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

Chapter One - Introduction

1.0 INTRODUCTION

Modern world characterized by its scientific and technological progress, vanishing national borders and economic mayhem has led us into a fast paced life. The fast pace of life forces us to be competent into many areas and perform many things at times. In fact this is an age of multi-skilled people and multi-task performance. Obviously the question that comes to mind is do we have capability to do multi-tasking ? Are we, evolutionarily endowed with the mental and physical capacity to do multi-tasking successfully ?

Although human interest and fascination in multiple-task performance dates back to the cradles of civilisation, Psychology which is largely influenced by cognitive paradigm these days, has naturally explored this aspect since its beginning in 1960s. Studies in multiple-task performance has share and overlap its boundaries with studies in attention and reaction time. Even basic philosophical issues about the nature of mind and matter have influenced theorisation in this field. Most used experimental approach to study multiple-task performance is psychological refractory period, which till date has been rampant with equivocal findings, competing theories and conflicting conceptualization.

Meyer and Kieras (1997) proposed a Computational Theory of Executive Cognitive Processes and Multiple-Task Performance. This computational theory accounted for a lot of equivocal findings in psychological refractory period studies. Present research aims at examining assumptions of this theory under different experimental conditions empirically and extends it to truly multiple-task situations.

This chapter presents philosophical, conceptual foundation of multiple-task performance along with detailed presentation of Executive Process Interactive Control (EPIC) theory, and Strategic Response Deferement (SRD) model of Meyer & Kieras (1997). First part of this chapter begins with the discussion of trends in theories of mind - classical and modern. One of the theories, Computational Theory of Mind (CTM), is discussed in detail in terms of its assumptions and successful theorisation. Second part discusses some major areas of study inspired by CTM viz., attention, reaction time and multiple-task performance and how three are inter-linked with each other. This is followed by discussion of Psychological Refractory Period (PRP) - an experimental approach of studying attention, reaction time and multiple-task performance together. It also discusses a typical PRP experiment, relevant empirical findings of different studies and major trends in theorisation of multiple-task performance.

Third part of the chapter discusses one of the recent computational theories of multiple-task performance, namely, Executive Process Interactive Control (EPIC). Details of the theory included here are : (1) Five features of EPIC, (2) Assumptions about EPIC components, (3) Modelling of human performance with EPIC in terms of single task and multiple-task performance, (4) The Strategic Response Deferment model (SRD), (5) Algebraic description of theoretical and simulated Reaction Times (RTs), (6) Theoretical PRP curves, and (7) Protocol for simulations with SRD model.

Fourth part discusses concepts of cognitive and affective styles as method of acting or performing, along with different types of styles. This part also discusses how the stylistic concepts could be of relevance to studies in multiple-task performance. The last part details the overall purpose and applicability of present research.

1.1 THEORIES OF MIND

While contemplating nature of reality, philosophers and scientists alike, have inevitably stumbled upon duality of the nature i.e. mind and matter, physical and mental processes, body and mind. Apparently physical events and mental events appear to belong to separate realms of existence and therefore has led to varying metaphysical assumptions about the dual nature of reality. Based on Colman (2001) classical views (before cognitive revolution in 1960s) about the nature of reality are summarized here.

1. **Monism :** This unitary concept of nature of reality denies the duality. According to this view "there is no essential difference between the mental and physical realms". Different forms of monism are -

   a. Neutral Monism : "This is a version of monism, asserting that the mental and the physical are both constructs of the same elements that are in themselves neither mental nor physical".

   b. Materialism : According to this view "only the physical realm is real and mental phenomena are merely functions or aspects of it". This is also known as Property Dualism.

   c. Identity Theory (IT) : This is a "form of materialism holding that mental states have no separate existence but are identical to physical brain states.

d. Double-aspect Theory : According to this view "mental and physical phenomena and processes are not two different kinds of things but rather different aspects of the same thing, just as a cloud and a mist are the same thing seen from different vantage points, or the morning star and the evening star are the same thing (the planet Venus)".

2. Dualism : According to this view "reality comprises two realms of existence, usually identified as mind and matter, or types of entities, mental and physical". Different forms of dualism are -

a. Cartesian Dualism : This view propounded by Rene Descartes (1644) who emphasizes that "mental experiences are functions of the soul and, because soul is immaterial, that they cannot be located in any particular organ of the body, but that the soul and the body influence each other, and that the seat of soul-body interaction is the pineal gland".

b. Epiphenomenalism : According to this view mind-body is "a form of dualism and one way interactionism, assuming as it does that mental experiences are real but are merely trivial by-products or epiphenomena of one particular class of physical brain processes, real but incidental, like smoke rising above a factory, so that physical processes can cause mental experiences and not vice versa".

c. Interactionism : This is a "form of dualism according to which events or processes in the mental and physical realms influenced or interact with each other".

d. Psychophysical Parallelism : This view propounded by Leibnitz (1646-1716) is a "form of dualism according to which mental and physical processes are perfectly correlated but not causally connected, like the movements of two clocks standing side by side. It is also called parallelism.

3. Linguistic Behaviourism : This view was mainly initiated by Wittgenstein, Ryle and Malcom. "It holds that mental concepts refer to behaviour and behavioural dispositions. A disposition is a tendency to behave in a certain way in certain circumstances; for instance, glass being brittle is a disposition, meaning to shatter when hit. Referring to someone as intelligent means that she will behave in certain ways under certain conditions; for instance, that she will score high marks in mathematics, that she will win a game of chess etc. The concept of intelligence as we use it in daily life does not refer to an inner mechanism of immaterial cogs and wheels but it serves to describe and predict behaviour. No reference to the inner life of a ghostly Cartesian mind-substance is needed" (Sacha Bem & Looren de Jong H., 1997).

Above classical views about the nature of reality, were either replaced or modified by modern views. "Contemporary views are strongly influenced by the ascent of computer models and more recently neuroscience" (Sacha Bem et al, 1997). Modern views of mind focuses on the characteristic nature of mind. The distinct characteristics of mental processes which distinguish them from physical processes are considered to be a) intentionality and b) consciousness. Consciousness is either considered as an activity, to some extent creating itself (Van Rappard, 1979) or as qualia, pure experiences or sensations : how it feels to have pain, or to see red" (Sacha Bem et al, 1997). Until 1990s importance of consciousness in theorisation about mind was less and attention was focused more on concept of intentionality.

Intentionality is "the property of mental experiences whereby they refer to objects or entities outside themselves : it is impossible to hear without hearing a sound, to believe without believing a statement or a proposition, to hope without hoping for something, to strive without striving for goal, to feel joy without feeling joyful about something, and so on. The concept was introduced by Brentano (1874), to distinguish psychological from physical phenomena, which lacks this property of outward-directedness" (Colman et al, 2001).

Theories of mind after cognitive revolution in 1960s assumed a materialist view on nature of mental processes. The ideal was to "understand intentionality as a property of natural systems, something that at least biological organisms can have, and perhaps machines and computers too, and to explain it in mechanistic, computational or biological terms" (Sacha Bem et al). Thus, rather than considering mind stuff or mental processes as mysterial or undefinable entity, the purpose was to naturalize the intentionality. In that process there emerged two distinct viewpoints about mental processes viz. mechanistic or cognitivists and anti-cognitivists or non-cognitivists.

Cognitivists or mechanistic theories have mainly considered "mind as a mechanical system, to be understood according to laws of the physical universe (Crane, 1995). Anti-cognitivists have mainly criticized the dualism of mind and body, organism and environment. Major theories of this nature are ecological psychology, phenomenological psychology, social constructionism, Hegelian and Vygotskian influences. Some other theorists have criticized the cognitivist successfully without presenting an alternative viewpoint such as Searl, Dreyfus, Arthur Still and Costall. Anti-cognitivist theories generally came up around 1990s.

Mechanistic or cognitivist theories in the beginning (after 1960s) assumed representational stand which was later in 1990s abandoned and a new set of theories were developed which were called nonrepresentational theories. Thus, mechanistic theories could be divided in two broad classes : representational theories and nonrepresentational theories. Representational theories assumed that "mental representations and mental computations constitute the machinery of the mind" (Sacha Bem et al). Therefore these views were called computational approaches to mind. Whereas nonrepresentational views assumed that mind "is not really a representation and hence there is no computation : there are no processing steps, algorithms or sequences of discrete operations or sub-tasks. Rather, it can be mathematically described as a dynamic system, in terms of equations that describe the changing of its states in numerical values" (Sacha Bem et al, 1997). Above theories of mind can be represented as under :

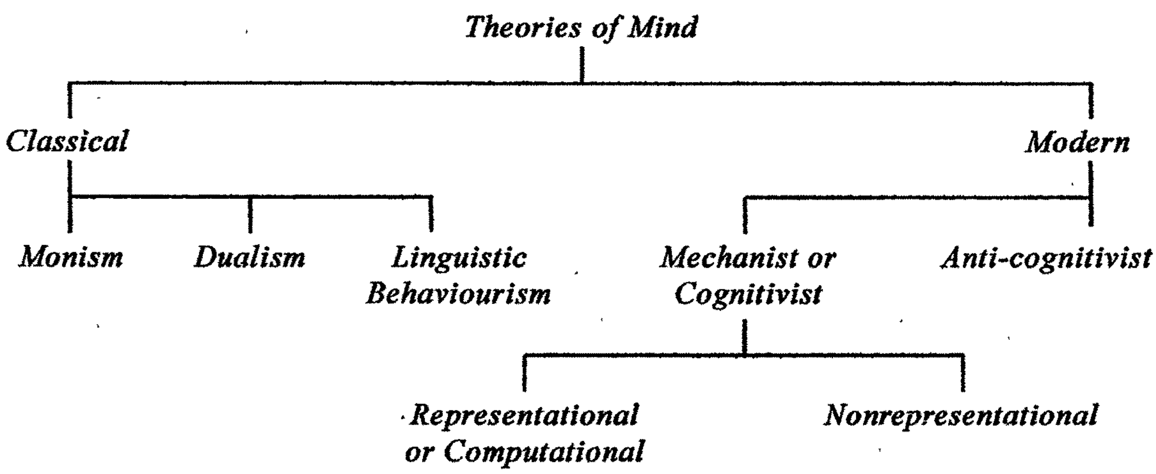

Fig. 1 Theories of Mind

1.2 COMPUTATIONAL THEORY OF MIND (CTM)

Computational approach to mind, as mentioned earlier, considers mental representations and mental computations as two main aspects of mind. Principal assumptions of computational approach are :

1. Key characteristic of mind is intentionality, as defined by Brentano (1874).

2. Mental representations are the stuff that makes up the mind.

3. Intentionality of mental representations require symbols, as symbols are the only known bearers of meaning we know.

4. Mental computations are combining and crunching of symbols or mental representations. Thus mind is a symbol manipulator and cognition is symbol manipulation.

