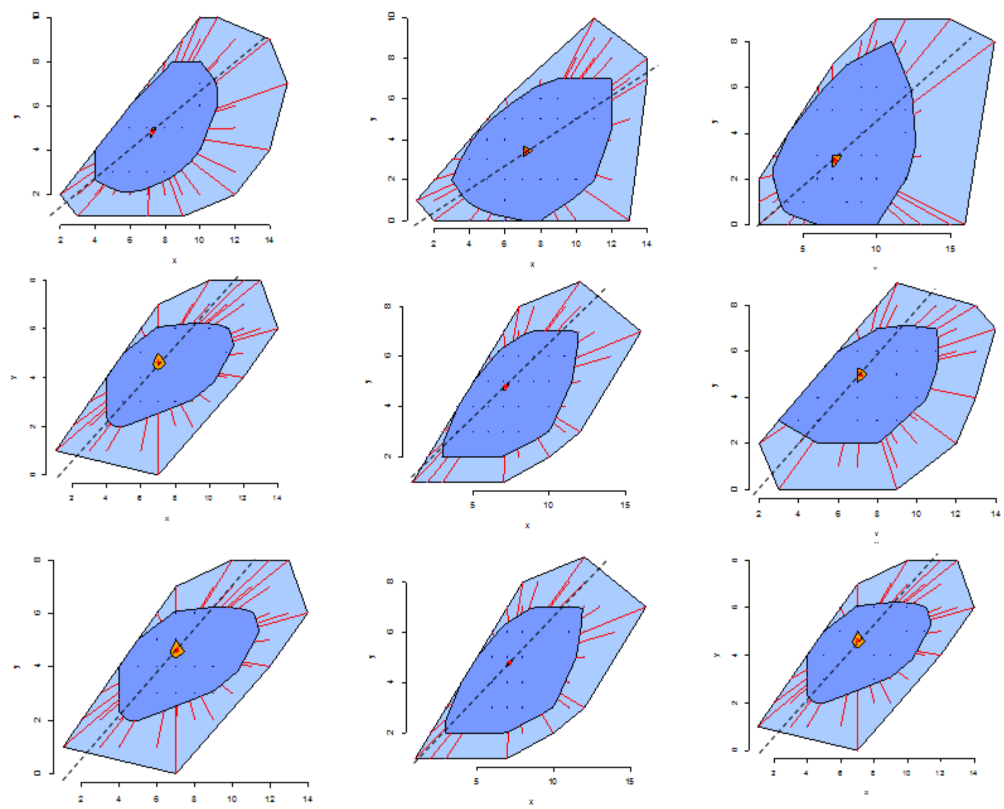


Fig. 43. Team members demand vs. ability comparison with the (3 x 3) bag plot matrix - of team members (row) and task difficulty (column), Team 8

CHAPTER VI: COGNITIVE GAP EFFECTS IN COLLABORATIVE SENSE-MAKING

This chapter describes ability-demand gap effects in human-agent collaborative sense-making. The statistics are based on the empirical cumulative distribution function (ECDF). We analyzed how ability-demand gap affects more in individual performance rather than team performance. The statistical tool used in such analysis is the non-linear mutual-information based Maximal Information-based Nonparametric Exploration (MINE) tools [102-104]. The MINE package encompasses a set of tools, maximum information coefficient (MIC) and maximum asymmetry score which are considered in gap effect analysis.

Section A address the analysis methods of different collaboration analysis methods and the ways we can follow in gap effects analysis. Section B illustrates some results with simple and complex cognitive and collaborative task interaction and the section C summarizes the findings. Only the HAP dataset [129] is used in the human-agent team shared cognitive and collaboration gap illustration.

A. Ability-demand gap effect in collaboration

Collaboration is defined as a process of joint decision-making among key stakeholders of a problem domain about the future of that domain with a high degree of information integration [94 -140]. Collaboration is a recursive process of working together to perform a task and to achieve a shared goal [93].

Collaboration requires two or more people (or software agent) or organizations to work together to realize that shared goals [94]. The shared goal can be formulated with sharing knowledge, learning and building consensus with or without leadership [94]. A schematic of collaborative activity in Human Agent Pair (HAP) dataset is shown in Fig. 44.

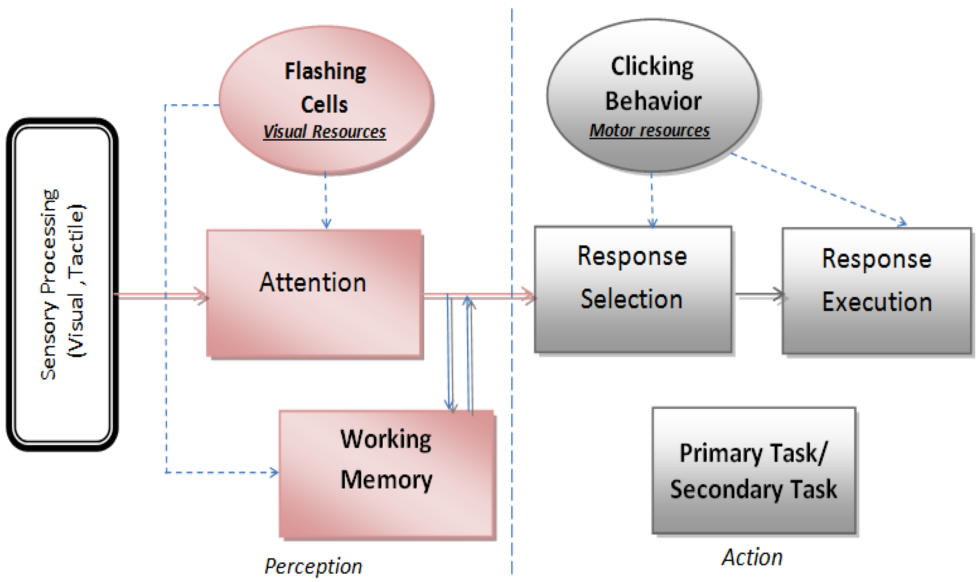


Fig. 44. Schematic of perception, action and collaboration in HAP dataset [129]

Another way to think collaboration information processing constructs is the shared cooperative activity formulation [204]. There are three essential characteristics in shared cooperative activity (SCA): (1) participants are mutually responsive to one another; (2) there is a shared goal in the sense that, each participant has the goal that we (in mutual knowledge) do joint-task together and (3) the participants coordinate their plans of action and intentions understanding that both roles of the interaction (role reversal) which so can at least potentially help the other with his role if needed. To keep things simple, Bratman

[204] focused on collaborative activities that involve only a pair of participating agents and are not the activities of complex institutions with structures of authority.

Accordingly, a triangular activity (Fig. 45) is formulated in shared cooperative task with joint intention and goal between two team members. In the case of cross-disability collaboration, establishing joint attention takes more effort and time, hence an extremely challenging issue. Figure 45 shows the shared collaborative task formulation and elements. G in (Fig. 45) represents shared goal, A1, A2 action taken by team members' g1; g2 sub-goals to be shared to form mutual goal using the individual's knowledge and skills.

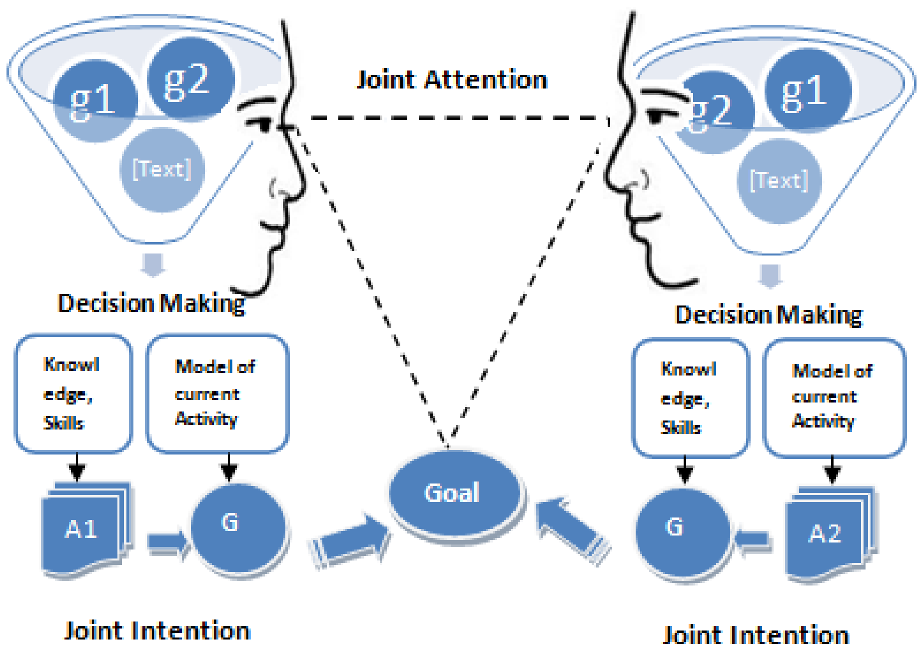


Fig. 45. Collaboration formulation– schematic diagram of shared task

Figure 46 illustrates the internal construct of collaborative activity: the rectangle shapes indicate an individual's ability elements and the circle represents collaborative ability elements. Colored and filled circles between team members overlapping regions (marked as CIS ability elements) indicate team members sharing ability of that elements color indicates particular teammate. The green circle in the middle indicates CIS element

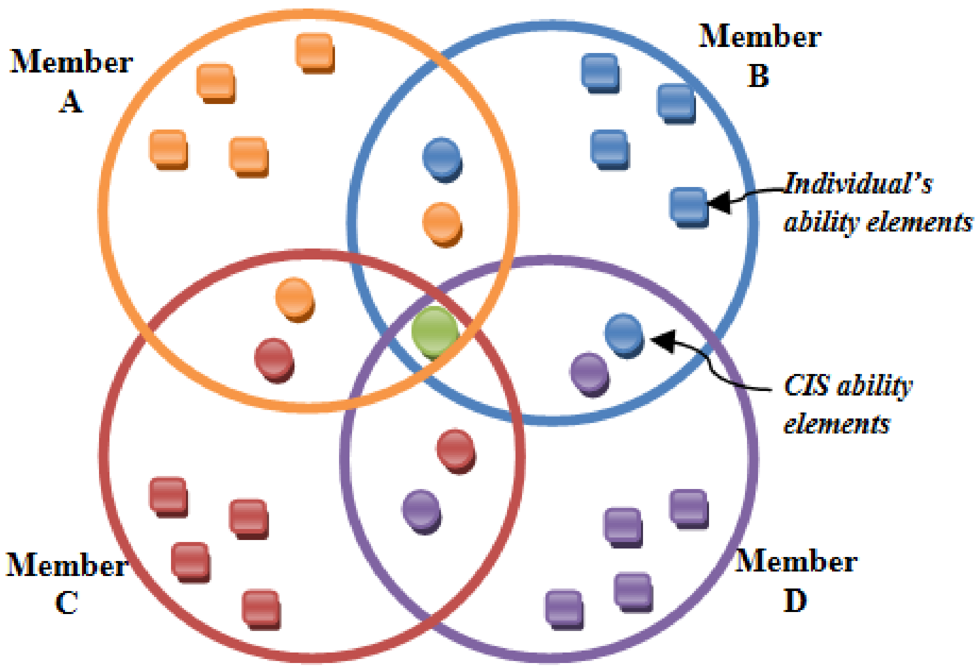


Fig.46. Collaboration formulation–shared cooperative activity elements among four team members

1) Index of collaboration and gap

A recent study [99] proposed a similarity index of collaboration by comparing team members' responses with an average response in the team or the response of the best team. Team average similarity index ($\mathbf{S_i}$) is defined as -

$$\mathbf{S_i = 1 - \left|\frac{X_i - X_{avg}}{X_{max}}\right|} \tag{46}$$

Where, X_i represents team member's response, X_{avg} team average response and X_{max} team member's highest response. A similarity index score of 1 is considered an indication of all responses are same as like the model (expected), whereas the score approaching 0 indicates all responses are different than expected. In a reverse analysis, we may consider the later part $\left|\frac{X_i - X_{avg}}{X_{max}}\right|$ of the equation (1) as a team level ability-demand gap or collaboration gap computation.

