A COMPUTATIONAL APPROACH TO
COGNITIVE AND AFFECTIVE PROCESSES
IN MULTIPLE-TASK PERFORMANCE

Chapter Two - Review of Literature

1.0 INTRODUCTION

In science and philosophy concepts, theories or ideas always have tumultuous history. Any concept, theory or idea, once presented, will be criticized, modified, updated and reviewed by umpteen number of other scientists and philosophers. Such diversity of thinking is at the base of human knowledge. Besides, such a spirit of review forms the core strength of science, 'replication' - verbal and experimental. It is through review, new hypothesis are formed, old ones are replaced, modified or updated.

Subject matter of current research also has its own tumultuous history, especially modern history. This chapter reviews scientific literature in this regard. Review has been focussed on two purposes :

1. To present emerging trend of researches, concepts, theories related to current research.

2. To present different shades of meaning attached to different concepts mentioned in Chapter 1 - Introduction.

Keeping in tune with dual purpose mentioned above, sequence of topic in this chapter is exactly as it is in first chapter, with a few omissions. First, there is discussion of theories of mind which gives context of functionalism, cognitive revolution and its relevance to computational theory of mind. This is followed by review of computational theories of mind. This part differentiates between broader philosophical version and a narrow modeling version of computational theories of mind.

Next is the discussion of Kahneman's summarization of attention research and its relevance with the concept of automaticity in varying degrees. This is followed by basic concept of PRP and its methodological implication in scientific studies. Different theorists of multiple-task performance have enthusiastically produced evidence in their support and evidence against other theories. A review of evidence, criticism and limitation of each theories follows in the next topic of theories of multiple-task performance. One of such theory is the EPIC based SRD model. SRD has been simulated on empirical data in order to evaluate its goodness of fit to empirical evidence. A detailed discussion of one representative simulation follows in the next part. This is followed by discussion of other simulation studies done on representative empirical studies. Although EPIC theory has not been related in any way with stylistic concepts in psychology, such relation is one of the objective of current research. Therefore, next discussion is about current state of researches on style. Finally, purpose of current research is discussed in the context of review of literature.

2.0 THEORIES OF MIND

"There are many specific mental phenomena with which the philosophy of mind is concerned : for example : free will, intention, introspection, mental causation, personal identity, qualia, reasoning, mental content, and consciousness" (Georges Rey, 1998). However, theorization in the field is largely focused on three mental phenomena viz. "consciousness, rationality, and intentionality" (Georges Rey, 1998).

"Emergence in the 1960s of the loose federation of disciplines called 'cognitive science', brought together research from, psychology, linguistics, computer science, neuroscience and a number of subareas of philosophy, such as logic, the philosophy of language, and action theory. In philosophy of mind, these developments led to Functionalism, according to which mental states are to be characterized in terms of relations they bear among themselves and to inputs and outputs, for example, mediating perception and action in the way that belief and desire characteristically seem to do.

This focus on functional organization brought with it the possibility of multiple realizations : if all that is essential to mental states are the roles they play in a system, then, in principle, mental states, and so minds, could be composed of (or 'realized' by) different substances: some minds might be carbon-based like ours, some might be computer 'brains' in robots of the future, and some might be silicon-based, as in some science fiction stories about 'Martians'. These differences might also cause the minds to be organized in different ways at different levels, an idea that has encouraged the coexistence of the many different disciplines of cognitive science, each studying the mind at often different levels of explanation". (Jackson, Frank & Georges Rey, 1998).

3.0 COMPUTATIONAL THEORY OF MIND (CTM)

"The idea that thinking, and mental processes in general, could be treated in computational terms, was inspired by the successes in the formalization of certain portions of reasoning......It emerges in the work of Newell and Simon, Putnam, Harman, and especially J. Fodor, who has been most explicitly developing the computational-representational theory of thought (CRTT) or the idea that thinking consists in computing upon sentences in a 'Language of Thought'.

Note that, CRTT is not the claim that any computer - even any existing computer - is or has a mind. Rather, it is the claim that a mind is a certain kind of computer, one with specific relations to the environment, which, together, are responsible for its having certain intentional content. It is, in fact, not so much a claim as a research program : the hope is that by understanding the brain as an elaborate computer - or, more realistically, as a complex assemblage of computers - one could ultimately define mental states in terms of the specific computational roles they play in that assemblage. This program is more or less the subject matter of cognitive science" (Georges Rey, 1998).

"There have been three main versions of Computational Theory of Mind, corresponding to three main proposals about the mind's Cognitive architecture. According to the 'classical' theory, particularly associated with Jerry Fodor, the computations take place over representations that possess the kind of logical, syntactic structure captured in standard logical form : representations in a so-called Language of Thought, encoded in our brains. A second proposal, sometimes inspired by F.P. Ramsey's view that beliefs are maps by which we steer, emphasizes the possible role in reasoning of maps and mental Imagery. A third, recently much-discussed proposal is Connectionism, which denies that there are any structured representations at all : the mind/brain consists rather of a vast network of nodes whose different and variable excitation levels explain intelligent Learning. This approach has aroused interest especially among those wary of positing much 'hidden' mental structure not evident in ordinary behaviour" (Jackson, Frank & Georges Rey et al).

Although a lot of theorization in psychology is inspired or influenced by such philosophical and/or fundamental issues, it is also possible to take a narrow view of computational theories of mind. Such view considers use of computational theories for the purpose of modeling human behaviour and evaluation of its theory. As Coltheart Max (2002) states "An important recent advance in cognitive psychology is the development of computational modeling as an aid to the theory evaluation. A computational model of some theory in cognitive psychology is achieved by representing that theory in the form of a computer program that is capable of carrying out the cognitive task in question, and which does so using exactly the procedures that, according to the cognitive theory, are used by human beings when they are carrying out that cognitive task. Making a theory into a computational model helps theorizing in a variety of ways. For example, it reveals hitherto unsuspected ways in which the theory is underspecified or implicit : One can not make a running program from a theory unless that theory is fully specified and explicit. Furthermore, if the program does run and is able to perform the cognitive task in question, and if the speed or accuracy of its performance is affected by the same stimulus variables that affect the speed or accuracy of human performance, that shows that the theory is sufficient one.