4. Symbols can be combined according to strictly formal rules.

5. The process of combining or crunching of symbol is called computation.

6. Since computations are strictly formal, algorithmic they could be mechanical.

7. As mind is a symbol manipulator, mind is also mechanical or computational.

8. Besides, as mental processes are instantiated in material processes (brain), there is no such things as disembodied or non-physical thoughts.

9. As it is possible to know the way a computer program e.g. Word works, without knowing anything about hardware, similarly it is possible to know how cognition works without studying neurophysiology (wetware).

10. Physical substrates of cognition may be different for different individuals, species and systems and therefore cognition could be realized in any system, not necessarily in mind. Functionalism defines this as multiple realizability. Hence we could study cognitive processes in artificial systems also. Such systems are said to possess artificial intelligence.

11. Artificial intelligence is implemented by Universal Turing Machine which is a general purpose symbol manipulator.

12. Universal Turing Machine executes any specific series of mechanical operations, an algorithm. Such procedures or programs have a cause force i.e. they execute intelligent behaviour by manipulating symbols according to strictly formal rules.

13. As mind is symbol manipulator and symbol manipulation is strictly formal. Contents

of mind, meaning or reference to environment are not the subject matter of cognitive science. Computational approach considers that although environment causally affects the body e.g. sensations, we only have to look at the individual system and not its environment. Thus computational approach holds in essence that only processes inside the organism can be studied. In this view psychology 'ends at the skin'.

14. The laws of psychology are intentional. They explain behaviour by citing mental content, the goals and desires an organism has; and that these are implemented in computational mechanisms. The harmonious relationship between the mechanism and meaning is contingent and not necessary. "The computational mechanisms have a causal history of interactions with the world that generally connect current outcome of the syntactic mechanisms with the right behaviour in the environment, that is, preserve the meaning or content of a belief or desire over a series of formal computations.

Such a computational approach to mind has been a base of much theorisation in psychology in general, and cognitive sciences in particular. There are several variations of CTM, however, almost all of them have one commonality, i.e. to consider computer as the most resembling metaphor so far as the understanding of human mind is concerned. Theorizing in CTM focuses on conceptualization of computational architecture which can instantiate human like processes through simulation and modelling. The more resembling the simulation or model is, more acceptable it is as a sound theory. Basic concepts of such theory are parallel distributed processing, information processing architecture, executive processes etc. Computational theories of perception, memory, thinking, intelligence, decision making and of mind are most successful examples of the same. Of this all examples, one interesting example of computational approach is attention.

2.1 ATTENTION

Attention has remained central topic in experimental psychology since its inception. There has been many trends in the researches related to attention especially after 1950, i.e. beginning of cognitive psychology. The result of these trends is the cumulative progress in the understanding of attention. As Logan G. D. (2004), puts it, "In the 1950s and 1960s, the focus was on selective listening. In the 1970s, it was automaticity and dual-task performance. In the 1980s, it was visual search, negative priming, and cuing. In the 1990s, it was the psychological refractory period and the attentional blink. Since the turn of the century, the focus has been on task switching."

Broadly speaking, the theories of attention have focused on three aspects, namely, (1) attention to dimension, (2) attention to objects, and (3) executive control of attention. Attention to dimensions experiments were characterized by a filtering task that examines subjects' ability to ignore changes in irrelevant dimensions. For example, subjects may judge the height of rectangles while attempting to ignore their width.

Attention to object essentially involves a visual search task in which a subject is faced with a display of many objects and must decide whether the display contains a target object. Whereas study of executive control of attention focuses on how do we optimize our performance by controlling our attentive processes. "Executive control is the process by which the mind programs itself. It is involved in understanding instructions, choosing among strategies, preparing and adopting a task set, monitoring performance, and disengaging task sets.....A key idea in many studies of executive control is that an executive process programs subordinate processes. " (Logan G. D., 2004).

Computational models related to attentive processes in 1990s focused on concurrent tasks and their relationship with psychological refractory period. Such models aimed at understanding of attention in terms of central resources, executive processes and resource allocation strategies in concurrent task situations under varying conditions. Before considering details of psychological refractory period further it is necessary to have some details about reaction time and multiple task performance.

2.2 REACTION TIME

Reaction time..."the great discovery of the 'new' psychology, because it appeared to give rise to a chronometry of mind" (Boring, 1950), has fascinated psychology since antiquity. According to Luce (1986) "reaction time is psychology's ubiquitous dependent variable". In fact, reaction time was one of the three empirical concepts viz. sensation, perception and reaction time, that imparted unique identity separate from philosophy, to the psychology as a new science.

Leipzig Laboratory, emphasized the importance of attention processes, besides expectation, and preparation while studying reaction time. Thus, enthusiastic studies in the field of reaction time soon revealed that reaction time can actually throw light on the mental activities and mental organisation both, quite empirically. However, Luce

(1986) has shown concern, "let me admit at the outset that there are reasons to be skeptical of the enterprise. Consider the task of inferring the architecture of a computer from measurements of its performance times using different programs and different inputs. This certainly would be difficult, especially if one lacked the technology of modern electronics to help carry out the measurement. At best, one would expect to learn something about the gross organization of the computer, but it seems unlikely that the fine details would succumb to such an attack".

Nevertheless, just within two decades, psychology has been making a Herculean effort to work out fine details of the working of human mind precisely on the basis of reaction time studies. Of course, these endeavours are being supported by (a) a host of interdisciplinary researches in cognitive science, neurology and artificial intelligence, and, (b) technology both of measurement and brain imaging. Computational approach to human mind has extensively used reaction time findings to formulate computational theories of mind, especially micro theories of human cognition. One such area is Multiple Task Performance.

2.3 MULTIPLE TASK PERFORMANCE

Humanity has always seen multiple-task performance with an awesome wonder. Anecdotes about such performance have been recorded in the history. A classic example in Indian history is that of Haider Ali (father of Tipu Sultan), who has been claimed to be capable of listening to seven people at the same time at his court. Another example is that of Shrimad Rajchandra, the teacher of Gandhiji, who is known for having demonstrated in presence of then British Judges of Bombay Court a yogic skill "शतावधानी", a capacity to do multiple tasks together. Innumerable examples of yogis demonstrating such skills are there in the collective unconscious of Indian mind.

The subject matter has gained more importance in the current milieu which is characterised by technological advancement and demand for highly effective performance especially from modern age executives. This is because a person's ability to cope with such situations depends on how information processing is coordinated across the task at hand, and the success or failure of this coordination can have significant consequences under a variety of real world circumstances. (Meyer & Kieras, 1997).

Intellectual curiosity in multiple-task performance has resulted into a plethora of methodological procedures, empirical findings and theoretical constructs (Atkinson, Hernstein, LIndzey, & Luce, 1988; Damos, 1991; Gopher & Donchin, 1986; Meyer & Kornblum, 1993). Multiple-task performance is generally studied in the Psychological Refractory Period Paradigm. However till date, we do not have any comprehensive theoretical framework for understanding of multiple-task performance (Allport, 1993; Broadbent, 1993).

2.4 PSYCHOLOGICAL REFRACTORY PERIOD

Colman (2001) defines psychological refractory period as "A period following a response to a stimulus during which reaction time to a further stimulus is increased." Whereas Pashler H., Johnston J. C., and Ruthruff E. (2001) define it as "The psychological refractory period (PRP) effect refers to a ubiquitous and often large slowing effect observed when people try to perform two speeded tasks close together in time (each task involving a choice of responses based on a distinct stimulus). While responses to the first-presented stimulus are often little affected by temporal proximity to the second task, responses to the second stimulus are usually slowed as the interval between stimuli is reduced. The increase in second task RTs as the interval between stimuli is reduced in the most commonly used measure of the magnitude of the PRP effect." Telford in (1931) while doing a reaction time study of two consecutive task as given below -

Task 1 (T1)	-	auditory tone	Response 1 (R1)	-	key-press
Task 2 (T2)	-	visual cue	Response 2 (R2)	-	naming

found that if relatively short interval (0.5 second or less) separated the stimulus from the next stimulus for a subsequent response, then the reaction time of the subsequent response i.e. R2 increased relative to ones with a longer interval (1s or more). This was termed as Psychological Refractory Period (PRP). Craik (1948) also reported that manual tracking of moving visual targets produced discrete intermittent responses separated by 0.5 seconds.