2) Precision computation

The precision is defined as the reciprocal of the variance and the precision matrix is defined as the matrix inverse of the covariance matrix. [61] The precision based measure first appeared in the works of Gauss (1809). Gauss defines the precision (1/var) with an explanation of the density function of a normal random variable with precision h.

In order to evaluate the team performance in complex human-machine(agent) collaborative task, several evaluation metrics were defined with the most popular being precision, recall and F-measure. *Precision* is the number of correctly clicked cells in shared belief map as percentage of the total number of identified items. Precision degrades by incorrectly identified items. In the following formula for the precision metric, *valid clicks* are the number of correctly identified items (correct answers), and *attempted* is the total number of items identified (answers produced):

$$\text{Precision (P)} = \frac{\text{Valid clicks}}{\text{Attempted}} \tag{47}$$

Similar to precision a Recall value can be computed as the number of correctly identified items as a percentage of the total number of items available to click. Here the degradation is induced by cells not being identified. In the following formula, valid clicks are the number of correctly identified items (correct answers), and demanded is the total number of cells demanded to click (possible answers):

$$\text{Recall (R)} = \frac{\text{Valid clicks}}{\text{Demanded}} \tag{48}$$

High precision may often be achieved at the expense of low recall and vice versa. A combined metric exists, F_measure, defined as:

$$F_{\text{measure}} = \frac{P * R}{\beta * P + (1 - \beta) * R} \tag{49}$$

In the above formula P is the precision, R is the recall, and the parameter β is the weight of the relative importance of precision/recall. Values close to 0 favors precision, values close to 1 favors recall

A value of 0.5 gives equal weight to precision and recall, which is the most commonly, used form or F-measure:

$$\text{F\_measure} = \frac{2 * P * R}{P + R} \tag{50}$$

With team average similarity index, the average precision is defined as,

$$\text{Avergae Precision (P\_avg)} = \frac{\text{Sum of precision of team members}}{\text{Total number of member}} \tag{51}$$

Similarly, the average recall is defined as,

$$\text{Average Recall (R\_avg)} = \frac{\text{Sum of recall of team members}}{\text{Total number of member}} \tag{52}$$

Finally, the average F-Score is computed as,

$$\text{Avergare F\_Score} = \frac{2 * \text{Average Precision} * \text{Avergae Recall}}{\text{Avergae Precision} + \text{Average Recall}} \tag{53}$$

Equation (53) is useful in team collaboration strength comparison.

3) Information theory of collaboration strength and gap

The maximal information coefficient (MIC) is a measure of two-variable (demand and ability) dependence designed specifically for rapid exploration of many-dimensional data sets. MIC is part of a larger family of Maximal Information-based Nonparametric Exploration (MINE) statistics, which is used not only to identify important relationships in data sets, but also to characterize them. MINE creates the characteristic matrix by searching for grids that maximize the penalized mutual information of the distribution induced on each grid's cells by the data. Different relationship types give rise to characteristic matrices with different properties. For instance, strong relationships yield characteristic matrices with high peaks; monotonic relationships yield symmetric characteristic matrices, and complex relationships yield characteristic matrices whose peaks are far from the origin. MIC is a correlation measure and applicable in measuring relationship strength between demand and ability vectors. Let, the demand ability vectors are defines as D and A respectively. MIC is defined as –

$$\text{MIC (M)} = \max_{\text{DA}<B(n)} \text{Mutual(M)}_{\text{D,A}} = \max_{\text{DA}<B(n)} \frac{\text{I} * (\text{M, D, A})}{\log(\min \text{D, A})} \tag{54}$$

where B(n) = n is the search-grid size, I(M, D, A) is the maximum mutual information over all grids D-by-A, of the distribution induced by M on a grid having D and A bins (where the probability mass on a cell of the grid is the fraction of points of M falling in that cell) . The Maximum Asymmetry Score (MAS) captures the deviation from monotonicity, and useful for detecting periodic relationships (unknown frequencies).

$$\text{MIC (M)} = \max_{\text{DA}<B(n)} |\text{Mutual(M)}_{\text{D,A}} - |\text{Mutual(M)}_{\text{A,D}}| \tag{55}$$

B. Gap Effect Analysis in Collaboration: Results

The main research objective of the third study was to identify an underlying relationship between ability-demand gap and collaboration strength in the collaborative sense-making process. Results explains the overall picture from cognition to collaboration (Fig. 47), collaboration strength computation with F-scores (Fig. 48 and Fig.49) and collaboration strength vs. gap trade-offs (Fig. 50, Fig. 51) with sense-making process (Fig. 52 and Fig. 53).

1) The Overall Picture of Cognition and Collaboration

The overall picture of dataset in terms of demand-ability performance measure is shown with CDF plot (Fig. 47). It is observed from Fig. 46, that all team members are given relatively same demand (the first row). It is also noticed that the increase of task difficulty does not impact on change of expected ability/demand (score = 7.5 in x dimension).

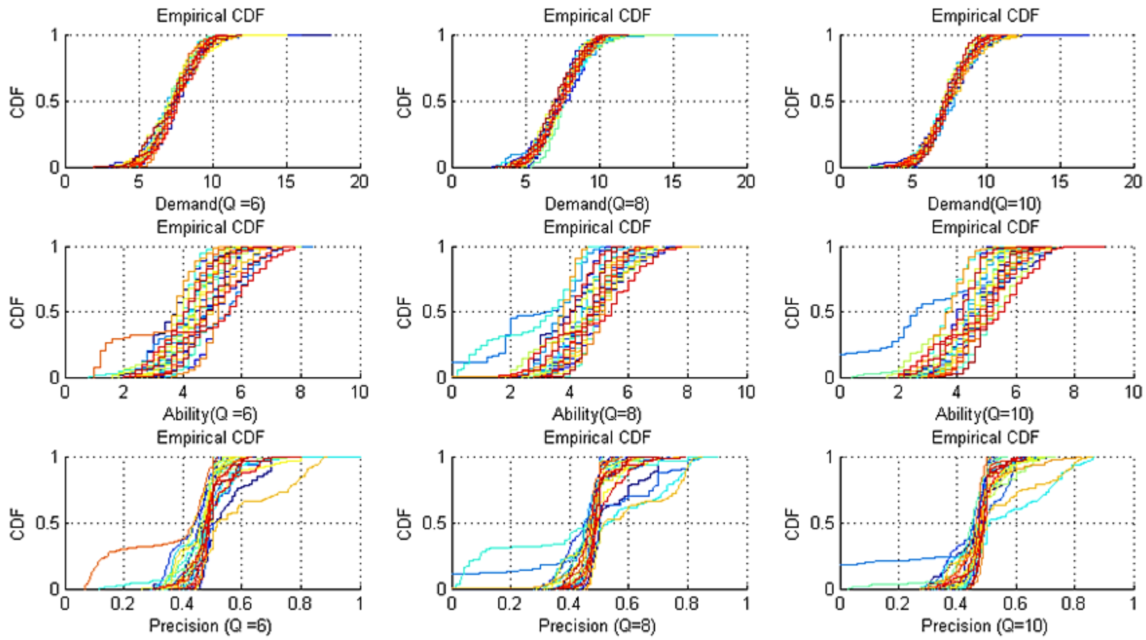


Fig. 47. CDF plot of all subjects' task demand, primary (cognitive) ability and precision

The overall primary ability varies with increase/decrease of task difficulty. The range of overall primary ability in easy (Q = 10) and medium (Q = 8) task interaction are (2.2 - 5.8) and (2-5.8), respectively. This is significantly different from the hard task (Q =6) interaction ability (3.8 - 5.8). Subjects are more precise in easy and medium task than hard task (bottom row of Fig.47).

2) Collaboration strength computation with average F-score

Figure 48 summarizes average F-score comparison of all ten teams participated in the collaborative task setting. The figure illustrates the comparative collaboration strength with increase of task difficulties by queue size. It is observed in the box that team three perform poorly, and the team eight performs the best among all, as it is expected with the earlier finding (chapter IV). The important observation we notices is that team individuals performance does not bias team overall ability-demand gap. Figure 49(A), (B) and (C) explains team individuals' performance with queue size 6, 8 and 10, respectively. More specifically, one of the team members in team three shows the best performance case of Q=6 (Fig. 49C).

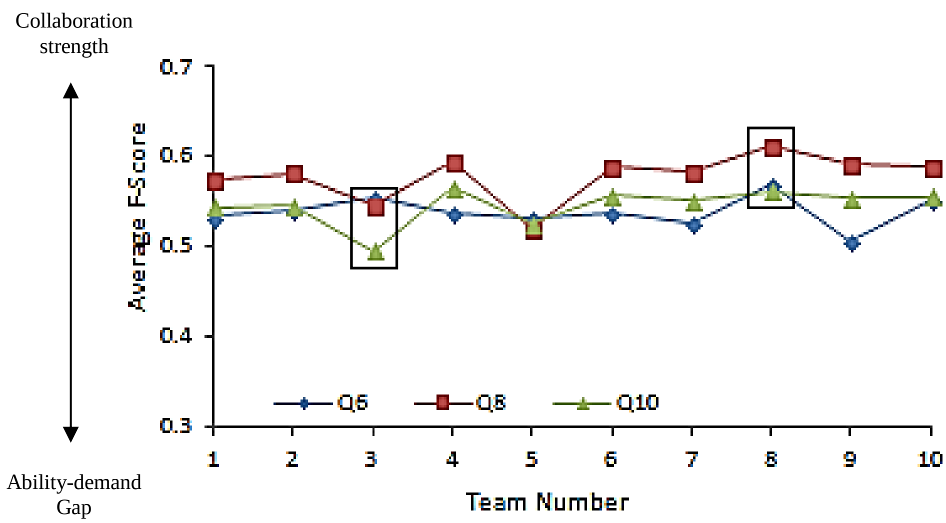
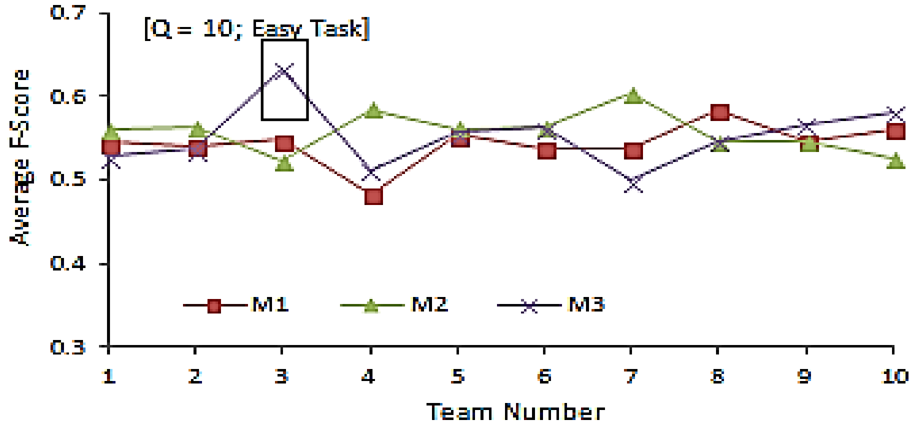
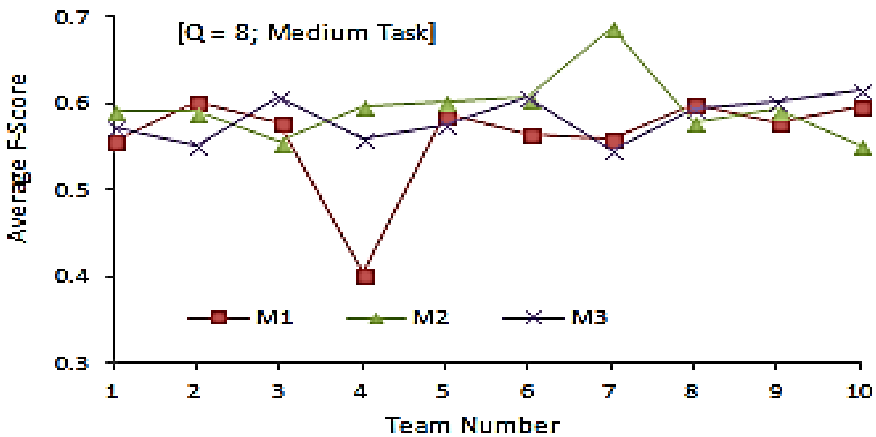