This way of doing cognitive psychology is called computational cognitive psychology, and its virtues are sufficiently extensive that one might argue that all theorizing in cognitive psychology should be accompanied by computational modeling - that is, that it should be standard practice for theorists in cognitive psychology to express their theories in the form of executable computer program"

A few examples of computational modeling would be very relevant here. "A particularly fruitful application of computational theories has been to Vision. Early work in Gestalt psychology uncovered a number of striking perceptual illusions that demonstrated ways in which the mind structures perceptual experience, and the pioneering work of the psychologist, David Marr, suggested that we might capture these structuring effects computationally" (Jackson, Frank & Georges Rey et al). Another example is "two different theories about how visually presented stimuli are recognized : the three module theory (a Face module, an Object module, and a Words module) and Farah's two module theory (a P module and an E module)" (Coltheart, Max, 2002).

4.0 ATTENTION

"Kahneman and Treisman (1984), in their excellent review on the behavioural-attention research, divide this research into two main categories : studies of selective attention and divided attention. According to authors, selective-attention research was directed mainly to issues involving resistance to distraction and to determining the locus in the processing chain beyond which relevant and irrelevant stimuli are differently treated, whereas divided-attention research sought the limits of performance and the extent to which different tasks can be combined without loss. A further important difference was the selective-attention studies dealt almost exclusively with perceptual performance, whereas perceptual-motor tasks were often employed in studies of divided attention (Naatanen, 1988). The early studies on selective attention exposed their subjects to high perceptual load, and usually a large difference in performance was established between selective and divided attention instructions" (Risto Naatanen, Kimo Alho, and Erich Shroger, 2002).

Generally, tasks which can be accomplished automatically are considered not requiring attention and those which can not be accomplished automatically requires attention. Thus issue of the degree of automaticity is central in the field, as the greater the extent to which information processing is automatic, the less there is to be explained by attention. Kahneman and Treisman (1984) distinguished three levels of automaticity :

1. Strong automaticity : An act of perceptual processing is neither facilitated by focusing attention to a stimulus, nor impaired by diverting attention from it.

2. Partial automaticity : An act is normally completed even when attention is diverted from the stimulus, but can be facilitated by attention.

3. Occasional automaticity : An act generally requires attention but can sometimes be completed without it.

5.0 PSYCHOLOGICAL REFRACTORY PERIOD

"Recent studies of the PRP procedure have used the parallel versus serial issue to localize a hypothetical bottleneck in processing (e.g. Pashler, 1984; Pashler & Johnston, 1989). By hypothesis, stages prior to the bottleneck can go on in parallel within and between tasks, whereas the bottleneck stage is strictly serial. Task 1 and Task 2 can be processed in parallel up to the stage at which they require the bottleneck. At that point, one task gets bottleneck (usually Task 1) and the other task has to wait for it (usually Task 2). The period during which Task 2 has to wait for the bottleneck is called slack, and the bottleneck can be located by finding the locus of the slack in the processing chain. Processes prior to the bottleneck are parallel and so can begin as soon as they receive input. There is no slack before them. The slack period appears just before the bottleneck begins, so localizing the slack also localizes the bottleneck....

.......The locus of slack logic is a generalization of Sternberg's (1969) additive factors method for decomposing single tasks into component stages The locus of slack logic is also a special case of a much broader and more formal generalization of the additive factors logic by Schweickert, Townsend, and Fisher (e.g., Fisher & Goldstein, 1983; Goldstein & Fisher, 1991; Schweickert, 1978; Schweickert & Townsend, 1989; Townsend, 1984; Townsend & Schweickert, 1989). In the general logic, underadditive interactions between difficulty variables are often diagnostic of parallel processes, whereas additive or null interactions are often diagnostic of serial processes (Townsend, 1984). This principles can not be applied universally, however" (Logan, Gordon, D., 2002).

6.0 THEORIES OF MULTIPLE-TASK PERFORMANCE

1. *Single Channel Hypothesis*

As mentioned earlier, PRP effect at zero SOA has not been found out to be always equal to mean Task 1 RT. This obviously forced the researchers to consider intervening mental processes and their influence on the PRP effect. While considering three intermediate stages one would be left to a choice of considering any one of the three stages as the place where bottleneck could occur. And there ensued three theories perceptual bottleneck, response-selection bottleneck and movement-production bottleneck models of PRP effect.

2. *Perceptual Bottleneck Model*

According to Broadbent et al information related to stimuli first goes to sensory buffer, then to selective attentional filter and then to a limited-capacity channel. Sensory buffer can work in parallel and it analyzes physical features of the stimuli such as locations, intensities and pitches of sounds etc. These analyzed features are then sent to selective attentional filter. Selective attentional filter would select a particular stimuli on the basis of features as identified by sensory buffer, past experience and task demands to a limited-capacity channel. This limited-capacity channel identifies them, determines their meanings and performs perceptual operations at a fixed maximum rate. Due to this limited-capacity channel task interference effects arises in concurrent task performance. Broadbent et al supported his theory on the basis of experiments on choice RT, dichotic listening, and oral shadowing (e.g. Broadbent, 1952, 1954; Cherry, 1953; Hick, 1952; Hyman, 1953).

However studies by Moray, 1959; Treisman, 1969, 1964; Corteen & Wood, 1972; J. A. Gray & Wedderburn, 1969; Lewis, 1970; MacKay, 1973, von Wright, Anderson & Stenman, 1975 provided counter-evidence to the Broadbent's theory. And so a theory was advanced to show interference effect in second stage.

3. Response-selection Bottleneck Model

Smith, 1967 and Welford, 1967 have considered response-selection model as evidence for PRP effect, -1 slope of PRP curve and less than Task 1 RT PRP effect. Besides, Davis, 1959; Fraisse, 1957; Kay & Weiss, 1961; Nickerson, 1965 found that PRP effect reduced when Task 1 response selection difficulty reduced and even disappeared when subjects were not supposed to respond overtly. Adams & Chambers, 1962 and Reynolds, 1966 found that null PRP effects occurs even when Task 1 involves only one S-R pair. Karlin & Kestenbaum, 1968 and Smith, 1969 have demonstrated that when numerosity of Task 1 S-R pairs is increased from 1 to 5 PRP effect also increases. Broadbent and Gregory (1967) reported that Task 1 RTs and PRP effect increases with increase in incompatibility between Task 1 stimuli and responses. Thus, number of studies such as Fitts & Seeger, 1953; Hick, 1952; Hyman, 1953; Kornblum, Hasbroucq & Osman, 1990, Sanders, 1980; Sternberg, 1969 have shown that S-R numerosity and S-R compatibility have their main effects on response selection. "Alternatively, it might be argued that stimulus-response (S-R) compatibility and S-R numerosity influence some other stages of processing (e.g. stimulus identification or movement production) besides response selection. However, Sternberg (1969) found that S-R compatibility effects are additive with those of factors (e.g. stimulus legibility and response probability) that presumably influence stages earlier and later than response selection. By contrast, S-R compatibility effects interact with those of S-R numerosity (Sternberg, 1969). This pattern suggests that both S-R numerosity and S-R compatibility have some effect during response selection. Indeed, a thorough review of the literature supports the conclusion that response selection is the locus for most, if not all, of both S-R numerosity and S-R compatibility effects (Sanders, 1980)" (Meyer & Kieras et al).