This intermittency was confirmed by Vince (1948). This led Craik to speculate that "the time lag is caused by the building up of some single computing process which then discharges down the motor nerves ....new sensory impulses entering the brain while this central computing process is going on would either disturb it or be hindered from disturbing it by some 'switching system' ....there is a minimum interval within which successive stimuli can not be responded to."

2.5 A TYPICAL EXPERIMENTAL DESIGN FOR PRP

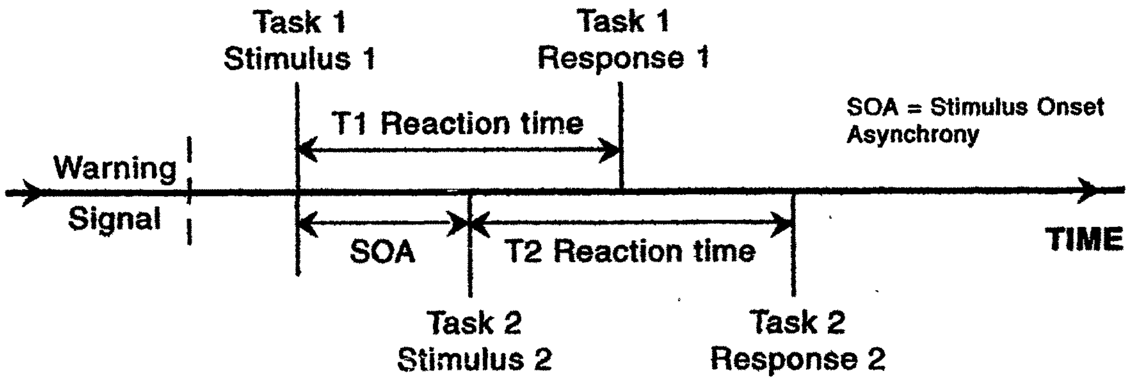

Fig. 2 A typical PRP experiment procedure

"The PRP procedure involves a series of discrete test trials (see figure 2). On each trial, a warning signal is followed by a stimulus (e.g. a visual letter or auditory tone) for the first of two tasks. In response to it, a participant must react quickly and accurately (e.g. by pressing a finger key or saying a word). Soon after the Task 1 stimulus, there is another stimulus for the second task. The sensory modality and semantic category of the Task 2 stimulus may or may not differ from those of the Task 1 stimulus. The time between the two stimuli is the Stimulus Onset Asynchrony (SOA), which typically ranges from 0 to 1 second. In response to the Task 2 stimulus, the participant again must react quickly and accurately. The effector used to make the Task 2 response may or may not differ from that for the Task 1 response. In any case, instructions for the PRP procedure typically state that Task 1 should have higher priority than Task 2 : they also may urge participants to make the Task 1 response first. RTs are measured to determine how much Task 1 actually interferes with the performance of Task 2.

Variations of PRP experiment design would consider following as variables -

1. Tasks could be of Simple Reaction Time or Choice Reaction Time

2. Tasks could be such that they have Stimulus-Response compatibility e.g. stimulus presentation on right side and response with right hand.

3. Tasks could vary in Sensory modality e.g. one task with auditory stimulus and another with visual stimulus.

4. Tasks could vary in Stimulus-Response numerosity e.g. response in terms of

multiple tapping or single tapping, or stimulus could be one or more than one.

5. Effectors used in responding could vary e.g. hand, speech etc.

6. Task priorities in responding e.g. Pashler (1984) instructed the subject "to respond as quickly as possible to both tasks in the two-task blocks, with the restriction that the first stimulus must be responded to before the second. Similarly in an another study Pashler and Johnston (1989) instructed subjects to "respond as quickly as possible to the first stimulus.

2.6 FINDINGS OF PRP AND RELATED EXPERIMENTS

1. Task 2 Reaction Time is higher at short SOA than at long SOA. (Davis, 1956, 1957; Vince, 1949; Welford, 1959).

2. The slope of the PRP curve equalled -1 at short SOAs; that is for each unit of time that the SOA decreased, the Task 2 reaction time correspondingly increased. (Davis, 1956, 1957; Vince, 1949; Welford, 1959).

3. PRP effect at zero SOA equalled the mean Task 1 RT.

4. At zero SOA PRP effect has not always equalled mean Task 1 reaction time but significantly less also. (Karlin & Kestenbaum, 1968).

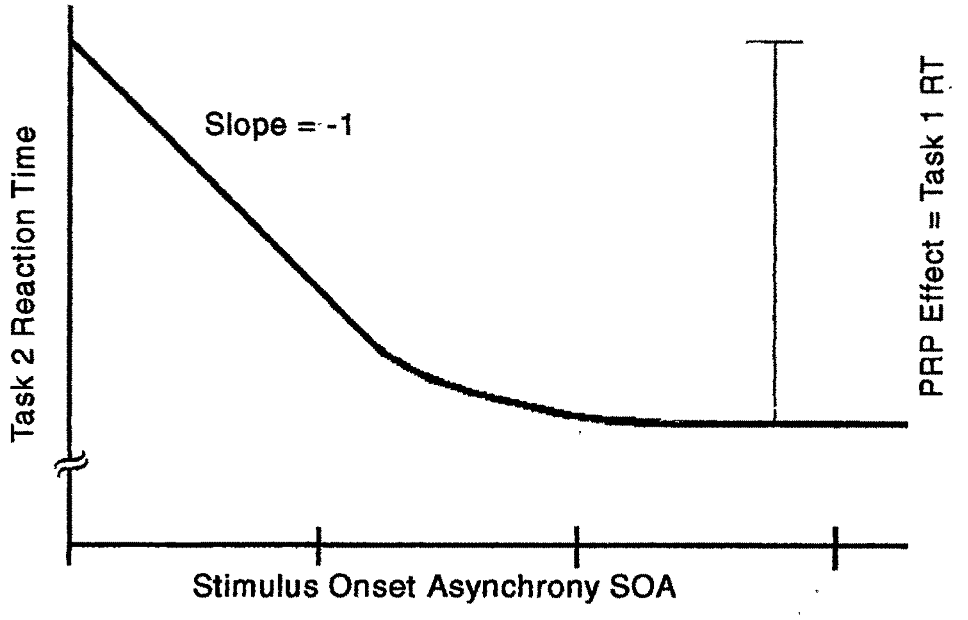

Fig. 3 A typical PRP curve

5. Studies have shown that subjects can notice significant amount of semantic information in unattended auditory messages. Thus, stimulus identification could perhaps proceed in parallel also.

6. PRP effect and reaction time are function of difficulty of response selection of Task 1 i.e. as response-selection difficulty of Task 1 decreases, PRP effect decreases. If Task 1 involves very simple response or no response, PRP effect becomes null.

7. PRP effect and reaction time are function of Task 1 S-R numerosity. When Task 1 S-R pairs increases PRP effect and Task 1 reaction time increases.

8. PRP effect and reaction time are function of S-R compatibility of Task 1. When Task 1 stimulus-response incompatibility is increased Task 1 reaction time and PRP effect increases.

9. Task 1 S-R compatibility effects are additive with the factors related to stimulus identification stage (stimulus legibility) and movement production stage (response probability).

10. Response selection stage has been found to be the locus of Task 1 S-R compatibility effects and S-R numerosity effects. Such effects are generally found to be interactive.

11. PRP effect and reaction time are function of difficulty of response selection of Task 2. There is an interaction effect between SOA and Task 2 response selection difficulty. Task 2 RTs at long SOA are greater under choice RT condition than under simple RT condition whereas no difference occurs between Task 2 RTs for both these conditions at short SOA. PRP effect is less in Task 2 choice RT in comparison to Task 2 simple RT.

12. SOA and S-R numerosity have additive effects on Task 2 RTs i.e. the difference between Task 2 RTs involving simple reaction and choice reaction were same at both short SOA and long SOA.

13. SOA and factors that influence Task 2 response selection have been found to have additive effects.

13. Task 2 factors have indirect effects on Task 1 performance. Participants are sometimes faster at performing a given task alone than at performing it as the first of two tasks (Gottsdanker, Broadbent, & Van Sant, 1963; Herman & Kantowitz, 1970).

14. Task 1 RTs sometimes increases with the number of S-R pairs in Task 2 (Karlin & Kestenbaum, 1968; Smith, 1969).

15. Occasionally, Task 1 RTs increase when SOAs are short rather than long (Gottsdanker & Way, 1966).

16. Generally, for any factor that influences a Task 2 stage of processing before the locus of the bottleneck, its effects on Task 2 RTs should interact with those of the SOA. For any factor that influences the bottleneck stage or other subsequent stages of Task 2, its effects on Task 2 RTs should be additive with those of the SOA.

17. Difficulty insensitivity : Varying the nominal difficulty of a primary task has little or no effect on participants' performance of a concurrent secondary task (e.g. primary visual manual choice reaction along with secondary digit cancellation task or visual manual tracking task).

18. Structural alteration effect : This effect occurs 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 tasks and, (b) this change does not increase the primary task's difficulty (e.g. primary task of manual or vocal response to auditory tones and secondary task of visual manual tracking task). Such effects have been obtained by changing primary-task response modality, stimulus modality and mental imagery code.