Fig. 48. Collaboration assessment: average F-Score comparison (all teams)

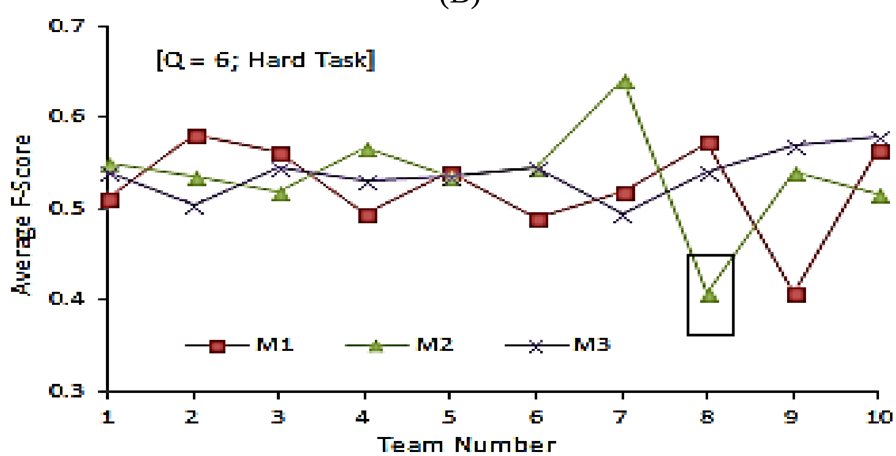
Similarly in case of Q = 8, team member one of team four shows the poorest performance but does not reflect collaboration performance. More interesting supporting evidence is in Q =8, even though team member two shows poorest among all team members, the team collaborative performance was the best. This phenomenon signifies that team individual cognitive performance does not always comply with team collaboration performance.



(A)



(B)



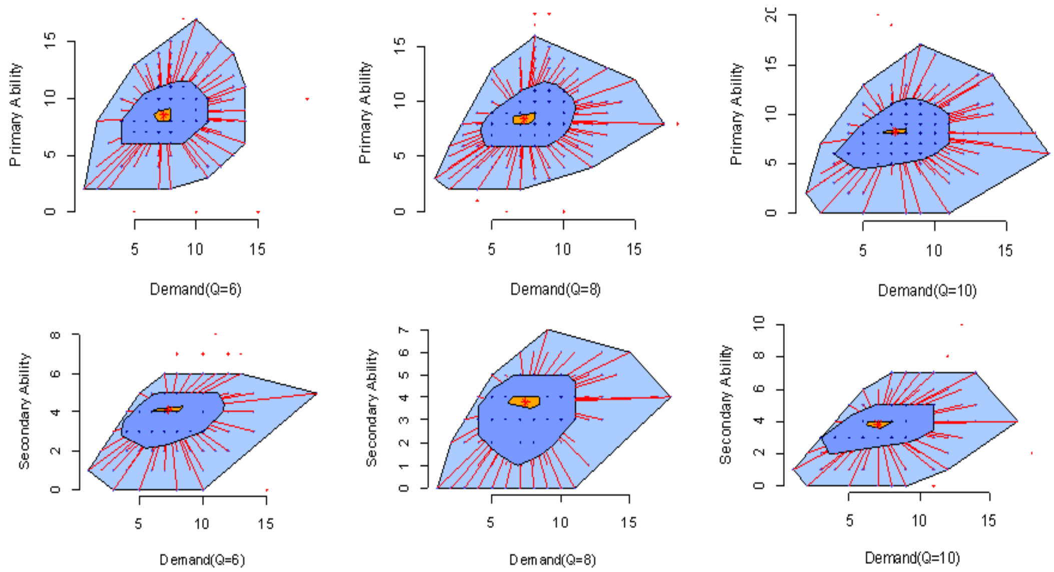
(C)

Fig. 49. Team individuals' average F-score comparison (A)Easy Task (Q =10), (B) Medium Task (Q =8) and (C) Hard Task (Q =6)

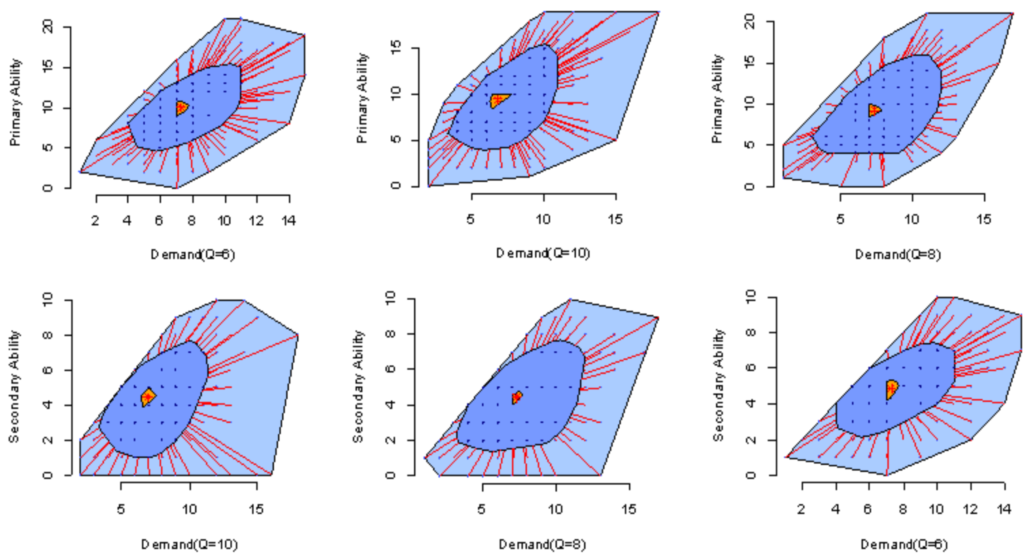
3) Ability-demand gap effect in collaboration

The second objective was to see the state of precision in visual and tactile working memory (whether it reaches a stable plateau/not) when individual item limits are exceeded in cognitive and collaborative task performance. Two sample K-S statistics were performed to identify the existence of gap, significance of gap and maximum gap computation. Fig. 50 shows the bag plot of two teams (Team 3 and Team 8). Team individual's cognitive and collaborative task performance are plotted in column wise. In each team, the first row represents the primary ability (cognitive ability) and the second row as secondary ability (collaborative).

To investigate the effect of outliers and median distribution, we performed the bag plots on team3 and team8. These plots differ with earlier plots (in chapter V), representing primary and secondary ability of these two representative teams with increase of task difficulty levels. With more clear and insightful investigation, it is observed that team 3 and team 8 differ in three data analytics as an effect of ability-demand gap (Fig. 50). These are (a) Outliers - whether primary or secondary, team 3 has outliers while team 8 is free from that. (b) Bag size – Team 8 shows near uniform bag size regardless of task difficulties, (c) Median distribution – team 8 are more uniform than that of team 3.



Team # 3



Team # 8

Fig. 50. Cognitive (primary) and collaborative (secondary) ability illustration: Bi-variate plots

4) Maximum Performance with Collaborative Task

Results from K-S goodness-of-fit statistics (chapter V) indicate that subjects have a significant gap in both cognitive and collaborative task completion. To illustrate detail orientation of team individual's maximum or a minimum demand, cognitive ability and collaborative abilities, we performed wind rose analyses which are shown in next Fig. 51.

Like the wind direction and wind speed, the frequency of cognitive task demanded clicking activity with respect to time presser (15 sec) is clearly observed through these plots. The overlapping edges graph (right side) shows cognitive load scores of all four team members over four types of design. The maximum and minimum demand distribution are clearly observed similar to change of task difficulty (Q = 6, 8, 10). Maximum and minimum cognitive or collaborative ability reflects a different picture. The closest gap is observed in medium (Q =8) collaborative task.

5) Collaborative Sense-making and Ability-Demand Gap with MINE tool

In terms of mutual information score maximal information coefficient is used to illustration collaboration strength among team participants. Team members good collaborative effort is observed in the hard task (q = 6) interaction with approximately similar gaps in easy and hard tasks. Collaborative task requires team members' synchrony in task execution process (Fig. 52). The top two rows illustrate team participants' maximum and minimum task demand, the middle two rows illustrate maximum and minimum primary ability, and the bottom two illustrate secondary abilities.