However a study by Karlin & Kestenbaum (1968) showed that when Task 2 response selection difficulty was increased at long SOA Task 2 RTs were greater in case of choice RT condition than under simple RT condition. Whereas at short SOA there was no difference in mean Task 2 RTs in both simple and choice condition. As PRP effect was found in both conditions, and it was less for choice reactions condition it was assumed that there was an interaction effect between SOA and Task 2 response-selection difficulty. Keele, 1973 and Keele & Neil, 1978 argued that this findings suggest that bottleneck may be in some later stage of processing.

McCann & Johnston, 1992; Pashler, 1984; Schweickert, 1980 have given explanation as to why such findings can be evidence against response-selection model as given in Figure 10.

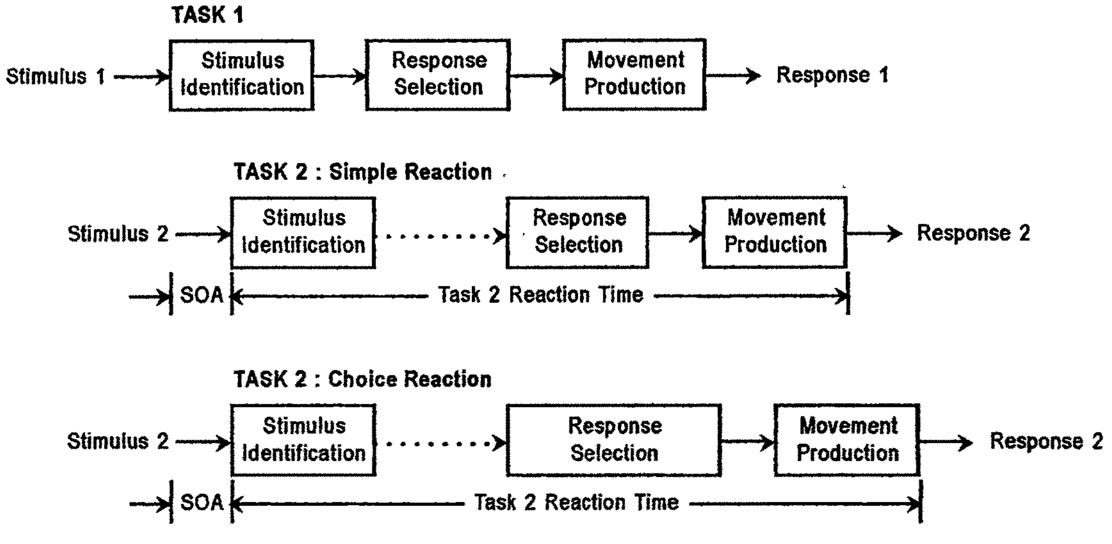

Fig. 10 : Sequence of processing stages that failed to account for Karlin & Kestenbaum results

Processes to perform Task 1 are shown on the top. Task 1 processes finishes from start to finish throughout. As soon as Task 2 is delivered after a short SOA stimulus identification processes runs in parallel to Task 1 stimulus identification processes. However, as there is slack in response selection stage, Task 2 response selection stage is interrupted until Task 1 response selection processes gets over. Subsequently Task 2 response selection process begins, followed by movement production process and response delivery. However, in case of choice reaction of Task 2 response selection processes takes longer to finish and so movement production also begins late and thus reaction time is different for Task 2. Interestingly, by decreasing SOA, the slack period for Task 2 response selection processes will increase and thereby Task 2 RT will also increase. However, there should not be any increase in the response selection processes as response selection processes in Task 2 begins only after completion of Task 1 response selection processes. Thus response selection difficulty of Task 2 RT should not change in case of change in SOA which is contrary to what Karlin and Kestenbaum (1968) found.

As Meyer & Kieras et al puts it, "The response-selection bottleneck model likewise has trouble explaining results reported by Schvaneveldt (1969). He presented visual stimulus digits whose identities and locations varied across trials. There were three types of trials : single-task trials with manual responses based on digit locations; and dual-task trials with vocal plus manual responses. The S-R compatibility also varied systematically. For vocal responses on single-task trials, RTs were longer when participants named the numerical successors (e.g. 3) of the stimulus digits (e.g. 2) than when they simply named the stimulus digits. Similarly, for manual responses on single-task trials RTs were longer when participants pressed finger keys at locations (e.g. right or left) opposite to those of the stimulus digits than when they pressed keys at locations corresponding to those of the digits. On dual-task trials, however, S-R compatibility affected the RTs much less. This reduction is analogous to the interaction that Karlin and Kestenbaum (1968) found between SOA and S-R numerosity effects on Task 2 RTs. Assuming that S-R compatibility influences response selection, Schvaneveldt's (1969) results suggest that response-selection processes in two concurrent tasks may temporally overlap, contrary to the response-selection bottleneck model (Keele, 1973, Keele & Neill, 1978)".

4. *Movement-Production Bottleneck Model*

Berlyne, 1960; De Jong, 1993; Herman & Kantowitz, 1970, Kantowitz, 1974, 1977; Logan & Burkell, 1986; Reynolds, 1964 and Keele 1973; Keele & Neill, 1978 proposed idea for movement-production bottleneck model. This model very neatly explains the results of Karlin & Kestenbaum (1968) experiment as given in Figure 11.