19. Difficulty-structure uncoupling : This occurs when structural alteration effect reduce the interference between the primary and secondary tasks at the same time as the primary task difficulty actually increases (e.g. primary auditory signal detection task or manual force generation task and secondary visual manual tracking task. This leads to more interference due to easier task than due to difficult task.

20. Perfect Time Sharing : This occurs when neither of two individually demanding tasks interferes with the other during dual-task performance (e.g. simultaneous shadowing of spoken message and playing of piano music from written scores).

THEORIES OF MULTIPLE-TASK PERFORMANCE

Several modern theoretical perspectives on multiple task performance in PRP paradigm are :

1. *Single Channel Hypothesis*

Welford (1952) proposed that "The refractoriness is in the central mechanisms themselves .....It is due to the processes concerned with two separate stimuli not being able to coexist, so that the data from a stimulus which arrives while the central mechanisms are dealing with the data from a previous stimulus have to be "held in store" until the mechanisms have been cleared."

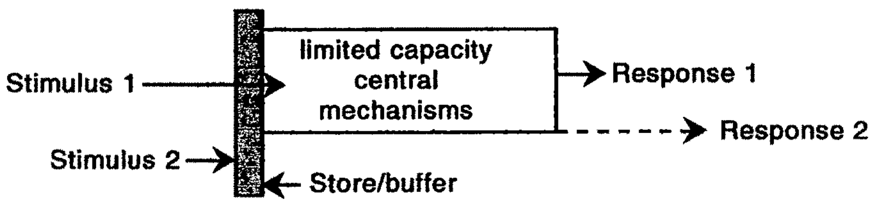

Fig. 4 Diagrammatic representation of Single Channel Hypothesis

Craik (1948) and Welford (1952) did not differentiate among the intervening mental processes in terms of different stages of mental processes. Rather they considered all the intervening mental processes as a single stage. and hence a single channel and therefore, the Single Channel Hypothesis can be termed as a Global Single Channel Hypothesis also.

Subsequently following three stages were proposed as intermediate stages which are composite of a set of intervening mental processes, viz. "Stimulus identification, Response selection, and Movement production stages in human choice RT (Sternberg, 1969). These three stages have been defined by Meyer & Kieras (1997) as -

1. *Stimulus Identification (SI)* : It "refers to perceptual and memory processes that convert an initial sensory code to an abstract symbolic code for a stimulus".

2. *Response Selection (RS)* : It "refers to a subsequent process that converts the stimulus code to an abstract symbolic code for a physical response based on some set of innate or previously learned stimulus-response associations".

3. *Movement Production (MP)* : It "refers to a process that converts the symbolic response code to commands for the motor effector system through which the response is physically produced".

"In terms of these definitions, there may be some cases in which stimulus identification and response selection are either equivalent or closely related processes, leading to systematic patterns of facilitation and interference effects, as has been found during studies of the Stroop phenomenon (MacLeod, 1991) and stimulus-response compatibility (Kornblum, Hasbroucq, & Osman, 1990). Nevertheless, in many other cases, the stimulus-identification and response-selection stages may be logically distinct and temporally separate from each other, especially if the prevailing stimulus and response codes have no obvious similarities" (Meyer & Kieras, 1997).

When these three stages were depicted as intermediate stages of PRP experiment, the new experimental design for PRP effect became as given below -

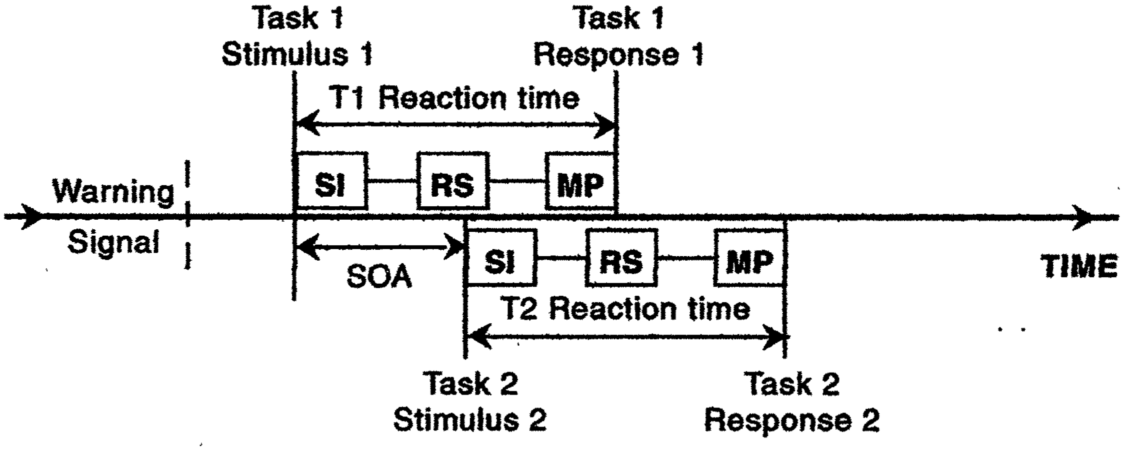

Fig. 5 Diagrammatic representation of PRP experimental procedure along with intermediate stages

Identification of these three intermediate stages led to three more theoretical models as under :

2. Perceptual Bottleneck Model

This model supposes that "the process that identifies stimuli (i.e. converts raw sensory representations to symbolic stimulus codes) and determines their meanings is limited. For concurrent tasks, this limit could force people to deal with only one task at a time. However, the perceptual bottleneck model makes no specific claim about what, if any, constraints exist on subsequent processes (e.g. response selection and movement production) after stimulus identification; therefore, it also has been called the Early-selection theory" (Meyer & Kieras, 1997). A special case of this theory is Broadbent's Filter Theory of Attention.

3. *Response Selection Model*

As per this model, multiple stimuli may be identified simultaneously. On the basis of identification the stimuli are selected for transmission to other stages such as conscious attention, memory storage, response selection and movement production. The interference effect arises in any one of this stage. Therefore such theories are also termed as Late-selection theory. Pashler (1984, 1990, 1993, 1994), Smith (1967) and Welford (1967) proposed response-selection bottleneck model. This theory assumed that stimulus identification occurs in parallel and then sent to working memory for response selection. The response selection process is able to accommodate only one task at a time and so there occurs a slack of time at this stage.

4. *Movement Production Bottleneck Model*

This model is also called Response Initiation Postponement Model. This model assumes that both stimulus identification and response selection can proceed simultaneously but there is bottleneck at movement production level. This process requires a lower priority task to wait temporarily until a higher priority task is completed.

As more empirical evidence were made available, dissatisfaction with these bottleneck theories lead to development of two new theory as given under -

5. *Unitary Resource Theory*

There are several versions of this theory. However, the central idea is that "multiple task performance is mediated by a mental commodity needed for various tasks, and this commodity is quantifiable, divisible, allocatable and scarce (Wickens, 1991). A representative model is of Kahneman (1973). Kahneman's (1973) theory is based upon four assumptions about the nature of available processing capacity as under :

1. Attention is a capacity, though limited but variable and is indicated by level of physiological arousal from moment to moment.

2. The amount of attention exerted at any time depends upon the demands of current activities.

3. Allocation of attention is a matter of degree and is contingent upon task load. At higher task load allocation becomes unitary.

4. Attention is selective and controllable. Allocation of attention is determined by disposition and temporary intention.

5. Multiple task performance also depends upon peripheral and central structures such as sensory receptors, memory stores and motor effectors. Thus, performance decrements occurs due to competition for access to such structures and it reflects structural interference. Nevertheless the theory emphasizes capacity interference due to demands on an overloaded supply of central processing capacity.

Considerable evidence supports Kahneman's Unitary-Resource Theory. "If multiple-task performance involves the flexible graded allocation of limited processing capacity to various competing processes, then performance decrements should emerge on a regular basis, but their apparent locus could and would fluctuate in response to differential task demands, as investigators have amply demonstrated through the PRP procedure" (Meyer & Kieras, 1997).

6. *Multiple Resource Theory*

This theory assumes that various disjoint sets of processing resources are used in combination for performing individual tasks. Each set of resources is assumed to have its own separate divisible source of capacity. If two or more tasks require the same set of resources, the capacity available to them is supposedly allocated in a flexible graded fashion depending on current task requirements. Consequently, the tasks may all be performed at the same time, albeit with a reduced rate of progress on each one relative to single-task conditions. By contrast, if each of two or more tasks requires an entirely different set of resources, progress on them may proceed simultaneously without any interference because there is no need to share the same capacity among tasks.

Thus, there are diverse theorisation of multiple task performance leading to diagreeement and confusion. Newell (1973) while suggesting a possible unification of diverse concept stated that -

"Construct complete processing models rather than the partial ones we now do...[These models should be] embodied in a simulation, actually carry out the experimental task....[and have] detailed control structure coupled with equally detailed assumptions about memory and elementary control processes....in the same fashion as discovering a program in a given programming language to perform a specified task....The attempts in some papers to move toward a process model by giving a flow diagram....seem...not to be tight enough."

Allport (1993), also stated that -

"What is urgently needed is....a computational theory, in the sense outlined by Marr (1982), of the many different functions of attentional selectivity and control....taking seriously the ideal that attentional functions are of many different kinds, serving a great range of different computational purposes."

While Broadbent (1993) stated that -

"We need computational theories of interaction between stages. As the number of theoretical entities increases in each area, it becomes increasingly hard to see the implications of combining them. Only computational systems can do this, and they will have the merit of stopping the laxness of definitions noted by Allport."