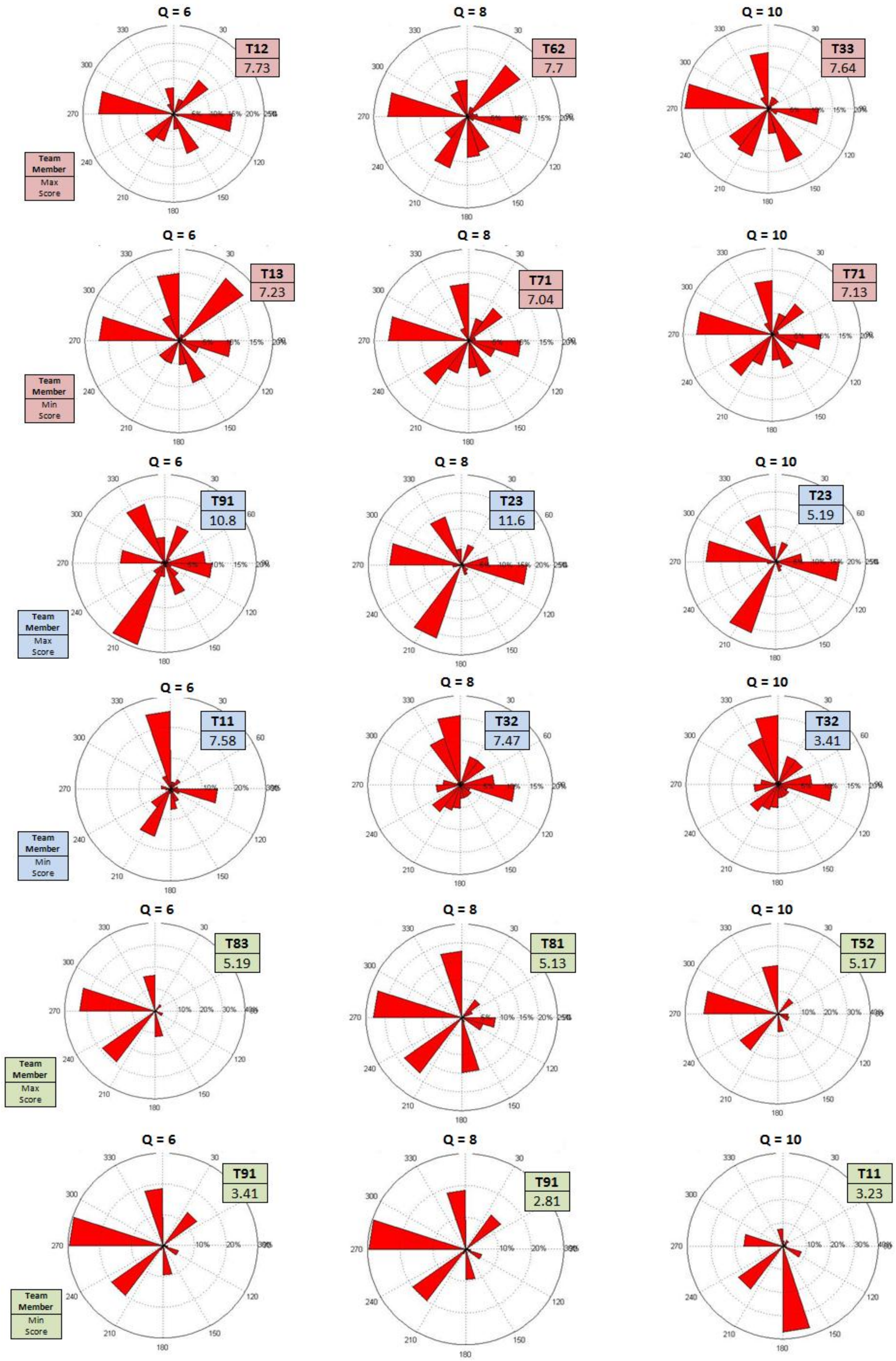


Fig. 51. Rose plot - average similarity index of maximum and minimum demand, cognitive ability and collaborative ability. Each column represent task difficulty (queue size), top two rows shows demand plots, middle two are primary ability plots and bottom two rows are secondary plots.

Legends with each show corresponding team and their average score with maximum and minimum performance. The three columns represent three difficulty levels (Q =6,8,10).

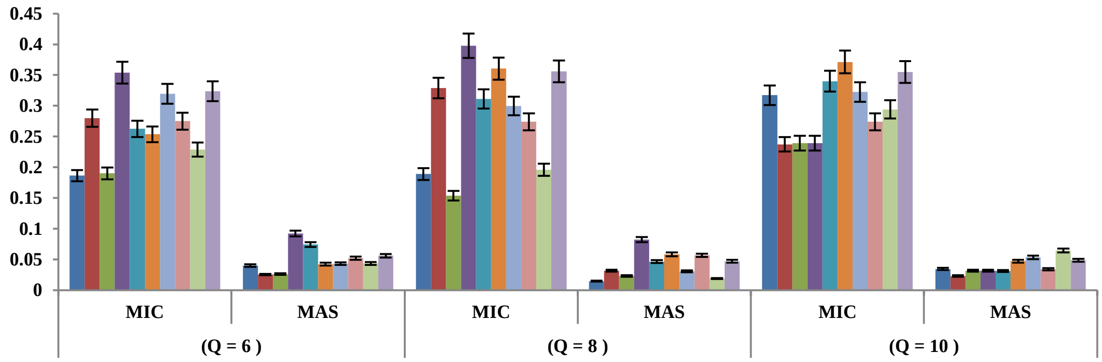


Fig. 52. MIC and MAS comparison with changing task demand (queue size)

Both collaborative and gap scores are spread in medium task than easy or hard task. The team level MIC and MAS plots (Fig. 53) shows that team 3 has uniform distribution of mutual information and asymmetry which results in poor performance. As an alternative account, team 8 has negligible asymmetry scores, hence good performance.

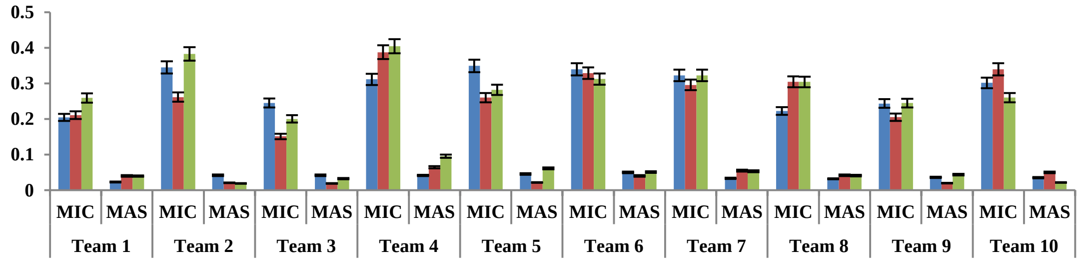


Fig. 53. MIC and MAS comparison of 10 teams

The noticeable observation is the similarity of gap and dissimilarity of the collaborative effort. Finally, the MIC and MAS exploration among team members of two experimental teams: team number 3 and team number 8 are shown in Fig. 54. Although the ability-demand gap scores (trend line in Fig.54) shows a linear trend in both team, the collaboration strategy affects their performance. The success of team 8 lies on the superior collaboration than the ability-demand gap.

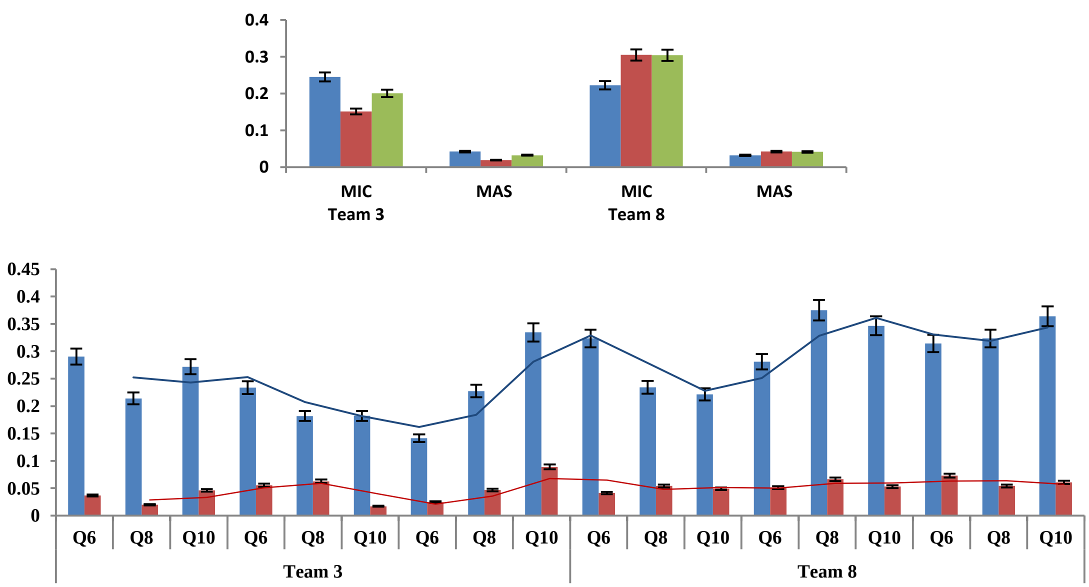


Fig. 54. MIC and MAS comparison of team number 3 and team number 8

C. Summary

Ability-demand gap, which occurs from the deficiency in collaborative task demand and individual's inherent ability, sometimes hamper the collaborative performance. An emerging body of multidisciplinary literature has documented the impact of cognitive load in information processing. Cognitive science studies have shown that research on cognitive load effect can improve a number of aspects of cognition and collaboration. Moreover, empirical study is required to understand the relationship between the strength of collaboration and gap effects during the collaboration process. This study aims to have a theoretical understanding on collaborative activity with members' ability constraints. Cross-disabilities collaborative behavior and human-agent teamwork model are studied throughout this research. Statistical analysis (Bi-variate analysis, Kolmogorov-Smirnov statistics and Maximal Information-based Nonparametric Exploration - MINE) are performed to identify relationships between the gap scores and collaboration strength. In MINE, the Maximal Information Coefficient (MIC) the Maximal Asymmetry Score (MAS) are found associated with collaboration strength and average gap scores, respectively. As is expected, team with higher collaboration strength showed more stable average gaps regardless of the increase of task difficulty.

CHAPTER VII: ASSISTIVE TECHNOLOGY SOLUTIONS

This chapter explains cognitive ability-demand gap application in assistive thinking and disability collaborative sense-making. Section A explains the assistive thinking approach with some simulation results with cognitive ability-demand gap effects. In section B, we explain the cross-disability collaborative sense-making with case studies over four different design of communication between deaf and blind. Both applications consider mixed approach (qualitative and quantitative) of data analysis. The assistive thinking integrates systems into design thinking with quantitative cognitive load values with qualitative observed value. The cross-disability collaborative sense-making compares user' observation and critical incidence with subjective rating data to have the mixed approach of research.

A. The disability model in assistive thinking

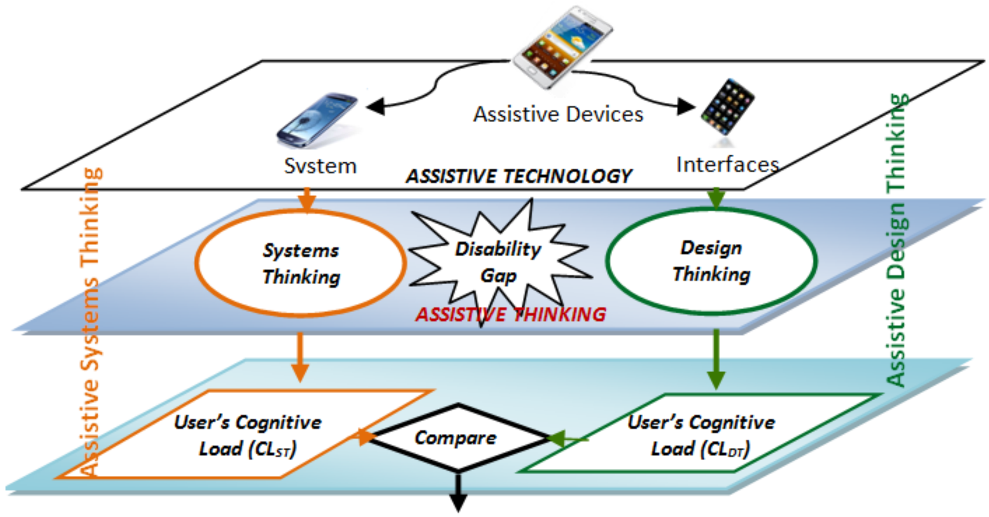
The *'assistive system thinking'* approach aims to optimize performance of the overall system following the same concepts of systems thinking. It describes the critical components of the system, finds operational trends/dynamics, identifies variables, sets system boundary, makes the system visible and determines leverage points. In modeling operational trends of the system, user's cognitive interaction capability and cognitive difficulties need to be accounted. Understanding user's cognitive load in system operation gives us the trace of user's cognitive capability. The assistive thinking approach is illustrated in Fig. 55.

1) Ability-demand gap in assistive thinking approach

Assistive design thinking thrives on helping designer to come up with an optimal user interface to best services and feedbacks in need. Usability is a quality attribute that assesses how easy user interfaces are to use [152].