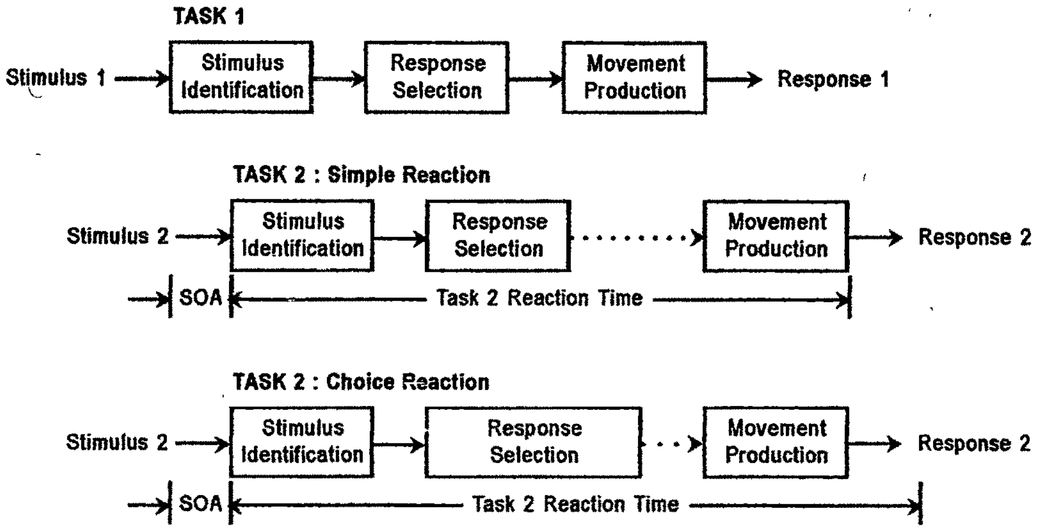

Fig. 11 : Sequence of processing stages that accounts for Karlin & Kestenbaum results

As can be seen above processes to perform Task 1 are shown on the top. Task 1 processes finishes from start to finish throughout. As soon as Task 2 is delivered after a short SOA stimulus identification processes and response selection processes run in parallel to Task 1 stimulus identification and response selection processes. However, as there is slack in movement production, Task 2 movement production stage is interrupted until Task 1 movement production processes gets over. Consequently Task 2 movement production process is delayed in simple reaction task therefore RTs of simple reaction task becomes equal to RTs of Task 2 choice reaction task at short SOA. However if SOA increases the Task 2 simple reaction RTs shall continue to be the same, whereas Task 2 choice reactions RTs shall increase. In fact, this logic applies to Schvaneveldt's (1969) experiment also.

However, Becker (1976) found contrary evidence which supports the response-selection bottleneck model. Becker et al found additive effects of SOA and S-R numerosity on Task 2 RTs i.e. Task 2 RTs were same for both simple and choice reaction task under short SOA and long SOA. Pashler, 1984; Fagot & Pashler, 1993; McCann & Johnston, 1992 and Pashler & Johnston, 1989 have reported similar findings.

Besides, indirect effects of Task 2 on Task 1 performance can not be explained by any of the bottleneck model. For example Gottsdanker, Broadbent, & Van Sant (1963) and Herman & Kantowitz (1970) found that participants are sometimes faster at performing a given task alone than at performing it as the first of two tasks. Karlin & Kestenbaum (1968) and Smith (1969) reported that Task 1 RTs sometimes increase with the number of S-R pairs in Task 2. Similarly, Gottsdanker & Way (1966) found that occasionally, Task 1 RTs increase when SOAs are short rather than long. Thus, there is no agreement as to where the bottleneck is.

Meyer & Kieras et al reflects, "given this state of affairs, one could reach several alternative conclusions :

(a) the human information-processing system has two or more distinct "hardware" bottlenecks in its component mechanisms (De Jong, 1993, 1994), and their manifestation depends on the prevailing task context;

(b) a bottleneck mechanism contributes to multiple-task performance, but the locus at which it operates is strategically programmable and varies from one situation to another rather than being immutable;

(c) there is no bottleneck mechanism per se;

(d) performance is mediated instead by a general-purpose central processor with limited capacity that may be allocated continuously and flexibly among the competing tasks". This alternative is the basis of Unitary-Resource theory.

5. *Unitary Resource Theory*

Under the rubric of Unitary Resource Theory varying concepts have been proposed to explain multiple-task performance such as operator loading (Knowles, 1963), processing capacity (Kiss & Savage, 1977), processing resources (Navon & Gopher, 1979; Normal & Bobrow, 1975), energy pools (Gopher, 1986), mental effort, and attention (Kahneman, 1973).

In one study, Kahneman, Beatty, and Pollack (1967) presented sequences of auditory stimulus digits (e.g. 3816); after each sequence, participants vocalized another sequence consisting of the stimulus digits' successors (e.g. 4927). During presentation of the auditory stimulus digits, the participants also monitored a sequence of visual letters for a specified target. Their pupil dilation and detection accuracy both increased throughout the presentation interval, whereas the vocal digits were produced equally well regardless of serial position. Because pupil dilation presumably manifests arousal and mental effort, these results imply that participants's capacity to detect the target letter grew over time, whereas the capacity allocated to the digit-production task remained constant (Meyer & Kieras et al).

Meyer & Kieras et al reports another study which supports the hypothesis that capacity is indeed divisible and can be flexibly allocated. "Brickner and Gopher (1981) had participants perform a visual-manual tracking task with one hand while they performed a visual-manual choice RT task with the other hand. In one task-emphasis condition, the participants were told to give 25% priority to the tracking task and 75% priority to the choice RT task; in other conditions, the requested percentage priorities were either 0 / 100, 35 / 65, 50 / 50, 65 / 35, 75 / 25, or 100 / 0 for the tracking and choice RT tasks, respectively. In particular, the 100 / 0 condition required participants to concentrate solely on the tracking task, whereas the 0 / 100 condition required them to concentrate solely on the choice RT task.....Some results of this manipulation appear in figure....Here, the speed of choice reactions (responses per second) is plotted against a measure of normalized tracking accuracy for each task-emphasis condition, yielding a performance operating characteristic curve...As this curve shows, participants achieved various intermediate levels of performance; they traded, in a gradual fashion, relatively fast choice reactions for relatively accurate tracking.....An alternative interpretation of the results in Figure 13 is that participants switched rapidly back and forth between tasks, devoting their processing capacity to one or the other task in an all-or-none fashion during successive intervals of time. Perhaps manipulating task emphasis simply affects the relative strength of the time interval that each task is given rather than affecting the proportions of capacity allocated continuously to the two tasks. However, note that in Figure 13 the attained performance levels for intermediate task-emphasis conditions (i.e. 25 / 75, 35 / 65, 50 / 50, 65 / 35, and 75 / 25) fall above an imaginary diagonal line that connects single-task tracking accuracy (i.e. results from the 100 / 0 condition) and single-task choice speed (i.e. results from the 0 / 100 condition). Such dominance suggests that participants may indeed have performed the two tasks in parallel rather than alternating serially between them (Sperling & Dosher, 1986)". Many other studies such as Gopher, 1993; Gopher, Brickner, & Navon, 1982; Kramer, Wickens, & Donchin, 1985; Navon, Gopher, Chillag, & Spitz, 1984; Sperling & Melchner, 1978; Wickens & Gopher, 1977; Wickens, Kramer, Vanasse, & Donchin, 1983, have clearly indicated elasticity, divisibility and flexibility of unitary resource.