Newell (1973), Allport (1980), J. R. Anderson (1976, 1983, 1990, 1993), Hunt & Lansman (1986), Laird, Newell & Rosenbloom (1987), Logan (1985), Seifert & Shafto (1994), and Townsend (1986) have suggested that the form of such computational model should be like production system (i.e. sets of condition-action rules that manipulate the contents of working memory and regulate input-output activities), as such form provides a powerful descriptive computational modelling tool. Broadbent (1993) has remarked that production systems are an especially useful formalism for multiple-task performance because they enable flexible shifting of task goals, context-dependent application of condition-action rules, and other operations for coordination of concurrent tasks. Secondly, computational models also requires specification of a general integrated information-processing architecture wherein different components have been clearly delineated. Such architecture shall obviously constrain the programmable components of the performance from one context to another.

Taking the lead Card introduced MHP (Model Human Processor) to model human-computer Interaction. Newell (1990) implemented SOAR system for computational models of learning, memory and reasoning. Whereas, Anderson (1983, 1993) proposed ACT* (Adaptive Control of Thought) and ACT-R architecture for the same. Obviously, specification of such architecture for multiple-task performance shall be of great help.

Besides, as part of architecture, detailed perceptual-motor processors must be included. As Allport (1980) puts it, "The constraints of the human body sets upper limits on the degrees of freedom of our physical action. A limb can not be in two positions at once. We can not shift our gaze simultaneously to right and left, nor vocalize two different syllables at the same time....Certainly, many of the phenomena attributed hitherto to 'attentional' or 'general capacity' limitations can be seen to depend on situations in which separate inputs compete for or share control of the same category of action.....It may be that, until we have a better description of what is being done by at least some of the subsystems, questions about the overall architecture will just be premature".

Various task strategies used by people in various situations could be analysed considered while preparing the model. Newell (1973) states that "The same human subject can adopt many radically different methods for the same basic task, depending on goals, background knowledge, and minor details of payoff structure....To predict a subject you must know : (1) his goals; and (2) the task environment....Until one has a model of the control processes....we will not be able to bring the problem of specifying subjects' methods under control". Neisser (1967) suggests executive processes as the control mechanism - "If we do not postulate some agent who selects and uses...stored information, we must think of every thought and every response as just the momentary resultant of an interacting system, governed essentially by laissez-faire economics. Indeed, the notions of 'habit strength' and 'response competition' used by the behaviourists are based exactly on this model. However, it seems strained and uncomfortable where selective thought and action are involved....Today, the stored-program computer has provided us with an alternative possibility, in the form of executive routine. This is a concept which may be of considerable use to psychology....Common practice is to make all subroutines end by transferring control to the executive, which then decides what to do next in each case....The executive may take only a small fraction of the computing time and space allotted to the program as a whole, and it need not contain any very sophisticated processes". Some interesting propositions for functions of executive processes are GOMS technology (goals, operators, methods, and selection rules) and

Critical-path analysis for representing temporal relations among serial and parallel component processes in interactive processing systems.

Last but not least, limited-capacity assumption should be dropped as it can be justified from neurophysiological considerations. To summarize, current status of theorisation in multiple-task performance requires following considerations -

1. Construction of computational models
2. Use of production system formalism
3. Specification of general integrated information-processing architecture
4. Specification of perceptual-motor processors
5. Analysis of executive processes
6. Omission of limited-capacity assumption

Meyer and Kieras (1997) proposed EPIC architecture specifically to implement multiple task performance. Later, in 2001, EPIC was modified to characterize the supervisory functions of executive mental processes.

3.1 EXECUTIVE PROCESS INTERACTIVE CONTROL (EPIC)

"EPIC was introduced for characterizing human performance of concurrent perceptual-motor and cognitive tasks. On the basis of EPIC, computational models may be formulated to simulate multiple-task performance under a variety of circumstances. These models account well for reaction-time data from representative situations such as the psychological refractory-period procedure. EPIC's goodness of fit supports several key conclusions :

(a) At a cognitive level, people can apply distinct sets of production rules simultaneously for executing the procedures of multiple tasks;

(b) People's capacity to process information at "peripheral" perceptual-motor levels is limited;

(c) To cope with such limits and to satisfy task priorities, flexible scheduling strategies are used; and

(d) These strategies are mediated by executive cognitive processes that coordinate concurrent task adaptively.

Formal concepts and algorithms from contemporary computer operating systems can facilitate efforts to precisely characterize the supervisory functions of executive mental processes. In particular, by helping to advance work with the EPIC architecture, a theoretical framework for computational modelling of human multi-task performance, operating system fundamentals provide insights about how people schedule tasks, allocate perceptual-motor resources, and coordinate task processes under both laboratory and real-world conditions. Such insights may lead to discoveries about the acquisition of procedural task knowledge and efficient multi-tasking skills" (Kieras, Meyer, Ballas, & Lauber, 2000).

3.2 FIVE FEATURES OF EPIC

Five heuristic principles of EPIC are (1) Integrated information processing architecture (2) Production system formalism (3) Omission of limited-capacity assumption (4) Emphasis on task strategies and executive processes, and (5) Detailed treatment of perceptual-motor constraints. Details of each principle follows now -

1. *Integrated information processing architecture :* EPIC incorporates known characteristics of human information processing and performance. Figure 6 outlines principal components of EPIC. They consist of several complementary memory stores and processing units that interact with each other hetrarchically. The processing units are implemented as modules of instructions written in LISP, a programming language for symbolic computation in artificial intelligence. EPIC includes basically a long-term memory, working memory, perceptual processors, a cognitive processor, and motor processors. Details of several components are as under -

1. Virtual eye : It is a simulated physical sensor for vision.
2. Virtual ear : It is a simulated physical sensor for hearing.
3. Virtual touch : It is a simulated physical sensor for tactile sensation.
4. Declarative long-term memory : This store contains knowledge expressed as propositions, which embody the gist of the verbal descriptions about when, where, why and how to perform particular tasks.

5. Procedural memory : This memory contains sets of PPS production rules that instantiate procedural knowledge for actually performing the tasks. These rules may be derived through a process of "proceduralization" that converts declarative propositional knowledge to a directly executable form.

6. Working memory : This memory contains symbolic control information needed for testing and applying the production rules stored in procedural memory. Symbolic representations of stimulus inputs and response outputs also are stored in EPIC's working memory for use by the system's production rules. Presently, EPIC's working memory is depicted as a single store that contains various types of functionally distinct information. In other contexts, however, it would be more appropriate to treat working memory as having a number of separate partitions, in each of which the form, amount, and duration of the contents differ from those of the other partitions.

7. Visual processor : It receives inputs from simulated physical eye and sends output to working memory.

8. Auditory processor : It receives inputs from simulated physical ear and sends output to working memory.

9. Tactile processor : It receives inputs from simulated effector organs and sends output to working memory.

10. Cognitive processor : It relies on PPS production rule interpreter, which tests the conditions and executes the actions of production rules in procedural memory.

11. Vocal motor processor : It receives selected symbolic responses from cognitive processor to simulate vocal actions.

12. Manual motor processor : It receives selected symbolic responses from cognitive processor to simulate manual actions.

13. Simulated interaction devices interface between simulated sensors and task environment.

14. Ocular motor processor : It moves EPIC's eyes whose spatial position determines what inputs may enter the visual perceptual processors.

In EPIC task environment sends signals to the simulated interaction devices which in turn sends signals to the virtual physical sensors viz. virtual eye, virtual ear, virtual skin. Virtual physical sensory sends input to visual, auditory and tactile perceptual processor. These perceptual processors sends output to working memory, which is used by a cognitive processor to perform various tasks. The cognitive processor relies on the PPS production-rule interpreter, which tests the conditions and executes the actions of the production rules in procedural memory. Through this interpreter, the cognitive processor selects symbolic responses and sends them to vocal and manual motor processors, which prepare and initiate movements by simulated physical effectors. In addition, there is an ocular motor processor for moving EPIC's eyes, whose spatial position determines what inputs may enter the visual perceptual processor. With its various components, EPIC has capabilities to emulate a broad range of human perceptual-motor and cognitive skills.