The *'assistive design thinking'* approach encompasses design thinking strategies based on higher level usability analysis and engineering with the same concept of design thinking. It included user's interaction behaviors, gaps in user knowledge and practice, and ways to bridge the gap between what users know and what they need to know. Assistive design thinking analyzes needs, looks for trends, identifies optimality, sets design challenges, generates solutions, and tests to realize the effectiveness. In short, assistive design thinking importance user need and grasp usability of user interfaces based on his/her cognitive capability and limitations that reflect through user's experienced cognitive load. Cognitive Load can be defined as the amount of instantaneous working memory capacity (thinking) required to understand something (e.g., an interface) while performing a task (or multiple task) that requires perception, problem solving or juggling things in memory. As an important part of usability, understanding the areas of high cognitive load helps the designer to consider what factors are causing the high load and potentially redesign the interface to reduce it.

Thus, cognitive load can be measured through both channels and became a key metric for assistive thinking. Different combination of assistive thinking score recommends us both systematic and design aspect to be considered. For instance, high cognitive load from both channels recommends some acceptable design of system and interfaces, but all other combinations may be acceptable for assistive technology users. In



CL_{ST}	CL_{DT}	Recommendation
High	*High*	*Not Acceptable*
High	*Low*	*Acceptable with Assistance (Feedbacks)*
Low	*High*	
Low	*Low*	*Acceptable*

Fig. 55. The Assistive Thinking Approach

need assessment, a disability model can be helpful and be an integral part in assistive thinking approach. System thinking approach [10], mostly stock and flow helps in understanding several aspect of the system. Nielsen's usability engineering approach can be applied in subjective cognitive capability assessment as part of assistive design thinking. These are explained later on.

2) Ability demand gap and (Dis)ability

Disability can be formalized as the difference between environment demanded cost parameters and individual's ability related parameter. Environmental demand is the function of physical/sensory demand, psychological demand and social demands. Similarly, individual's ability can also be defined by a function of his physical ability, psychological ability and social abilities.

In new technology adaptation, any user may start with some disability gaps and the gap can be reduced with an increase of skill and experiences. Users with physical or sensory disability may always have some gaps (in their ability) to be considered with holistic design. Similarly, they might have some minimum level of their abilities that are not considered as demand, but known as common sense. Thus a disability model and be drawn as an interplay of in between as shown in Fig. 56.

The discrepancy between ability and demand, which is known as disability gap is also known as cognitive gap. Cognitive task interaction may introduce intrinsic cognitive load (ICL) and influence other cognitive loads, namely extraneous cognitive load (ECL) and germane cognitive load (GCL) [167-168]. In another term, ICL is a type of cognitive load that signifies the complexity of learning instruction and their demand of working memory recourses when a number of information elements are under process simultaneously. ICL as an inherent part of total cognitive load also influences another cognitive load types, namely ECL, which is mostly caused by bad representation of multimedia and user interfaces in assistive apps design. The third type of cognitive load GCL corresponds to the deeper learning of the user and represents the efficiency of the user. While the ultimate goal of this paper is to give direction to improve design thinking by system thinking procedure, the job needed to be done is to improve user's sense making capability through assistive apps interaction. In other words, it is necessary to improve user's germane cognitive load in assistive apps interaction.

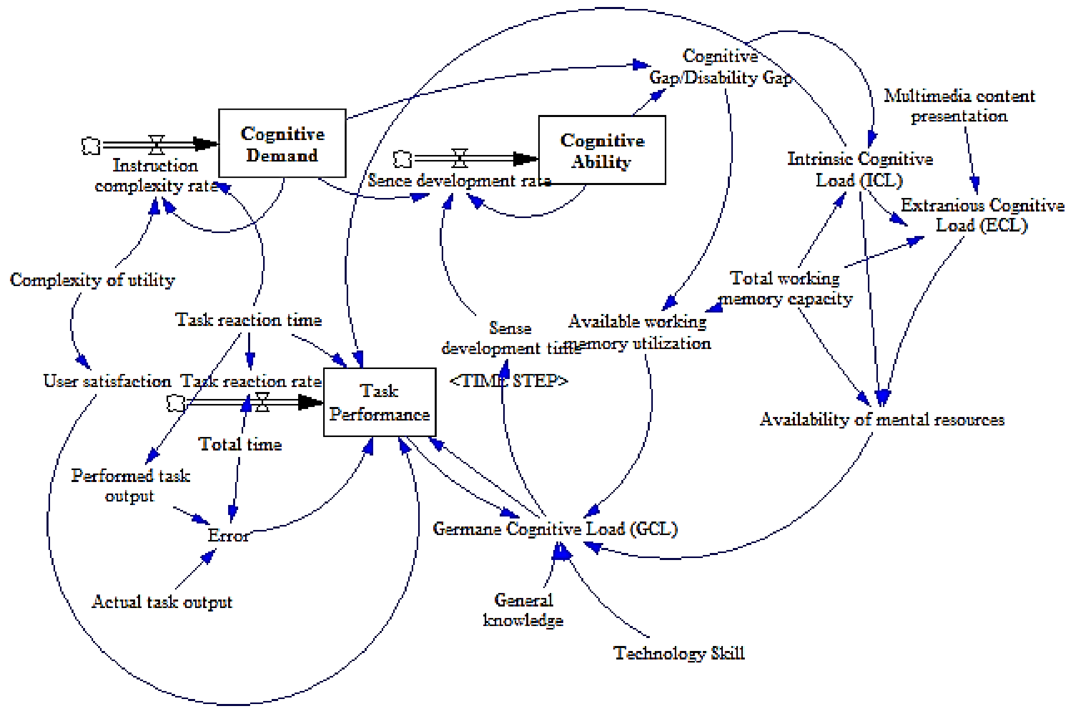


Fig. 56. The Assistive thinking model of disability for assistive apps design; this model only considers the phycological demand and ability in cognitive task interaction

3) Results: Ability demand gap analysis with assistive thinking

Based on Nielsen's five usability attributes (table 11 in chapter III) in computing cognitive load of the user, we consider three questions for cognitive load assessment. In intrinsic cognitive load (ICL) assessment, the question we considered is "How difficult was the experiment instruction content for you?" In terms of usability metric, it corresponded to the '*memorability*' score explaining how easily a user can reestablish proficiency when he returns to his interaction. In extraneous cognitive load (ECL) assessment, we considered the question, "How difficult was it for you to learn with the instruction format?" This maps '*learnability*' in terms of how easy is it for users to accomplish basic tasks the first time they encountered the design. The germane cognitive load (GCL) score is considered through the question "How much did you concentrate during experiment?" related to user *'efficiency'* score of usability which explains how quickly he/she can perform the learned tasks. According to the theory of cognitive load assessment, these three cognitive loads are additive [178]. A sketch of the final model is shown in Fig. 46 with three major stocks, cognitive demand, cognitive ability and task performance. The role of disability gap in ICL, ECL and GCL are also simulated using VINSIM. Fig. 57 shows cognitive load comparison of system and design solutions.

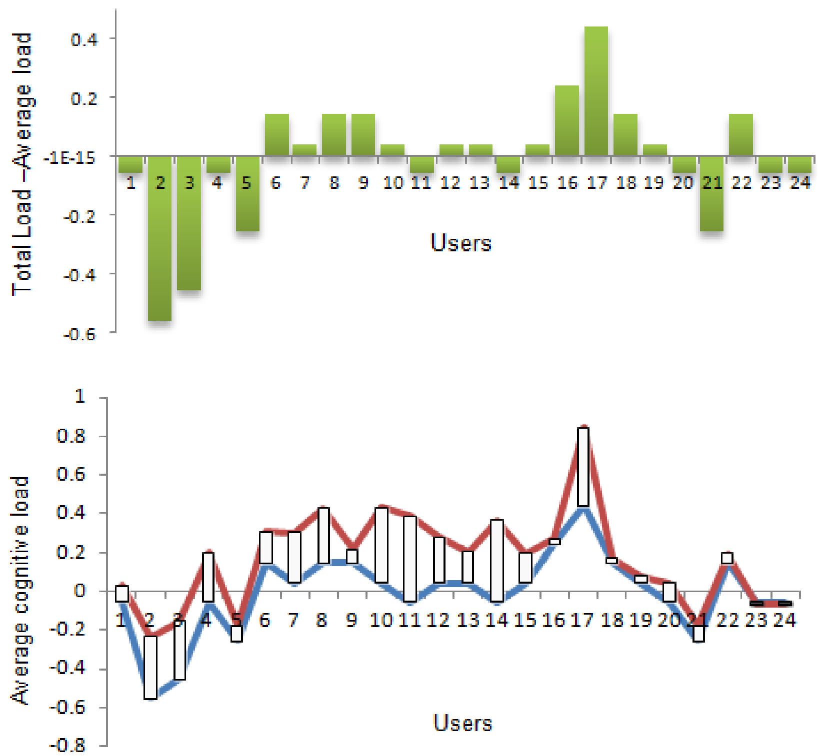


Fig. 57. Cognitive load assessment and comparison, (Top) Cognitive load comparison from overload and average load (Bottom) Cognitive gap in user centered design; The 'blue' line indicates CL from design perspective, the 'red' line is from systemic load assessment (simulated) and the boxes indicate differences between two cognitive assessments

B. Ability-demand gap in Cross-disability Collaborative Sensemaking

We performed an empirical study to gain knowledge by means of direct and indirect observation or experience from end users (Blind or Deaf people) using these systems.

1) The Cross-Disability communication problem

In a collaborative experimental setting, moderator initiated different topics for conversation and recorded three types of data from usability questionnaires, user observation and post-task interview. The snapshot of the conversation is shown in Fig. 58 and Fig. 59.

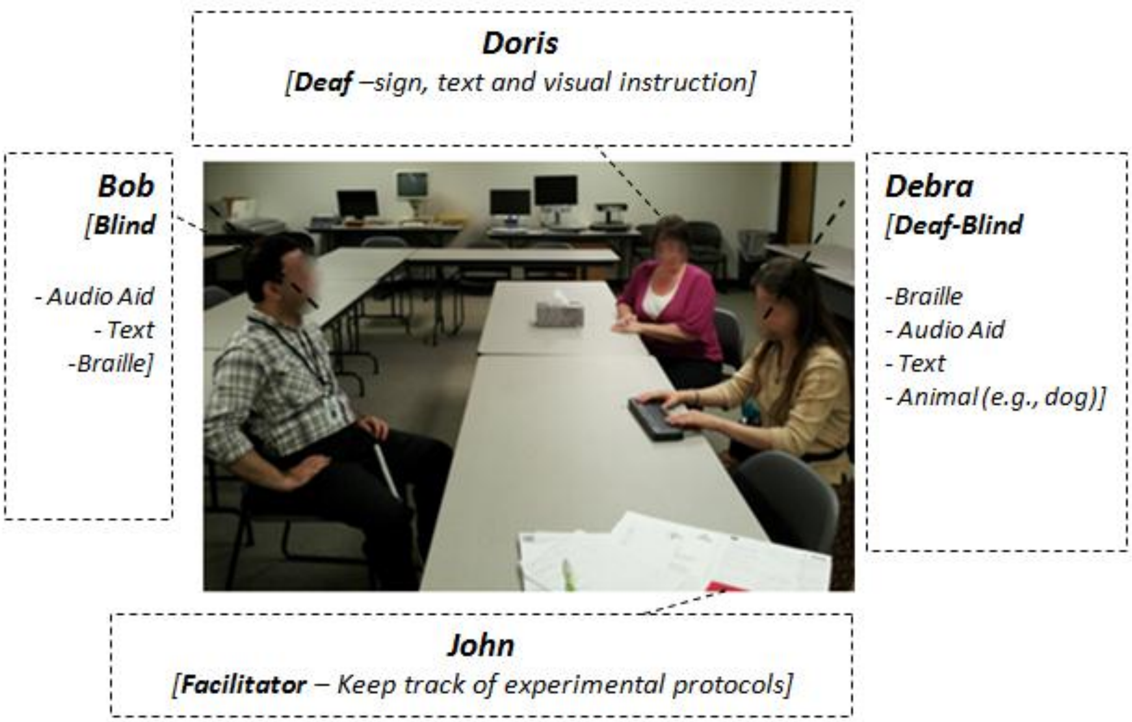


Fig. 58. Cross-disability collaborative sense-making experiment

John: Good morning everybody. How do you feel today? *[also translates in sign language]*
Bob: I'm pretty good.
Doris: *[Shows some sign language]* I am fine, thank you.