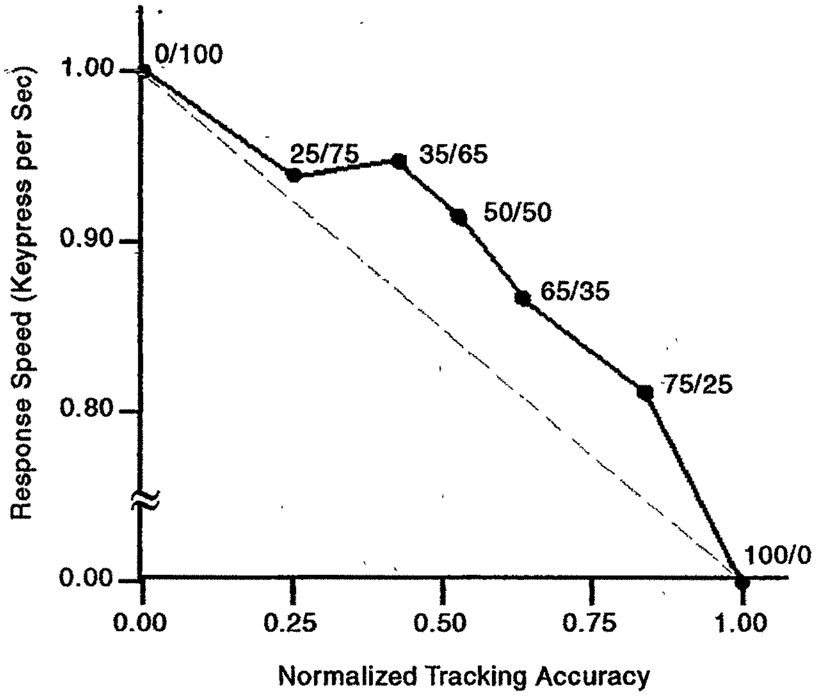

Figure 12 Performance operating characteristic (POC) curve from a study by Brickner and Gopher

Kahneman (1973) quoted "A theory which identifies attention with effort and limited capacity entails two predictions concerning interference between concurrent activities : (1) interference will arise even when two activities do not share any mechanisms of either perception or response; (2) the extent of interference will depend in part on the load which each of the activities imposes, i.e. on the demands of competing activities for effort or attention". Whereas Wickens (1980, 1984, 1991) has cited following four problems with this theorization.

1. Difficulty insensitivity : Studies have shown that nominal variation of Task 1 difficulty has little or no effect on Task 2 performance in concurrent task trials. For example, North (1977) had participants perform a primary visual-manual choice RT task along with either a secondary digit-cancellation task or a secondary visual-manual tracking task. The primary task's difficulty was varied by manipulating the complexity of decisions that participants made there. When performed alone, the primary task yielded increasing RTs and error rates as its difficulty increased. Performance on the secondary digit-cancellation task also became worse as the primary-task difficulty increased. Thus, the processing capacity required by the primary task presumably increased with its difficulty. However, manipulation of the primary task's difficulty did not significantly affect performance on the secondary tracking task.

2. Structural-alteration effects : "Structural-alteration effects occur when two circumstances jointly prevail : (a) primary-task interference with a secondary task is dramatically reduced by changing which structural components are needed to perform the primary task and (b) this change does not decrease the primary task's difficulty. For example, McLeod (1977, Experiment 1) had participants perform a secondary visual-manual tracking task along with a primary choice RT task. The primary task required either manual or vocal responses to auditory tones. Both types of primary-task responses were about equally difficult to make. However, the primary task interfered much less with the secondary visual-manual tracking task when the primary-task responses were vocal rather than manual. More generally, structural-alteration effects have been obtained through variations of not only primary-task response modalities (Harris, Owens, & North, 1978; McLeod, 1978; Wickens, 1980; Wickens, Sandry, & Vidulich, 1983) but also stimulus modalities

(Martin, 1980; Treisman & Davis, 1973; Wickens et al., 1983) and mental imagery codes (Brooks, 1968; Friedman, Polson, Gaskill, & Dafoe, 1982; McFarland & Ashton, 1978; Wickens & Sandry, 1982; Wickens et al., 1983). Such results suggest that decrements observed in multiple-task performance may stem not from capacity interference per se but rather from stimulus confusions, response competition, and other sources of structural interference" Meyer & Kieras et al.

3. Difficulty-structure uncoupling : When an easier task interferes more than the difficult task after reducing interference between primary and secondary task by structural alteration effect, it is called as difficulty-structure uncoupling. Wickens (1976) performed a secondary visual-manual tracking task together with either a primary auditory signal-detection task or manual force-generation task. According to unanimous subjective reports, the force-generation task was easier than the signal-detection task. Nevertheless, the force-generation task interfered more than the tracking task. "As before this casts doubt on the limited-capacity and capacity-demand assumptions, which predict more interference between signal detection and manual tracking given the greater difficulty of the detection task" Meyer & Kieras et al.

4. Perfect time sharing : This occurs when two task which are reasonably demanding do not interfere at all with each other when done concurrently. Meyer & Kieras et al. reports "for example, Allport, Antonis, and Reynolds (1972) showed that participants could simultaneously shadow spoken messages and play piano music from written scores with essentially no performance decrements compared with single-task levels. Similarly, using the PRP procedures, Greenwald and Shulman (1973) virtually eliminated the PRP effect when both Task 1 and Task 2 involved ideomotor-compatible S-R mappings. Shaffer (1975) found no marked performance decrements when skilled typists simultaneously typed written text and orally shadowed spoken messages. Hirst, Spelke, Reaves, Caharack, and Neisser (1980) found that after some practice, participants successfully comprehended written stories while they manually transcribed auditory stimulus words". Obviously such findings are also contrary to limited capacity assumption of unitary resource theory.