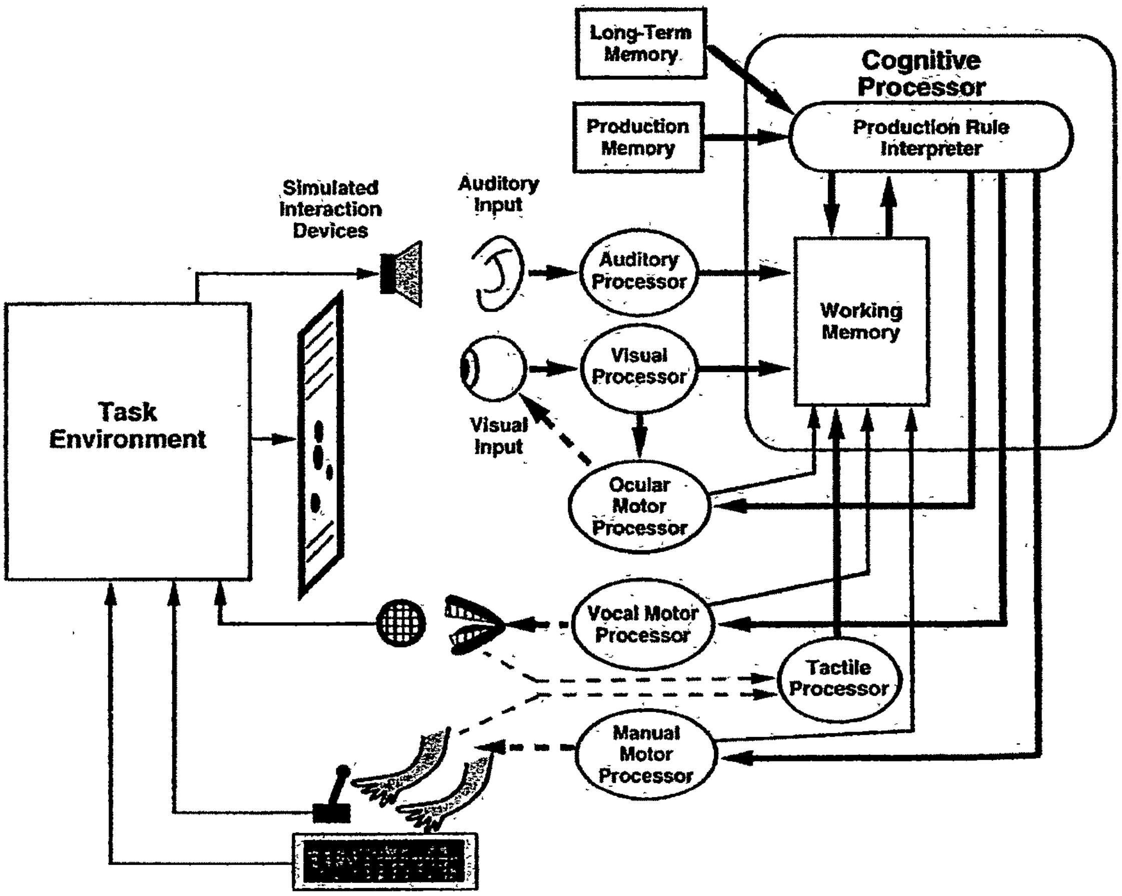

Fig. 6 Overview of information-processing components in the EPIC

2. *Production-system formalism :* EPIC adopts production-system formalism which allows specification of exactly what procedural knowledge is used to perform particular tasks separately and in various conditions. EPIC uses Parsimonious

Production System (PPS). PPS has a working memory, production rules expressed as condition-action (if-then) statements and a rule interpreter. The components of PPS are tailored to promote computational simplicity, clarity, flexibility and power.

PPS uses no complex conflict-resolution criteria or spreading-activation mechanisms to control which production rules are applied at a particular moment in time. Instead, the application rules in PPS depends solely on the rule's conditions and the contents of working memory. Whenever the condition of any PPS rule is satisfied by the current contents of working memory, all of its actions are executed immediately regardless of the status of other rules. To preclude simultaneous conflicting actions, the conditions of the rules must be defined such that two or more rules are never applied at the same time if their actions conflict. This is achieved in part by having rules' conditions include explicit steps, which help guide the sequence of rule applications.

Another important feature of PPS is that it enables substantial parallel processing. With the PPS production-rule interpreter, multiple production rules are tested at the same time, and all of their actions may be executed simultaneously whenever the conditions associated with them are mutually satisfied by the contents of working memory. This facilitates construction of computational models that omit central processing bottlenecks.

3. *Omission of limited processing capacity assumption :* EPIC does not impose obligatory upper bound on the number of tasks for which information may be processed centrally at the same rate as in single task situation.

4. *Emphasis on task strategies and executive processes :* EPIC attributes decrement in multiple-task performance to flexible strategies that people adopt to satisfy particular instructions about task priorities. Thus, role of supervisory executive processes have been emphasized.

5. *Detailed treatment of perceptual-motor constraints* : EPIC takes into account constraints of perceptual-motor processes on multiple-task performance based on empirical data.

3.3 ASSUMPTIONS ABOUT EPIC COMPONENTS

EPIC makes explicit assumptions about the symbolic representations, input-output transformations, and process durations needed to model human performance. The assumptions are guided by the desire to make EPIC parsimonious, precisely specified and consistent with empirical data. Assumed properties of EPIC's perceptual processors, motor processors, working memory and cognitive processor are as given below -

1. *Perceptual Processors :* Perceptual processor uses simple table lookup in transforming sensory inputs to symbolic perceptual outputs (e.g. stimulus identities). EPIC has not yet implemented complex pattern-recognition algorithms as part of the perceptual processors because this is not necessary to achieve its current theoretical objectives. Perceptual processor makes assumptions about temporal relations among perceptual operations and the activities of other processing units; the forms of input and output used for stimulus detection and identification; and the magnitudes of the processing time taken in going from input to output. The assumptions are about following properties :

(a) Temporal relations : EPIC's perceptual processors provide direct "pipelines" between the external environment and working memory. For each modality (e.g. vision, audition, and touch), transformations from sensory inputs to perceptual outputs occur asynchronously, in parallel with operations by the cognitive and motor processors. Sensory inputs may enter the perceptual processors at any moment; perceptual outputs are temporally offset from the inputs by parametrically specified amounts of time.

(b) Forms of input and output : The inputs to EPIC's perceptual processors are assumed to be physical stimuli (i.e. categorizable objects and events) presented through simulated display devices (e.g. a virtual CRT screen) for each relevant sensory modality (e.g. vision, audition, and touch). After a stimulus arrives at a perceptual processor, the processor sends symbol strings to working memory, first indicating that a stimulus has been detected in a particular modality (e.g. AUDITORY TONE ONSET) and later specifying its identity (e.g. AUDITORY TONE 800 ON). Symbols denoting other relevant stimulus features (e.g. size, shape, colour, loudness, etc.) also may be placed in working memory by the perceptual processors.

(c) Perceptual transmission times : In EPIC models, numerical parameter values are assigned to the times taken by each perceptual processor for sending stimulus detection and identification symbols to working memory. Typically, the detection times would be short and depend on factors such as stimulus intensity and sensory modality, consistent with data from simple RT experiments (e.g. Woodworth & Schlosberg, 1954). Consistent with data from choice RT experiments, the identification time would be longer, vary as a function of stimulus discriminability, and perhaps exhibit a different pattern of modality effects than detection times do. As discussed later, the exact values of these parameters are determined either from representative measurements reported in the literature or from estimates provided by data sets being modelled at the moment.

(c) Role of attention : In EPIC, the perceptual processors also depend on one basic type of 'attention'. Through actions directed by the cognitive and motor processors, virtual physical sensors may be oriented to facilitate the acquisition of sensory information. For example, EPIC's eyes may be moved to look at particular locations and objects in space. It is assumed that the speed and accuracy with which visual information reaches working memory is a function of the 'retinal zone' on which it falls. In this sense, EPIC has properties related to early selection theories of attention. EPIC omits assumption that perceptual information processing is modulated by internal selective filters or attenuators, thus EPIC has properties related to late selection theories of attention. This has been done to begin with as few "central" bottlenecks as possible in the architecture, so that it is possible to determine as to what extent apparent limits on multiple-task performance can be attributed instead to peripheral structural constraints (e.g. finite numbers of physical sensors and effectors) and to people's strategies for satisfying instructions about task priorities.

2. *Motor processors :* EPIC's motor processor makes assumptions about the forms of input that they receive, the transformations that they perform, and the forms of output that they produce. As in perception, these transformation are assumed to take specified amounts of time depending on their degree of complexity. Explicit constraints also are placed on the degree to which diffeıent movements produced by the same motor processor may be independent of each other.

(a) Response symbols and movement features : The inputs to the motor processors are assumed to be symbols that represent the abstract identities of responses (e.g., LEFT-INDEX) selected by the cognitive processor. The motor processors transform the response symbols to output commands that control simulated physical effectors (e.g., fingers on the right and left hands), which in turn operate simulated external devices (e.g., virtual response keyboard). Consistent with past studies of manual, vocal, and ocular motor programming, this transformation involves preparing movement features appropriate to the intended response modality. For example, these features might specify the hand and fingers (e.g., LEFT and INDEX) to be used in a manual keypress or the place and manner of articulation (e.g., LABIAL and STOP) to be used in the initial consonant of a vocal syllable. The feature specification determines which effector actually is moved.

(b) Serial feature preparation and movement initiation : Consistent with some past research on human motor programming, EPIC's motor processors prepare movement features serially before the movements are initiated and executed physically. The preparation of each feature is assumed to take an increment of time whose value constitutes a specified parameter of our models. After feature preparation has been completed, a subsequent initiate operation by the relevant motor processor starts over movement. Thus, after receiving a response symbol as input, the time taken by a motor processor to start overt movement would equal a sum of individual feature preparation times and the duration of the initiate operation.

Although results of some past research suggest that feature preparation can occur in parallel for multiple movement features or can consume lesser amounts of time per feature than embodied by the present motor-processor parameters, other studies and data tried on this model fits well with the current assumptions.

(c) Anticipatory movement-feature preparation : On some occasions, the time increment that a motor processor contributes to overt RTs may be reduced through anticipatory movement-feature preparation. EPIC's cognitive processor enables such preparation by providing a motor processor with advance information about anticipated features of a forthcoming movement. For example, if the next response is expected to be a right-hand keypress, the manual motor processor may be informed about this ahead of time, and it may program the hand feature early, before receiving later information about what the response's other required features are. This opportunistic programming decreases the additional time that the motor processor has to take after it receives the final response symbol, consistent with previous studies of anticipatory movement preparation.

For some situations, such as "simple" reactions involving one stimulus-response pair, it is possible that all of the required movement features are prepared in advance before stimulus onset occurs. If so, producing an overt movement after detecting the stimulus onset merely would entail having the cognitive processor instruct the appropriate motor processor to issue a movement-initiation command without further ado.