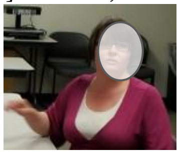


Fig. a. Doris answering using sign

Debra: *[using a hearing aids, shows similar sign language for the question asked by Facilitator]*

Fig. b. Debra showing sign to deaf

Debra: *[Translates the sign to speech]*. We are fine. How can we help you?
John: I want to know how you guys communicate each other.

Bob: I can understand you easily. I always like audio based feedback.

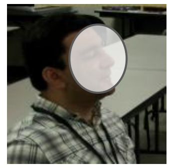


Fig. c. Blind like auditory conversation

Debra: I don't like audio feedback; I love my Braille Display. Do you want to see how I use it?
John: Of course, Can you text or email?
Debra: Let me show you how I text. *[She typed using a Wireless Braille Display and sent a message to her iPhone. Message content: What do you think of weather today?]*

Fig. d. Debra using wireless Braille display

John: *[Responds verbally] sunny. [and typed sunny]*

Fig. e. Debra sending text to iPhone

Debra *[replied via text]* Yes; it will get hot soon.
Bob: See, how we communicate each other!
John: Yes, it was difficult to imagine!

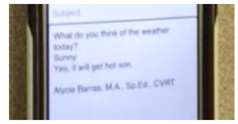


Fig. f. Final conversation between Debra and Facilitator showed

John: What do you think if we have a common app in our smart phones to communicate?
[Shows the questions written to the deaf]
Bob: It will be awesome.
Doris: It will be a blessing to me.
Debra: Do you think to incorporate any Braille Display?
John: We are working on that.
Debra: Man! That will be excellent.

Fig. 59. A snapshot of cross-disability sense-making through ability base collaborative information seeking scenario

2) Results: Ability-demand gap analysis in disability sense-making

Data flow diagrams (DFDs) are used to identify critical problems a user faces in the communication protocol while using experimented applications. Once we have cognitive interaction DFD, we can apply a cyclometric complexity measure to see the complexity of cognitive interactions (communication - collaboration). The relationship of complexity and gap is depicted in Table 13. An example of DFD is shown in Fig. 60. The diagram has complexity <5, hence an acceptable communication between deaf and blind.

TABLE 13.Cyclometric complexity and gap

Cyclomatic Complexity	Complexity level and gap
<=5	A simple communication task, low gap, and low sensemaking cost.
>5 but <9	More complex, moderate gap, moderate sensemaking cost.
>=9	Most complex, unacceptable gap, high sensemaking cost.

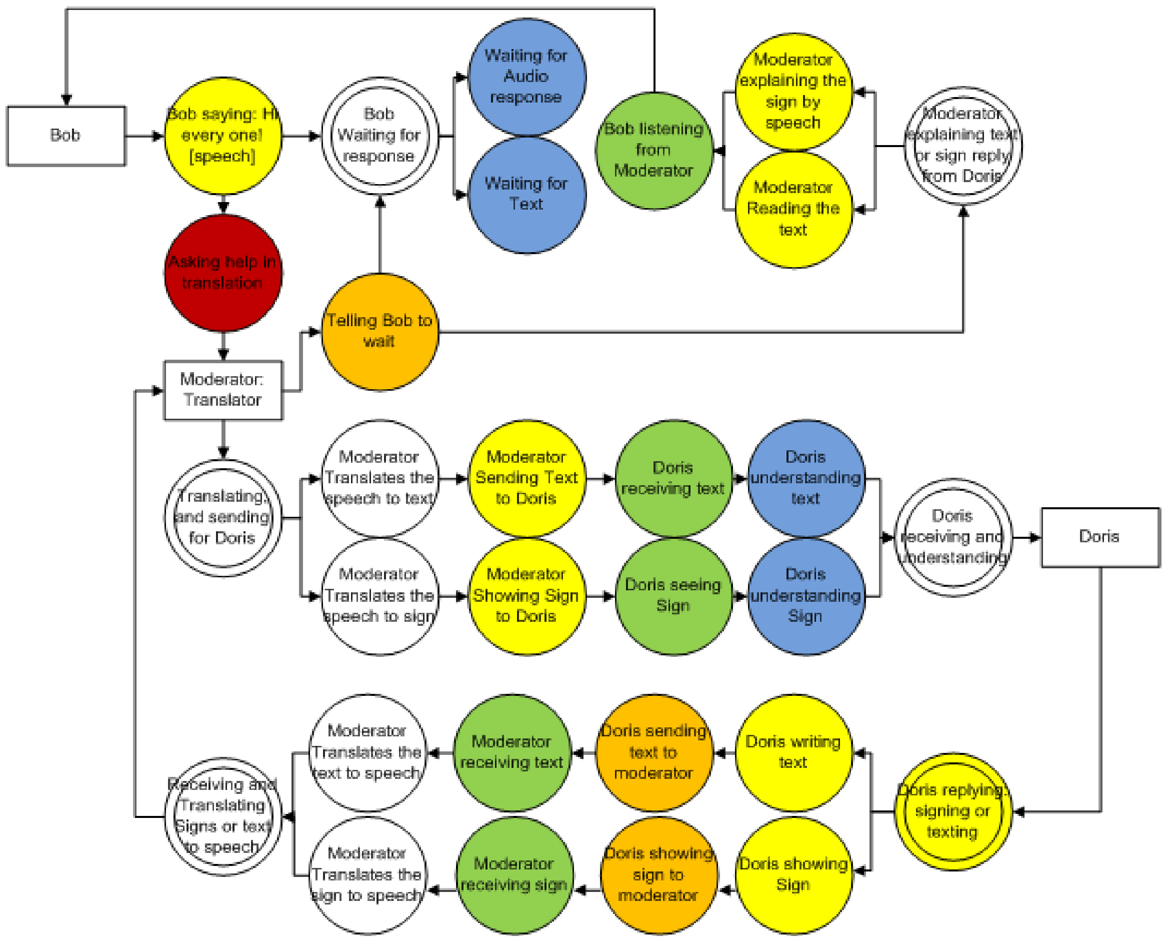


Fig. 60. Conversation flow diagram between Bob (Blind) and Doris (Deaf): telling/saying/speaking/showing/writing (yellow), asking (red), receiving/listening (green) thinking/waiting/understanding (blue)

C. Summary

People with disabilities are unique in their own ways. Existing solutions lack the level of adaptively required in effectively assisting individuals with disability. Assistive thinking is a paradigm shift in the design and implementation of technology solutions. It calls for an in-depth analysis of user's needs as well as preferences, estimate ability-demand gap and integrate them using design and system thinking to develop assistive technology. In addition, it advocates effective use of existing resources in managing disability with the sustainability plan to maximize the utility of technology solutions. This is expected to transform the designs implementation and use of assistive systems that not only meet user needs but also address their situational and social needs with resource constraints. It is imperative to understand the causal relationship and confluence of both controllable and uncontrollable factors that are critical in managing complex problems, be it socio-economic or technology solutions. In this study, we are reporting the culminating experiences of designing assistive systems and a pilot study that was performed using a set of usability questions and observed cognitive capabilities of representative users. This participatory approach communicates directly with "user" in the analysis phase of application development and resolves failure. It also addresses the unintended consequences and facilitates subsequent modeling to evaluate the performance. More details can be found from [143], [145].

CHAPTER VIII: DISCUSSION AND CONCLUSION

"We might be measuring things right, but are we measuring the right thing?" - Drucker, 2006

In this section we review the discoveries that have been made through the investigations in this work, we enumerate the contributions of the work, and we consider implications and opportunities for future work. We believe that the method used in this work would be useful in other types of behavioral and physiological data processing, and we offer some final thought about some probabilistic graph theoretic approaches in human ability-demand gap analysis research correspond to human brain and behavior analysis.

A. Summary of Findings

From the latent response model based ability-demand gap analysis, we draw the following conclusions.

1) Probabilistic differences between expected ability and actual ability (the residues) are representative indicator of ability-demand gap in dichotomous response modeling.
2) However, in complex ability-demand gap analysis, in case of polytomous (graded) response, the average response attitude can be applied.
3) Differential item functioning (DIF) is useful in group based ability-demand gap categorization.
4) Likewise, Rasch tree is applicable in the multidimensional response categorization.

5) Moreover, Item-person maps with Bond and Fox pathway are applicable in gap affected item/person identification.

From the second analysis, we draw the following conclusions.

1) The probabilistic cumulative distribution plot of precision indeed provides an adequate description of the cognitive ability-demand gap in terms of working memory resources.
2) Kolmogrove - Simonov (K-S) statistics is a good analysis tool to estimate maximum gap with significances.
3) K-S statistics as non-parametric estimation and exploratory methods can work as a separator in cognitive dissonance and overload estimation. More specifically, the combination of K and H values gives us the ceiling of cognitive dissonance that riches to overload/technostress.
4) Unusual behavior might (outliers) cause more ability-demand gaps.
5) Increase of task difficulty has negative impact on ability-demand gap

From the third analysis, we draw the following conclusions.

1) Task difficulty has less influence in collaborative gap than cognitive gaps.
2) Team individual's ability-demand gap has legitimate influence in team ability-demand gap and/or collaborative performance.
3) The combination of MIC and MAS gives a higher level overall ability-demand estimate during collaborative sensemaking process.

B. Contributions

As a result of this research effort, we have made the following contributions to ability based human-agent (device) collaborative sense-making.

1) *A mathematical analysis of ability-demand gap problem:* This work demonstrates that variant of item response models are useful in quantifying ability-demand gap in terms of residue, response latitude and confidence intervals.

2) *Association of ability-demand gap confluence with limited capacity of working memory resources:* Cognitive gap (e.g., confusion) motivates the cognition process. But, how much gap is acceptable can be hypothesized by K-S test between ability and demand distributions.

3) Ability demand gap effects in collaborative sense-making: We demonstrate the effect of ability demand gap in collaborative sense-making. Collaborative team can adopt some gaps although the task is complex, while individualism cannot.

4) Analysis of a variety of exploratory non-parametric tools to quantify ability-demand gap types. K-S statistics are useful in maximum gap, gap confluence, and gap significance analysis. Rose plots are good in individual activity and gap illustration. Bi-variate plots are more insightful in gap effects analysis. MINE tools (MIC and MAS) are good in gap influence in collaborative sense-making analysis.

C. Discussion

Science progresses by continuous iteration between theoretical ideas and experimental observations. In my work, I attempted to move back and forth to understand human ability-demand gap issues towards making senses of communication, coordination, cooperation and collaboration between human and machine (agent).

The work was initially motivated by recent experimental observations using Universal design by Finn [1]. It was shown that the gap between human ability and environmental demand relates to disability research. In both environmental (situational) demand and user's ability, they consider three layers of gap, psychological, physical and social. We consider the gap as an umbrella term of error, confusion, questions, uncertainties, noise (and more unknown). The gap is identified as the key barrier in sense-making (Dervin 1977) [5].

With the basis of these two studies and some other relevant studies [2],[3],[4],[5],[11],[12],[15],[16] we introduced a mathematical framework to estimate ability-demand gap in the context of cognitive and collaborative interaction between human and machine (agent).