Although a few attempts have been made to reconcile with such counter evidence, generally unitary resource theory has been criticized for limited central-processing capacity assumption and for lesser analysis of relationship between specific central and peripheral processing structures. "Proponents of simple bottleneck models also have sought to reconcile their views with phenomena such as difficulty insensitivity. Specifically, Broadbent (1982) tried to account for structural-alteration effects, difficulty-structure uncoupling, and perfect time sharing in terms of rapid serial interleaving of various processing stages" Meyer & Kieras et al.

6. Multiple Resource Theory

Wickens (1984) proposed a three-dimensional taxonomy of resources based on stages, codes and modalities of processing. Stages include perceptual-cognitive stage and response stage and both of them have their own divisible capacity. So, if two tasks demand same stage, there will be an interference effect, if not, then both tasks could run in parallel. Codes include two types of codes viz. spatial and verbal. Here again interference will be there if same code is required by both the task and otherwise not. Whereas modality includes both sensory and motor modalities. Here again, if two tasks demand same sensory or motor modality, there will be interference effect and otherwise not.

Multiple resource theory seems to account for all the relevant findings in PRP experiments. Meyer & Kieras et al. notes that "in addition, some aspects of neuroanatomy and neurophysiology accord well with multiple-resource theory. For example, Kinsbourne and Hicks (1978) noted that concurrent tasks may be easier when one of them relies on the brain's right hemisphere and another relies on the left hemisphere. This easy concurrency could stem from the two hemispheres providing distinct resources that mediate the use of spatial and verbal codes, respectively. Similarly, Pribram and McGuinness (1975) suggested that processing capacity may have two distinct sources : 'arousal' from the brain's reticular activating system and 'activation' from the limbic system and basal ganglia. Following this suggestion, Sanders (1983) and Gopher & Sanders (1984) related reticular activating system arousal to the perceptual-cognitive stage of processing and limbic system activation to the response stage. These putative relations are consistent with the selective effects of psychoactive drugs (e.g. barbiturates and amphetamine) on human performance (Frowein, 1981)".

Despite being such a comprehensive theory, Multiple-Resource theory has been criticized for lack of sufficient principled constraints. Therefore, it is likely that more and more resources shall be hypothesized whenever any result is contradicting the expected one. Empirical studies have also shown certain problems with the theory. For example, Duncan (1980) has shown decrements in stimulus detection, recognition, identification and classification when multiple targets are presented simultaneously and even when do not require overt responses. Long (1975) has shown that this decrement occurs even when stimuli are presented through different sensory modalities. McCann & Johnston, 1992; Pashler, 1990; and Pashler & Johnston, 1989 have reported PRP effects on Task 2 RTs even when Task 1 requires vocal responses to auditory stimuli and Task 2 requires manual responses to visual stimuli. Meyer & Kieras et al. reports that "Task 2 RTs may manifest additive effects of SOA and various Task 2 factors that presumably influence response selection, including decision type (positive vs. negative; Pashler, 1984), S-R numerosity (Becker, 1976; Van Selst & Jolicoeur, 1993), S-R compatibility (McCann & Johnston, 1992), S-R repetition (Pashler & Johnston, 1989), and S-R conflict (Stroop interference; Fagot & Pashler, 1993). Such additivity can occur even when participants respond to two perceptual features of the same stimulus (Fagot & Pashler, 1993).....these findings seem to suggest a bottleneck in response selection rather than flexible allocation of capacity to concurrent selection processes. Further complicating the theoretical picture, hybrid models with a combination of both response-selection and movement-production bottlenecks have been proposed (De Jong, 1993)".

7.0 EXECUTIVE PROCESS INTERACTIVE CONTROL (EPIC)

During the initial development of SRD model several preliminary versions of it were tested. Such tests revealed that each executive-process component may contribute significantly to an overall account of empirical RT data. Initial simulations focused on a PRP study by Hawkins (1979). Hawkins (1979) had participants perform various types of Task 1, across which the stimuli were either auditory or visual, and the responses were either vocal or manual. Also included were a manipulation of Task 2 response-selection difficulty and a broad range of SOAs with numerous intermediate values. This design yields detailed PRP curves with systematic additivities and interactions among several factor effects, which offer a challenging context to evaluate the SRD model.

Specifically, there is one key set of conditions in this study that is important. Task 1 required manual choice reactions (left-hand finger presses) to auditory stimuli (tones), and Task 2 required manual choice reactions (right-hand finger presses) to visual stimuli (digits). The difficulty of the response-selection process for Task 2 was varied by having participants deal with either two or eight alternative S-R pairs during Task 2. When Task 2 involved two stimulus-response (S-R) pairs, the stimuli were the digits 2 and 3, and the responses were keypresses with the right-hand index and middle fingers, respectively. When Task 2 involved eight S-R pairs, the stimuli were the digits 2-9; for four of them (2, 5, 6, and 9), participants pressed the right-hand index finger key, and, for the other four (3, 4, 7, and 8), they pressed the right-hand middle finger key.

The results of this experiment were as follows. The mean RTs in Task 1 were moderate (about 630 ms on average) and varied little across the SOAs (SEM = ~ 10 ms). These results replicate ones obtained by other investigators (e.g., Karlin & Kestenbaum, 1968; McCann & Johnston, 1992); Pashler, 1984, 1990; Pashler & Johnston, 1989). They are consistent with typical instructions for the PRP procedure, which emphasize completing Task 1 quickly regardless of the SOA and Task 2 response-selection difficulty. Likewise replicating results from previous PRP studies, this study found out substantial PRP effects during Task 2. The mean Task 2 RTs were more than 400 ms greater at the shortest (0 ms) SOA than at the longest (1200 ms) SOA.

In addition, there was an interesting pattern of response-selection difficulty effects on these mean Task 2 RTs. At intermediate and long (greater than 200 ms) SOAs, the Task 2 responses were much slower on an average in the condition with eight S-R pairs than in the condition with two S-R pairs (the mean difficulty effect was about 200 ms at the longest SOA). This temporally localized difficulty effect was reliable compared with Task 2 RTs' standard errors of the mean, which equaled about 10 ms on average. At the shorter (less than 200 ms) SOAs, however, the number of S-R pairs affected the Task 2 RTs much less (only about 35 ms). Thus, overall, a substantial interaction was present between the effects of SOA and response-selection difficulty on mean Task 2 RTs in this PRP study with auditory-manual Task 1. This interaction replicates and extends results reported by Karlin and Kestenbaum (1968). It is also consistent with first family of theoretical PRP curves that the SRD model can produce.