(d) Motor-processor memory buffer : To prepare for movements, and to benefit from repetitions of successive responses, EPIC's motor processors have memory buffers that retain recently programmed movement features. The buffers' contents remain until they are deleted by the cognitive processor or changed for another future movement. Stored features from past movements can be reused if some of them match those needed next. For example, if the next desired movement is identical to the immediately previous one, it may be produced simply by having the motor processor start an initiate operation, reusing all the movement features already in its buffer. As a result, response repetition effects like those found in choice RT can be obtained.

(e) Efference copy : As part of movement preparation and initiation, EPIC's motor processors send efference copies of their inputs, intermediate status, and outputs back to working memory in the form of symbolic representations. These representations may be used by the cognitive processor for monitoring and regulating the progress of ongoing system operations, as previous studies of perceptual-motor interaction, response adjustment, and error correction have suggested.

(f) Unitary manual motor processor : EPIC's manual motor processor is a unitary component that produces movements by both the right and left hands; each hand does not have a separate independent controller. As a result, interference between two concurrent tasks can occur when they respectively require responses with the right and left hands, even though the two hands themselves are separate physically. Supporting these assumptions, manual-manual tasks have been found to yield substantially more interference than do manual-vocal tasks in at least some multiple-task situations.

Interference typically occurs when the response for each of two manual tasks must be produced at different times by different hands. However, under conditions in which left- and right-hand responses are initiated simultaneously, they will not necessarily interfere as much with each other. This has been modelled through a compound-response style that EPIC's manual motor processor uses on occasions in which response grouping takes place.

3. *Working memory :* EPIC's working memory is characterized by assumptions about the form, amount and durability of its contents.

    (a) Form of contents : In EPIC, working memory contains information produced through operations by the perceptual, cognitive, and motor processors. This information includes task goals, steps (sequential control flags), and notes (e.g. stimulus-identity symbols, response-identity symbols, efference copies of motor-processor status reports, and task strategies). They provide the basis on which the conditions of production rules are tested for successful matches with the present state of the system.

    (b) Amount and durability of contents : EPIC assumes that working memory has sufficient capacity and durability to preserve all of the information needed in elementary multiple-task situations such as the PRP procedures. The initial version of EPIC includes no explicit mechanisms of information decay or overflow. Items are deleted from working memory if and only if the actions of particular cognitive-processor production rules specifically do so. Of course, assumptions about working memory may not suffice more generally. Significant capacity limits on the verbal articulatory loop, as well as other forms of temporary storage, already have been demonstrated in more complex multiple-task situations. Thus, initial version of EPIC will have to be modified and elaborated in future theoretical work.

4. *Cognitive processor :* Assumptions about EPIC's cognitive processor concern how it is programmed and what its temporal properties are during the performance of single and multiple tasks.

    (a) Production-rule programming : EPIC's cognitive processor is programmed with production rules stored in procedural memory. To ensure that the conditions and actions of these rules are simple and explicit, they conform to the syntax of the PPS.

(b) Representation of rule condition : The conditions of the production rules are symbol strings that refer to goals, steps, and notes stored in working memory. Goals consist of items (e.g., GOAL DO TASK 1) that enable the performance of particular tasks to proceed. Steps consist of items (e.g., STEP DO CHECK FOR TONE 800) that help control exactly when a rule has its actions executed during the course of task performance. Notes consist of items that keep track of inputs and outputs by the perceptual, cognitive, and motor processors; they contain information about the status of test trials (e.g., TRIAL UNDER WAY), task progress (e.g., TASK 1 DONE), stimulus identities (e.g., AUDITORY TONE 800 ON), response identities (e.g., RESPONSE IS LEFT-INDEX), and task strategies (e.g., STRATEGY TASK 1 IS IMMEDIATE).

(c) Representation of rule actions : The actions of the production rules contain instructions for updating the contents of working memory and programming EPIC's motor processors. Working memory is updated by adding and deleting goals, steps, and notes in the memory database (e.g., ADD [STEP WAIT FOR TASK 1 RESPONSE COMPLETION]; DEL [AUDITORY TONE 800 ON]). Motor processor instructions consists of commands (e.g., SEND-TO-MOTOR [MANUAL PERFORM LEFT-INDEX]) that direct subsequent movement preparation and initiation.

(d) Tests of rule conditions and execution of rule actions : During the operation of EPIC's cognitive processor, production-rule conditions are tested by the PPS interpreter. If, at some moment, these tests indicate that all the conditions of a particular rule match the current contents of working memory, then the interpreter immediately executes all of the rule's actions. For example, suppose that in Task 1 of the PRP procedure, a keypress with the left-hand index finger should be made immediately when an 800-Hz stimulus tone is presented. If so, the cognitive processor might use the following rule :

IF

((GOAL DO TASK 1)

(STRATEGY TASK 1 IS IMMEDIATE)

(AUDITORY TONE 800 ON)

(STEP DO CHECK FOR TONE 800))

THEN

((SEND-TO-MOTOR (MANUAL PERFORM LEFT INDEX))

(ADD (TASK1 RESPONSE UNDER WAY))

(ADD (STEP WAIT FOR TASK 1 RESPONSE COMPLETION))

(DEL (STEP DO CHECK FOR TONE 800))

(DEL (AUDITORY TONE 800 ON)))

For this rule to apply, the contents of working memory must match four conditions. The first relevant condition is "GOAL DO TASK 1," for which a corresponding item would be put in working memory at the start of each trial during the PRP procedure, thereby enabling progress on Task 1 to proceed. The second relevant condition is "STRATEGY TASK 1 IS IMMEDIATE," for which a corresponding item also would be put in working memory at the start of each trial, thereby indicating that a Task 1 response should be produced as soon as it is selected. The third relevant condition is "AUDITORY TONE 800 ON," for which a corresponding item would be put in working memory by EPIC's auditory perceptual processor when it identifies the stimulus tone. The fourth relevant condition is "STEP DO CHECK FOR TONE 800," for which a corresponding item would be put in working memory during the Task 1 response-selection process. If and when the contents of working memory match all four of these conditions at the same time, the above rule's five actions would be executed simultaneously. As a result, the action "SEND-TO-MOTOR (MANUAL PERFORM LEFT INDEX)" would instruct the manual motor processor to prepare and initiate a movement by EPIC's left index finger. The actions involving "ADD" instructions would add the items "TASK 1 RESPONSE UNDER WAY" and "STEP WAIT FOR TASK 1 RESPONSE COMPLETION" to working memory; the actions involving "DEL" would delete the items "STEP DO CHECK FOR TONE 800" and "AUDITORY TONE 800 ON".

(e) Cyclic operation : EPIC's cognitive processor operates in cyclic fashion, with no pause between the end of one cycle and the beginning of the next. During each cognitive-processor cycle, three types of operation takes place. First, the contents of working memory are updated to incorporate the results of activities completed by the perceptual, cognitive, and motor processors during the immediately preceding cycle. Second, the conditions of production rules are tested to determine which ones match the current contents of working memory. Third, the actions of rules whose conditions pass these tests are executed.

The cognitive-processor cycles are not synchronized with external stimulus and response events. Inputs from the perceptual processors are accessed only intermittently, after working memory is updated at the start of each cycle. Any input that arrives during the course of a cycle therefore must wait temporarily for service until the next cycle begins. This is consistent with the temporal granularity of perceived stimulus successiveness, the spectral characteristics of simple RT distributions, and the periodicity of electroencephalographic brain activity.

(f) Inherent parallelism : On each cognitive-processor cycle, the PPS production-rule interpreter tests the conditions of all rules stored in procedural memory. For every rule whose conditions match the current contents of working memory, its associated actions are all executed in parallel at the end of the cycle. The durations of the cognitive processor's cycles do not depend on the number of production rules involved. EPIC imposes on upper limit on how many rules may have their conditions tested and actions executed at the same time. When simulating participants' performance under the PRP procedure, for example, EPIC's cognitive processor can select responses simultaneously for both Task 1 and Task 2. Such capabilities may lead instead to identify and describe other alternative performance limitations, including conservative task strategies and structural constraints on perceptual or motor processors.

Above mentioned assumptions about components of the EPIC architecture are summarized in Table 1.

3.4 MODELLING HUMAN PERFORMANCE WITH EPIC

To use EPIC for constructing computational models of human performance, two complementary steps are necessary. First, we must consider how various individual tasks might be performed, if our architectural assumptions are correct. Second, we must consider how individual tasks might be coordinated during multiple-task performance.

Table 1 shows EPIC components and their assumed properties

Type of component	Assumed properties
Perceptual Processors	Operations are parallel and asynchronous. Stimulus identities sent to working memory. Transmission times depend on modality, intensity and discriminability.
Motor Processors	Response identities received as inputs. Movement features prepared for physical outputs. Feature preparation done serially with set time increments. Advance feature preparation done for anticipated responses. Movement initiation done after feature preparation. Efference copies of motoric representations sent to working memory.
Cognitive Processors	Programmed with production rules (if condition, then action). Rules interpreted by parsimonious production system. Conditions refer to goals, steps, and notes on working memory. Step in conditions govern flow of control. Complex conflict-resolution criteria and spreading activation not used. Actions regulate working memory and perceptual motor processors. Cyclic operation with set mean cycle duration. No limit on number of rules being tested and applied simultaneously.
Working Memory	Contents consists of goals, steps, and notes. Contents used and managed by cognitive processor. Capacity and duration sufficient for performance in PRP procedure.