The results of these studies suggest that maximum and overall cognitive ability-demand gap can be computed in a variety of ways. Latent response theories, K-S statistics and MINE toolbox are some non-parametric approaches.

First, we computed the gap from human ability-demand inconsistencies using latent response models. In a very simple yes/no (dichotomous) case, residue between ability and expected ability represents the gap value, and in a complex (multiple response option) case, response latitude values are found to be correlates of gap. The gap values are analyzed with toy examples and benchmark datasets obtained from reputed Universities. Simple datasets (e.g., mental multiplication and RMAP) are applied in this study. Our insights can be seen, in essence, as the individual item/person level gap assessment with very controlled task experiment. In case of complex collaborative task/multi-task, the theory is not examined. Moreover, variants of item and response parameters are not considered, which might be useful in further study.

Second, the types of possible gaps are analyzed which is considered as initial stage (cognitive psychology) in gap resolution. Working memory resources, their correspondence with task cognitive demand and human ability is considered as gap. The gap is found to be related to cognitive dissonance, and the maximum possible value of gap represents the threshold of dissonance and overload. The 3D cognitive task load model [67] was adopted to visualize the confluence of ability-demand gap with cognitive dissonance and overload.

Human inherent ability impacts more in individualistic task, than collaborative task when even the complex task is assigned to share right information with right party at the right time. The third study uncovers the impact of gap in collaborative sensemaking. Some psycho-physiological (EEG, ECoG, Eye activity etc.) experiments are carried out through this study. However, much can be done with ability-demand research including improvement of cyber physical infrastructure and systems.

I hope the work presented above will evoke further enquiries into the relations between ability-demand gaps in adaptive, assistive and collaborative sense-making.

D. Conclusion

A number of factors such as error, confusion, uncertainty, cognitive cost (i.e, cognitive inertia, will power etc.) are considered as barrier in information processing, but are often ignored. This study considers these factors under an umbrella term called "ability-demand gap". This dissertation addresses the ability-demand gap problem that users face when they expect the system (agent) to co-op in their task.

The first study considers the understanding of how ability-demand gap might occur in technology interaction. It is one of the key issues in adaptive and assistive technology design. The gap or (dis) ability can be analyzed using an item response model with the assumption that the model should consider the negative probability of occurrence of success in item (task) interaction. Given the interdisciplinary nature of this work, results from this study may have broad impact in many different fields of human computer interaction, novel assistive technology and augmented cognition. The IRT analysis of ability-demand gap is expected to be useful in piloting version of human-system (agent) interaction as shown in Fig. 2. The threshold for gap in interaction can help the system to provide feedback to its user and assist him in need. The IRT analysis also has in depth analysis of how the instructions are worked as total information towards interaction process. Differential item functioning and Rasch tree and principal component analysis explains more extended features of categorical impact on gap and helps to have a general idea of group trends. Our findings indicate that item response models which are useful in ability estimation are also useful in ability-demand gap estimation. More research is necessary with larger datasets and variant of item and response parameters.

The second study contributes empirical findings on the confluence of ability-demand gap with cognitive dissonance and overload in complex collaborative task interaction. The study summarizes how statistical analysis techniques can be used to add value and insight into the nature of cognitive ability-demand gap types, especially in maximum gap identification and application as a threshold between dissonance and overload. K-S statistics and bi-variate analysis (bag plot and box plots) was practical to reliably report team individual's ability-demand gap and were found effective in terms of quantitative and qualitative analysis. Our empirical results show that team and members' maximum ability-demand gap can be identified through the maximum K value (with K-S statistics). Having team or team member's ability demand gap, individual's similarity/dissimilarity with their team mates can be observed through median distribution and bag sizes. Our research offers novel techniques to analyze the relationship of ability-demand gap with cognitive load effects - dissonance or overload.

The 3D response model with 80-20 rule, which is theoretically explained with gap threshold identification and cognitive load classification, further enriches the way that researchers can evaluate cognitive task load and effects. In this study, the probabilistic difference between ability and demand vectors with CDF represents the gap score. Further analysis will be done with the ability based demand vector and conflict metrics analysis with multiple resource theory and cognitive signal flow graph – a similar concept of resource allocation graph. Next, analysis will be applied to interference computation, signal flow graph mining and gap pattern identification. Connection of cognitive lockup and cognitive resources interference will also be accomplished in future studies.

Collaborative ability is the capacity to perform higher mental processes of reasoning, remembering, understanding, and problem solving in addition to action dynamics. Important research trends toward collaborative sense-making are a concern on whether the team's average cognitive ability might predict advancing adaptive technology solutions which will be more practical in user centric design. This study identified important statistical properties associated with gap effects in collaboration sense-making. Average F-score based similarity index, K-S statistics and MIC-MAS combination analysis showed similar results in maximum and minimum collaboration strength comparison. Moreover, K-S statistics and MAS signify the gap effects in collaboration process. More specifically, the unacceptable gap is indicated by $h = 1$ in K-S statistics signifying that the collaboration is meaningless. Similarly, team members with similar MAS (gap score) but different MIC score indicates collaborative strength can overcome gap effect.

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APPENDIX A: COGNITIVE LOAD KEYWORDS

TABLE 14. Review of cognitive load related research articles Obtained from Microsoft academic search (search date Nov 28, 2013)

Specific Search Terms	***Workload***	***Mental workload***	***Cognitive load***
Subjective Ratings	2409	449	1601
Activation Scale	248052	204	1657
Bedford Scale	633	3	3
Defense Research Agency Workload Scale (DRAWS, DSTL, QinetiQ)	635	21	3
Perceptual Control Theory (PCT)	4950	1454	4970
Instantaneous Self Assessment of workload (ISA)	12	256	3
Malvern Capacity Estimate (MACE)	19	64	495
Modified Cooper-Harper (MCH)	20	56	143
Multiple Resources Questionnaire (MRQ)	80	838	1948
NASA Task Load Index (NASA TLX)	698	248	1232
Observer Rating Form	742	5730	21959
Prediction of Operator Performance (POP, DSTL,QinetiQ)	2636	5552	17509
Pro-SWAT	3	0	0
Quantitative Workload Inventory (QWI)	46	292	99
Rating Scale Mental Effort (RSME)	2948	2470	1971
Raw TLX (RTLX)	6	3	2
Self report	1610	348	1991
Subjective Workload Assessment Technique(SWAT)	3739	935	284
VACP	3	1	2
W/Index	515	38	189
Performance Measures			
Dual task	417	110	774
Embedded task	1010	53	359
Primary Task	828	199	1000
Reaction Time (RT)	702	187	1172

Specific Search Terms	***Workload***	***Mental workload***	***Cognitive load***
Secondary task	461	156	668
Subsidiary task	15	10	26
Psychophysical Measures			
Psychophysiological	152	89	140
Eye movement measures			
Blink duration	30	19	41
Blink latency	5	2	37
Blink rate	66	46	86
Endogenous eye blinks (EOG)	3	57	171
Eye blink	80	46	96
Eye fixations	104	65	217
Eye movement	260	146	539
Glissadic saccades	1	1	1
Oculographic activity	1	0	1
Pupil diameter	50	38	49
Saccade duration	23	11	62
Saccadic velocity	10	6	23
Cardio-vascular/respiratory measures			
Blood pressure	821	99	271
Heart Period (HP)	550	81	140
Heart rate	1684	271	387
Heart rate variability	538	1858	4520
Inter-beat-interval (IBI)	8	47	177
Respiration	269	55	82
Respiratory Sinus Arrhythmia (RSA)	16	129	141
Stress-related hormone measures			
Adrenaline	57	7	16
Catecholamines	176	11	69
Cortisol	137	36	167
Epinephrine	71	8	28

Specific Search Terms	***Workload***	***Mental workload***	***Cognitive load***
Noradrenaline	64	3	46
Prolactin	23	1	20
Vanillyl mandelic acid	1	1	4
Electrical bio signals			
Autonomic nervous system (ANS)	112	1135	2343
Central nervous system (CNS)	117	3898	9520
Electrocardiogram (ECG)	200	14	38
Electrodermal activity (EDA)	39	29	33
Electroencephalogram (EEG)	280	171	484
Electromyogram EMG	32	1	11
Event related potentials	500	6112	17636
Evoked cortical brain potential	5430	1270	2146
Evoked potential	69	23	314
P300 amplitude	27	26	109
P300 latency	10	8	63
Parasympathetic nervous system	50	241	921
Peripheral nervous system (PNS)	73	1186	3242
Skin conduction response (SCR)	81	936	2855
Skin resistance level SRL	44	9	31
Skin resistance response SRR	43	6	32
Somatic nervous system	9	449	1069
Speaking fundamental frequency	7	94	434
Speaking rate	138	26	158
Sympathetic nervous systems (SNS)	118	964	1754
Vocal intensity	16	3	20
Formant frequency	6	0	14
Behavioral Biometrics			

Specific Search Terms	***Workload***	***Mental workload***	***Cognitive load***
Keystroke	34	12	45
keystroke latency	4	1	3
mouse click	39	14	41
tapping	189	31	528

APPENDIX B : ANDROID APPLICATIONS REVIEW

TABLE 15. Android application summary - Deaf -Blind communication research (Searched on: Nov 29 - Dec 10, 2013)

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
Text to Speech	3.9	33,183	- Text to speech library - Extendable to Android TTS API - Easy to handle	-useful for blind people
Text Plus	4.2	38394	- Free texting worldwide - Free and cheap calls in USA and Canada - Text plus call from anywhere in the world using WiFi, 3G, 4G	Blind people can send and receive message
SVOX	3.9	5542	- 40+ natural sound voice - 25+ languages	
Vlingo Virtual Assistant	4.3	36,098	- Siri-like functionality - Send texts and emails - Voice dial - Search web - Find local businesses - Get directions - Update social network statuses - Ask most any questions - Open other apps	
IVONA	3.9	1,488	- Reads aloud several things like: - Directions while driving - Ebooks with apps like Book Speech and ReadBoox - SMS messages - System menu - Plus other speech enables applications	In beta testing
Voice search	4.1	138,249	- Search the web and your phone by voice - Includes Voice Actions to control your phone	
Edwin, speech to speech	4.1	1,763	- Tweet - Text - Translate - Weather - Conversions - Make calls	
ezPDF Reader	4.6	9,396	- Annotate, Listen, and Fill out PDF Form -	
Talk-Text to voice	3.8	1,106	- Reads text - Multi-lingual	
Mr. Number Text, Call & Block	4.5	56,312	- Fast, free texting - replaces your old text and calling apps - can make texting fast and free and know when	

Apps Name	*Rating (out of 5)*	*Number of users*	*Features*	*Comments*
KakaoTalk Free Calls & Text	4.5	878,324	- Good for group or one-to-one chats and free calls anywhere in the world. - Unique voice filters option.	
Super Text To Speech Free	3.6	127	- Can amaze (or annoy) your friends! - locale -pitch and speed control - Email	Language dependent
Text 2 Speech	3.5	26	- Simple and efficient Text-to-speech program. - Ad Free! Text 2 Speech - Very simple and basic program that converts text to speech.	
Talkadroid Lite	4	885	- Phone says aloud whatever you type into it. - Useful to set speed, pitch, and language! - Text to Speech application makes phone speak aloud for anything.	
Text To Speech - Text Reader	3.5	35	- This app allows you to hear the words you type into your phone! Copy and paste a whole book into the text box and listen to it instead of reading it.	
Speech To SMS	3.5	35	- A simple Virtual Text Message Assistant - send text messages. - one button tap / voice, - send SMS text messages. - Speech To SMS option - talk and type's the message for you.	
Speaking Pad	3.7	3809	- A talking notepad for Android. - Speak the typing. - It uses the TTS (Text-To-Speech) library for Android.	
All translate	4.1	255	- Translate text in 33 languages by writing or speaking, dictionary and voice - Translate 33 languages with this professional translator. - Send the text/ use E-Mail and Messages. - Fastest translation during text input by realtime processing. No need for button use. - Reference books over 30 languages - Dictionary in over 30 languages - Text-To-Speech (TTS): Voice output of the translation. - Dictate and write messages(SMS)/mails in your own language.	
SMS Speaker	3.3	454	- Read the SMS messages out. - upgraded to uses Google's Donut Text-To-Speech (TTS) library for higher quality speech. - update Talking Caller ID and SMSpeaker for bug fixes.	Note free: $0.99