Given the benchmark results reported by above study, tests were conducted to assess how well various models account for participant's performance under PRP procedure. Simulation was first done with response-selection bottleneck model, then it was done with preliminary SRD model and finally with augmented SRD model.

a. <u>Simulation with response-selection bottleneck model :</u> This simulation entailed three steps : (a) specifying a set of production rules that can be used to perform auditory-manual Task 1; (b) specifying two additional rules sets that can be used respectively to perform easy and difficult visual-manual Task 2; and (c) specifying a set of executive production rules that emulate a response-selection bottleneck while coordinating task performance as required by the PRP procedure's standard instructions.

The executive production rules that were specified to emulate the response-selection bottleneck model were straightforward. On each simulation trial, they withheld the note "GOAL DO TASK 2" from working memory until the Task 1 response had been selected and its movement production was well under way. This complete lockout scheduling precluded any temporal overlap between the response-selection processes for Task 1 and 2, just as the response-selection bottleneck model required.

Using the executive and task production rules for the bottleneck model, a series of simulation trials were conducted under conditions like those used in the experiment. The simulation relied on the EPIC architecture. Subject to constraints imposed by the bottleneck model's complete lockout scheduling, EPIC's context-dependent parameters were assigned numerical values that maximized the goodness of fit between simulated mean RTs and the experiment. The obtained fit was good; its root mean square error (RMSE) did not exceed empirical task 1 RTs' standard errors of the mean (6 vs. 10 ms respectively). In contrast bottleneck model produced a markedly poorer fit ($R^2 = 0.89$) between the simulated and empirical mean Task 2 RTs. The inability of the bottleneck model to account well for empirical mean Task 2 RTs stemmed from its complete lockout scheduling of response selection. Because of such scheduling, response selection for Task 2 never started until after Task 1 was essentially done, so the difficulty of Task 2 response selection propagated forward to affect Task 2 RTs regardless of the SOA. That this propagation did not occur in the experiment, when Task 1 involved auditory-manual choice reactions raised the need for a more veridical model whose scheduling algorithms had greater efficiency and flexibility. In particular, the SRD model whose optimized executive processes enabled temporally overlapping response selection for Tasks 1 and 2 of the PRP procedure. To confirm this a preliminary SRD model was simulated.

b. Simulation with preliminary SRD model : In this simulation Task 1 and Task 2 production rules, which perform response selection for the two tasks, were the same as in previous simulation with the response-selection bottleneck model. All that changed from one model to the next was the executive process and its task-scheduling strategy. As anticipated already, the preliminary SRD model's executive process put the notes "GOAL DO TASK 2" and "STRATEGY TASK 2 MODE IS DEFERRED" in working memory at the start of each simulated test trial, enabling Task 2 response-selection to proceed concurrently with Task 1 response selection. In this respect, the preliminary SRD model was more efficient than the response-selection bottleneck model. However, some of the SRD model's other useful executive optimization features were omitted.

For example, in its preliminary version, the executive process never shifted the Task 2 production rules from the deferred to the immediate response-transmission mode. Instead, regardless of progress made on Task 1, the Task 2 rules always operated in the deferred mode, putting the selected Task 2 responses temporarily in working memory. To accommodate the latter constraint while ultimately completing Task 2, the executive process permitted Task 2 responses to be sent from working memory to their motor processor after Task 1 was done. This indirect route continued to be taken over at long SOAs, where Task 2 response selection did not start before Task 1 was done. The preliminary SRD model did not include any extra suspension waiting time or anticipatory movement preparation, which might have contributed beneficially, if response transmission was shifted from the deferred to the immediate mode.

The additional simulations were conducted with preliminary SRD model. Here, as before, EPIC's context-dependent parameters (e.g., stimulus-identification times) were assigned numerical values that maximized the goodness of fit between simulated and empirical mean RTs. The mean Task 1 RTs produced by the preliminary SRD model for the experiment, fit the empirical ones extremely well. The goodness of fit was equal to what was obtained with response-selection bottleneck model. This was because both models treated Task 1 in the same way, using the same Task 1 production rules and high Task 1 priority. Simulated mean Task 2 RTs compared with what the bottleneck model produced were markedly better ($R^2 = 0.968$, RMSE = 43). The preliminary SRD model yielded a substantial interaction between the effects of SOA and Task 2 response-selection difficulty;

the difficulty effect on simulated mean Task 2 RTs was much less at the short SOAs than at the longer ones, just as the experiment. This interaction stemmed directly from concurrent response selection being enabled for Task 1 and Task 2 at short SOAs. Yet, the simulated Task 2 RTs from preliminary version of the SRD model did not fit the empirical Task 2 RTs in all respects. Instead, several noticeable discrepancies, each substantially greater than the standard errors of the the empirical mean RTs. First, the simulated mean RTs at the longest (1200 ms) SOA exceeded the corresponding empirical ones by about 100 ms. Second, at the intermediate (600 ms) SOA, exactly the reverse relations held when Task 2 was difficult; here, the simulated mean Task 2 RT underestimated the corresponding empirical one by about 100 ms. Third, at the shorter SOAs, the response-selection difficulty effect on the simulated mean Task 2 RTs was even less than on the empirical RTs. The relationships between the empirical and simulated mean Task 2 RTs suggested that preliminary SRD model provided a theoretical step in the right direction. Enabling concurrent response selection for Tasks 1 and 2 accounted better for the observed interaction between SOA and Task 2 response-selection difficulty effects. However, remaining discrepancies implied that the model needed refinement, which involved adding more features to its initial partially optimized executive process.

c. <u>*Simulation with augmented SRD model :*</u> The executive processes of augmented SRD model were progressively refined. These refinements involved (a) shifting the production rules for Task 2 from the deferred to the immediate response-transmission mode while Task 2 was being unlocked; (b) inserting additional ocular orientation and suspension waiting times; and (c) preparing movement features in advance for Task 2 responses after Task 2 had been resumed in the immediate mode. Interestingly, each of these refinements improved a particular aspect of the fit between simulated and empirical mean Task 2 RTs for the PRP study.

Further simulation with other experiments of Hawkins (1979) proved goodness of fit of the SRD model in emulating the PRP effect under varying conditions. To test the SRD model further and to demonstrate its generality more fully, more simulation with participant's performance in other representative studies with the PRP procedure was carried out. For example PRP studies by Karlin and Kestenbaum (1968) and by McCann and Johnston (1992) whose RT data came from different families of PRP curves that depended on crucial details of task conditions. These new simulations revealed that the

SRD model provided good parsimonious quantitative fits between theory and data under additional conditions in which there are various combinations of perceptual-motor modalities and stimulus-response (S-R) mappings.

However, it is not claimed that the SRD model described thus far accounts fully for human multiple-task performance under all circumstances. Rather depending on circumstances at hand, the model may have to be modified and extended. An outline of several specific extensions that are still within the domain of the PRP procedure but that foreshadow some future directions where theorizing could go, are -

1. Use of conservative strategy for using the deferred response transmission mode to avoid producing the Task 2 response before Task 1 responses, thereby delaying the Task 2 responses more than necessary after Task 1 was done.

2. Progressive unlocking which involves making successive contingent choices about what the Task 1 unlocking event will be during a trial. Among the possible choices for this events are the following : (a) the identity of a selected Task 1 response is sent to its motor processor for movement-feature preparation and execution; (b) preparation of the movement features for the Task 1 response is completed; or (c) the overt Task 1 response has begun.

3. Control of eye movements by the model's executive process.

8.0 COGNITIVE AND AFFECTIVE STYLES

Sternberg & Grigorenka (1997) defined cognitive style as "people's characteristic and typically preferred modes of processing information.......they may indeed provide inroad to predicting school and other kinds of performance as do abilities". Study of cognitive styles offer following advantages :

1. Cognitive styles represent a bridge between two distinct areas of psychological investigation : cognition and personality. Examples such bridge are Factor B in 16PF questionnaire, MBTI, Big Five theories of personality, Social intelligence, Practical Intelligence, Emotional intelligence etc.

2. Cognitive styles have important implications for educational theory and practice. Perhaps prediction of achievement could be improved by adding measures of styles to measures of abilities as predictors of performance. For example, impulsive

children should show lower performance on school because of their tendency not to be careful in their work, above and beyond any question of their intellectual abilities (Kagan, 1965, 1966).

3. Cognitive style may play important role in occupation choice and performance. While giving example, Sternberg & Grigorenko (1997) states "those who have styles compatible with the kinds of learning required for multiple-choice tests, for example, may not have styles compatible with the kinds of performance required on a job for which the courses using the multiple-choice tests are supposedly preparatory. For example, psychologists need to come up with the ideas for theories, experiments, and therapy, but they rarely, if ever, have to memorize books or lectures."

Study of cognitive style should consider following important aspects -

1. Operationalization : There should be at least one measure of the style or styles posited by a given theory;

2. Theoretical specification : There should be a reasonably complete, well-specified, and internally consistent theory of styles that makes connection with extant psychological theory;

3. Internal validity : There should be a demonstration that the measures of styles correlate with other measures with which, in theory, they should correlate;

4. Convergent external validity : Measures of styles should correlate with measures with which, in theory, they should correlate;

5. Discriminant external validity : Measures of style should not correlate with other measures, with which, in theory, they should not correlate; and

6. Heuristic generativity : It is the extent to which the theory has spawned and continues to spawn psychological research and ideally, practical application.

As current research focuses on only two styles, namely, reflection-impulsivity and field dependence-field independence. These two styles are discussed here keeping in mind above six criteria.

1. Conceptual tempo : Many empirical findings about conceptual tempo have emerged.

For example, impulsivity as a cognitive style appears to be different from impulsiveness as a personality trait. (Glow, Lange, Glow, & Barnett, 1983), at least as the latter is measured by the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975). For example, children with an impulsive style, in contrast to those with reflective style, make more errors in reading prose, make more errors in reading prose, make more errors of commission on serial-recall tasks, and are more likely to offer incorrect solutions on inductive-reasoning problems and visual discrimination tasks (Stahl, Erickson, & Rayman, 1986). Reflective people tend to make fewer errors in word-recognition, serial learning, and inductive-reasoning tests (Zelniker & Oppenheimer, 1973). Impulsive individuals tend to have minimal anxiety about committing errors, an orientation toward quick success rather than avoiding failure, relatively low performance standards, low motivation to master tasks, and little attention in monitoring of stimuli (Kagan, 1966; Messer, 1970; Paulsen, 1978).

2. Field dependence - independence : Because concept of Field dependence - independence was originated to overcome the incompleteness of conventional intelligence tests as bases for explaining individual differences in cognition, researchers have attempted to find the relation between conventional measures of intelligence and field dependence-independence (Witkin, 1975) claimed that research showed the independence of the construct from verbal skills as tapped by the Wechsler scales. Moreover, Eagle, Goldberger, and Breitman (1969) found no difference between groups in ability to acquire new information. However, the story changes with spatial aspects of abilities. Witkin (1975) himself suggested that field independence is "essentially identical" with the abilities required for Wechsler Block Design, Object Assembly, and Picture Completion subtests. (Cronbach and Snow, 1977) suggested that field dependence-independence adds nothing to the concept of fluid ability (Cattell, 1971), or the ability to think flexibly and cope with novelty, and MacLeod, Jackson, and Palmer (1986) used structural equation modeling to argue that field independence is identical to spatial ability. Goldstein and Blackman (1978), reviewing 20 studies, found consistent correlations between measures of field independence and both verbal and performance aspects of intelligence. Thus, the evidence suggests a close connection and perhaps an identity between field independence and aspects of intelligence.

9.0 PRESENT RESEARCH

Review of relevant literature suggest that multiple-task performance studies have been equivocal about its findings. Meyer & Kieras (1997). EPIC based SRD model has obviously presented a comprehensive model to account for a number of divergent finding under an unitary framework. The SRD model has been simulated on a number of empirical studies as mentioned in the present chapter. Goodness of fit evaluated for such simulation and empirical data has been of fairly good degree. Present research aims at strengthening the EPIC based SRD model by suggesting consideration of more relevant parameters which could help in generalizing the model to future data. Besides, it also explores alternative ways of approaching multiple-task performance through tripple task conditions, influence of stylistic parameters, individual differences and importance of ignored dimensions of stimuli and responses.

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