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
Magic Text	217	4.0	- Send/receive high quality pictures, videos. - Send/receive documents, office files and any type of files. - Auto-backup SMS/MMS to email account. - Backup all SMS/MMS/attachments to sdcard or computer. - Recipients no need to install a thing to receive your attachment, just simply access/download the attachment with a browser. - Recipients any you are easy to access/download via computers (each attachment provides a link to allow you to access them by computers or any kind of browser). - Send your location, your contacts. - Speech to text, no longer need to type your message again, just speak out softly, then your voice will be transcript into text, 1-click to send. - Reply messages from emailing. - Easy-use and beautiful and clean interface. - Trash box, popup window and quick reply. - Much easier to send multi-recipient messages. - Translate Message to other language. - Emotion icons support, android and full emoji support, send and receive iphone emotion icons. - And more to be discovered.	
Focustrate Voice Texting	3.5	75	- Text without looking at phone. - Uses voice recognition and text to speech technologies as a part of the Android operating system. - Use simply click to select the contact by pressing the button. - To text, the contact presses the button again.	Intrepid control systems
AAC Speech Communicator	4.0	6	- Smart, pictogram-based speech communicator for people with speech disabilities. - An Android application for people with speech disabilities, - a generic and easy to learn communication method for anyone with speech disabilities that forms grammatically correct sentences from a list of pictograms clicked and reads them (text-to-speech). - Because of pictograms it's especially good for children on ones who have limited reading abilities.	

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
JABtalk	4.5	29	- Navigation designed to be intuitive for toddlers - Build sentences from words - Organize words into user-defined categories for simple navigation - Hepatic feedback (vibration) when touching a word or category for immediate physical feedback - Ability to rearrange and resize pictures - Ability to capture pictures directly from your device's camera - Ability to import pictures from your device's memory card - Ability to record your own audio for words using your devices microphone. - Ability to import audio files from a memory card - Supports text-to-speech if you don't want to record or import your own audio files - Easy to use passcode protected administrative tools for managing words and categories - Full screen mode to prevent kids from easily exiting app - Easily backup/restore your data to preserve your changes or move your entire dataset to a different device	
Speech to Text to speech	2	20	- Transcript voice into text. - Helps taking notes from speech input - Helps in writing SMS from speech input - can correct the words if there are any mistake, - Can SMS the text, or play it with the Text to Speech function. - Can also change the language for the Text To Speech.	Not free: $1.45
SMS Translator	4	71	- SMS Translation software. - Translates SMS to other languages and auto-translates all incoming SMS to your language. - Type of speak your messages. - Text to speech of messages for 16 languages saves to a library for listening and training. - Can create custom library. - Includes an auto-translate option under Options. When selected, all incoming SMS messages will be automatically translated and appended to the bottom of the original message - Includes speech to text. - Speak your message instead of typing. Speech to text use the language you have set as your language in the options. -	Localized

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
Google Voice	4.5	92,954	- Makes cheap international calls with your Google number. - Send free text messages. - Place calls and send text messages showing your Google number. - Listen to voicemail and read transcripts.	
Dictus Free	3.5	94	- Speech to text - Speech recognition and synthesis in more than a dozen languages. - Dictation system: Speak one or more sentences to Dictus and convert them to text. - The text can be sent as SMS or e-mail, or copied and used in any other program on your Android unit. - The text may then automatically be read aloud by one of several synthetic voices, as any text from any program on your Smart Phone, e.g., e-mail, may be copied to Dictus and read aloud. - up to 5 times faster recording and recognizing	
Sonalight Text by Voice	4	378	- Allows safely text through voice while driving. - No need to touch or look at the screen at all. - Automatically read incoming text messages aloud and give you a chance to respond. - It runs in the background and useful for other apps at the same time.	
ListNote Speech to text Notes	4.3	122	- Speech recognition	
Speech to text	2.8	229	- Turns speech to text for messaging	
Sonalight text by voice	4.1	378	- Text while driving	
ShoutOUT	3.6	2,221	- Voice addressing - Speech to text - Handsfree composition - Smartword editing - Speakable punctuation - Threaded discussions - Popup notification - Text to speech (hear your texts)	Speech to text messaging, helpful for blind to text and send.

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
BrailleReader	3.5	3	- Allows reading SMS using Braille, without any peripherals. - It opens automatically when a new SMS is received and by sliding your finger across the screen, you can read your message one character at a time. - displays a character at a time using all the available space, to mimic a Braille character. - Each character is represented by a maximum of six dots, which vibrate when you slide your finger over them. - By using vibration, one can identify which dot is "raised" and after having touched all the display, get a notion of the character represented. - Right now several gestures can be used: - Flick right to left to advance one character - Flick left to right to go back one character - Double tap anywhere to go back to the beginning of the message When you're done reading your message, just press the Home button to leave the application. - Note: this a work in progress and a technology preview, so please mind the missing features that will come over the coming months. - Allows the app to receive and process SMS messages. Malicious apps may monitor your messages or delete them without showing them to you. -	

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
Accessible Web Browser US	2	2	- Designed for people who are blind. - Powerful but incredibly accessible and packed with complete navigation options what users are used to on their desktop computers. - Allows Large Font and option to zoom for Low vision users. - Allows Simple Slide up and down gestures to navigate and read webpage. - Allows Simple slide Left and Right to jump web elements back and forth. - Easy to use with navigation aid such as trackball or directional pad. - Simple double tap or enter to activate links and form fields. - Can be used as default web browser for the system. - Quick Navigation Modes for Words, Characters, Headings, Lists, Tables, Forms and Links using long press of menu key. - Comprehensive navigation mode for all web elements from the menu. - Comprehensive reading options including continuous reading and webpage title and summary reading. - Ability to use virtual touch keyboard. - Ability to use Speech recognition for text input. - Ability to search within page for faster access to specific information. - Navigation options for browser history. - Comprehensive speech and browser settings for controlling voice output and browser functionality. - Features bookmark option to create list of favorite link pages. - Self voicing using Nuance Vocalizer for vision impaired users. - Ability to use system default TTS.	Note free: $19.99 - Notes: - Use Triple tap on screen or menu key to get application menu. - On webpage, tap and move finger on the screen to read web elements under your finger. - By default the navigation mode is reset to links on activating a link on a webpage, use “Reset navigation on Download” under settings to change the behavior.
Virtual Voice	4.0	33	- Designed to use the text to speech (TTS) and the speech recognition features. - Created with deaf and/or mute people in mind, so they can communicate with others without the need for sign language or lip reading. - It has a very simple interface, with large lettering for those that are visually impaired. - Developed to use your device's NATIVE language. - It can connect to the Google recognition services.	Notes: "Speak" needs a text-to-speech engine installed on device such as Pico TTS. "Listen", needs to check an internet connection available (WiFi or 3G data enabled)

Apps Name	***Rating (out of 5)***	***Number of users***	***Features***	***Comments***
BrailleNotes			- Allows to write in Braille and save it as a text file in your SD card. - A letter is written by touching the screens one dot after another, then swipe the screen from left to right. Capital, numbers, and symbols are also available by swiping from left lower corner to right upper corner, left upper corner to right lower corner, and right lower corner to left upper corner. Next line can be generated by swiping right upper corner to left lower corner. - To save the file, swipe down and the first up to 4 letters will be the name for the text file. - To open a file and add more letters, simply write the 4 letters of the text file and swipe up. - This app is a simple note taker designed best for jotting down ideas and contacts.	For sighted user
Braille Interpreter	1	1	- Captures the image of a Braille sheet and converts it to text. - Braille is a method that is used by the visually impaired to read, using the sense of touch. - Intended to make the process of reading or learning Braille easier for those who do not understand the language. - Works for Grade 1 Braille: uses numbers, and the letters in the alphabet set. The other two grades are forms of shorthand. - This application is aimed at bridging the gap between the visually impaired and the sighted. - It can also be used in the evaluation of Braille assignments, submitted by students on Braille sheets, by examiners who do not understand Braille. - Hence the sighted need not spend much time in learning and understanding Braille. - This can eliminate the need for training the staff in Grade 1 Braille in schools for the visually impaired, thus saving time and cost.	Requires camera with auto focus feature.
Text to Braille	5	1	- A simple app allows simply entering name, addressing etc, in the text field and taps the convert button and reveals your text as Braille! - This app was designed and developed with the sole intention of giving a visual representation of Braille and is to provide a basic level of education about the Braille system.	

APPENDIX C: IRB APPROVALS

THE UNIVERSITY OF MEMPHIS

Institutional Review Board

To:	Gahangir Hossain Electrical and Computer Engineering
From:	Chair or Designee, Institutional Review Board For the Protection of Human Subjects irb@memphis.edu
Subject:	A Study of Disabilities in Social Coordination through Technology Tools Interaction (#2246)
Approval Date:	June 25,2012

This is to notify you that the Institutional Review Board has designated the above referenced protocol as exempt from the full federal regulations under category 4. This project was reviewed in accordance with all applicable statuses and regulations as well as ethical principles.

When the project is finished or terminated, please submit a Human Subjects Research Completion Form (COMP) to the Board via e-mail at irbforms@memphis.edu. This form can be obtained on our website at http://www.memphis.edu/irb/forms.php.

Approval for this protocol does not expire. However, any change to the protocol must be reviewed and approved by the board prior to implementing the change.

Digitally signed by Jacqueline Y. Reid
DN: cn=Jacqueline Y. Reid, o=The University of Memphis, ou=Institutional Review Board, email=jreid@memphis.edu, c=US
Date: 2012.06.26 08:49:11 -05'00'

Chair or Designee, Institutional Review Board
The University of Memphis

THE UNIVERSITY OF MEMPHIS

Institutional Review Board

To:	Gahangir Hossain Electrical and Computer Engineering
From:	Chair or Designee, Institutional Review Board For the Protection of Human Subjects irb@memphis.edu
Subject:	Study on Cognitive Load Dynamics in Human Technology Interaction (#2247)
Approval Date:	June 25,2012

This is to notify you that the Institutional Review Board has designated the above referenced protocol as exempt from the full federal regulations under category 4. This project was reviewed in accordance with all applicable statuses and regulations as well as ethical principles.

When the project is finished or terminated, please submit a Human Subjects Research Completion Form (COMP) to the Board via e-mail at irbforms@memphis.edu. This form can be obtained on our website at http://www.memphis.edu/irb/forms.php.

Approval for this protocol does not expire. However, any change to the protocol must be reviewed and approved by the board prior to implementing the change.

Digitally signed by Jacqueline Y. Reid
DN: cn=Jacqueline Y. Reid, o=The University of Memphis, ou=Institutional Review Board, email=jreid@memphis.edu, c=US
Date: 2012.06.26 08:51:33 -05'00'

Chair or Designee, Institutional Review Board
The University of Memphis