1. *Single-task performance :* Following steps are involved in modelling single-task performance :

a. Analyze the information-processing requirements of each task at hand;

b. Specify a set of production rules to be used by EPIC's cognitive processor in performing the task;

c. Specify the initial contents of working memory;

d. Specify stimulus inputs from the external environment that get the task started;

Following constraints are imposed on modelling :

a. The properties of EPIC's cognitive, perceptual, and motor processors remain the same across all tasks;

b. The production rules used to program the cognitive processor may differ across tasks. But within a task, these rules remain constant unless an explicit learning algorithm is included to describe practice effects;

c. Rationality principle i.e. production rules to be specified as per the goals of the tasks and instructions that people receive about how to achieve them

d. Production rules are specified such that they can mimic basic factor effects on RTs.

   a. Stimulus numerosity effects could be brought about by changing the number of production-rule steps and hence the number of cognitive-processor cycles, that take place during each trial depending on the levels of relevant task factors;

   b. S-R repetition effects are achieved by repetition-bypass feature such that whenever the same stimulus occurs again on the next trial, the same response as before is selected immediately for it;

   c. S-R compatibility effect is achieved by producing a stimulus identity code through perceptual processor, whose features are isomorphic to ones used by a motor processor for programming response movements. Consequently, the cognitive processor may pass this code directly to the motor processor, reducing the processor cycles taken for response selection and thereby decreasing overall RT.

   Through the same approach, it is also possible to characterize other factor effects, including ones that stem from stimulus probability and response competition (stroop effect).

2. *Multiple-task performance :* For multiple-task performance it is necessary to specify how the functions performed by the distinct sets of production rules for each of two or more concurrent tasks are coordinated. For every task to be completed properly, there must be some supervisory control to ensure that the tasks' production-rule sets do not try to use the same physical sensors (e.g. eye) or effectors (e.g. hands) simultaneously in conflicting ways. Also supervisory control is needed to ensure that performance obeys instructions about relative task priorities. This is achieved by -

   a. Executive processes : The executive processes maintain task priorities and coordinate progress on concurrent tasks through various types of supervisory control. For example, they insert and delete task goals in working memory, direct the eyes to look at one place or another in visual space, send selected responses either to motor processors or working memory, and prepare movement features of anticipated responses, all depending on the current context and task instructions. Such executive functions are performed by additional sets of production rules distinct from those for the individual tasks. As executive processes are specified in form of production rules set whose format and application parallel the rules sets used to perform individual tasks they have a considerable architectural homogeneity. Executive processes have some additional important properties such as -

a. They do not contain procedural knowledge sufficient to perform any individual task;

b. They do not modify the individual tasks' production rules;

c. They coordinate progress on individual tasks only by manipulating goals and notes in working memory;

d. They may change as a function of particular task combinations, priorities, experimental paradigms, and subjective strategies;

e. They allow the production-rule sets for individual tasks to be used across a variety of multiple-task situations.

b. Scheduling algorithm : Performance of concurrent tasks may be coordinated through various scheduling algorithms such as lockout scheduling or interleaved scheduling.

   a. Lockout scheduling : Under such schedules tasks are performed one by one in strict sequence; each successive task remains entirely suspended (i.e. locked out) until its turn for processing comes. This progression is achieved by having the executive process insert and delete the tasks' main goals one after another in working memory. Cross-task coordination then has much the same temporal character as under the global single channel hypothesis, but the seriality of performance stems from option supervisory control rather than from one task inherently blocking another task's entry into a single information-processing channel.

Lockout scheduling has the virtue of being simple and easy to implement. It requires minimal executive process and provides a type of coordination that novice multiple-task performers might favour because of its conservative nature, which eliminates potential conflicts over access to perceptual-motor components. However, lockout scheduling has disadvantages too. It precludes highly efficient multiple-task performance because no temporal overlap is allowed in the performance of two or more tasks even though such overlap might be possible from the standpoint of available system resources.

b. Interleaved scheduling : Under it some of the component processes for multiple tasks are allowed to proceed concurrently; an individual task is suspended only during minimal time periods when unavoidable conflicts with competing tasks might otherwise occur. This requires a more complex executive process whose production rules are highly specific to particular task combinations. Consequently, a major contribution of practice at multiple-task performance may involve enabling a shift from lockout scheduling to fully interleaved scheduling.

3.5 THE STRATEGIC RESPONSE DEFERMENT MODEL (SRD)

An explicit computational model based on production-system formalism and EPIC information-processing architecture is SRD. Using their capabilities, SRD model accounts for a variety of quantitative results from the PRP procedure and leads to interesting new predictions as well. As PRP procedure has some similarity to real-world situations involving human multiple-task performance, such as aircraft cockpit operation, air-traffic control, control rooms in industries and call centres this model may set stage for extending EPIC framework to other relevant contexts also.

Details of SRD model are :

1. *Rationale :* Performance decrements under the PRP procedure stem at least partly from optional strategies adopted to satisfy task priorities and to avoid perceptual-motor conflicts rather than from permanent central bottlenecks in response selection and other decision processes.

2. *Basic assumptions :* Following are basic assumptions -

a. Participants try to use their available processing resources to the maximum extent possible, given whatever the task instructions and perceptual-motor limitations are.

b. When SOA is short, stimulus identification and response selection for Task 2 of the PRP procedure may proceed at the same time as Task 1 is being performed but initiation of overt movements of Task 2 is deferred temporarily.

c. Temporal overlap of these stimulus-identification and response-selection processes is achieved through EPIC's cognitive processor which has the unlimited capacity to test and apply distinct sets of production rules in parallel.

d. At intermediate SOA, the selection of Task 2 responses is suspended briefly by an executive process, which shifts Task 2 from the deferred to the immediate response transmission mode.

e. Executive process controls the flow of information through temporary programmable lockout; it is not constrained by a permanent hardware bottleneck.

f. Motor processors for different response modalities (e.g., manual and vocal) may function simultaneously; it has no peripheral amodal movement-production bottleneck per se.

These assumptions form the basis of EPIC theoretical framework that attributes PRP effect and other related phenomena to strategic partial lockout scheduling and deferred response transmission, which are governed by the SRD model's executive process for satisfying task priorities and avoiding conflicts within the same (e.g., manual) motor processor.

3. ***Production Rules :*** SRD model has two distinct sets of production rules for Task 1 and Task 2 of the PRP procedure and one set of production rules for executive processes that coordinates the two tasks. These rule sets are modular; no set "knows" about the content or status of the rules in the other.

One important aspect of task production rules is that they have two alternative response-transmission modes : immediate and deferred. With them, access to EPIC's motor processors can be managed flexibly, enabling efficient strategies that optimally satisfy task instructions. Also potential conflicts between tasks that require access to the same motor processor can be avoided.

The immediate transmission mode is used in performing a task that has the current highest priority for response output. The SRD model's executive process invokes the immediate mode by placing the note "STRATEGY TASK N IS IMMEDIATE" in working memory, which then may be matched with the conditions of production rules that do immediate-mode response selection and transmission. When a task's rules are applied in immediate mode, they send the products of response selection (i.e. symbolic identities of selected responses) directly to the appropriate motor processor, where corresponding movement features are prepared and overt responses are initiated without further ado. In essence, the immediate mode helps maximize preparation for task completion. Its function may be related to the sensorial strategy of performance noted by early introspectionists (Lange, 1888). According to Lange (cited in Boring, 1950), a participant who adopts the sensorial strategy would "direct the whole preparatory tension towards, the expected sense impression, with the intention, however, of letting the motor impulse follow immediately on the apprehension of the stimulus, avoiding any unnecessary delay". This is exactly what the immediate transmission mode enables.

By contrast, the deferred transmission mode is used for performing lower priority tasks while higher priority tasks are under way. The executive process invokes deferred mode by placing the note "STRATEGY TASK N IS DEFERRED" in working memory, which then may be matched with the conditions of production rules that do deferred-mode response selection. When the task's rules operate in the deferred mode, they do not send symbols for selected responses directly to a motor processor; instead, the response symbols are put in working memory, where they remain temporarily until it is time for them to be output. This allows the production rules of lower priority tasks to progress as far as possible on response selection but to avoid disrupting or usurping other higher priority tasks. Subsequently, sometimes after this rule has been applied, another production rule would send the identity of the selected Task 2 response from working memory to its motor processor when permission for the latter transmission is given. Such permission occurs through a process called "unlocking," which is described in more detail later. The deferred transmission mode also might play a role in other contexts. It provides a natural way to attain intermediate levels of preparation in some types of response-priming procedure, where participants are told beforehand to prepare for producing a specific response but must then withhold overt physical movement until a later go signal occurs.

a. Task 1 Production Rules : These rules do task initiation, response selection, repetition bypass and task completion when a Task 1 stimulus is presented. Application of these rules proceeds as information passes through the components of the EPIC architecture, leading from stimulus to response.

   In principle, the form and content of the response-selection rules may stem from an initial skill-acquisition process that converts declarative knowledge to procedural knowledge about how the tasks should be performed. Requisite declarative knowledge could be obtained through the PRP procedure's verbal task instructions. For example, the instructions might state that "if the tone is low, then press the left middle finger key; if the tone is high, then press the left index finger key." When given these instructions during practice under the PRP procedure, the skill-acquisition process might convert them to two production rules that are stepped through successively.

   Task 1 completion is declared when the motor processor signals that all of the movement features for the Task 1 response have been prepared and movement is about to be initiated overtly. Alternatively, depending on contextual circumstances, other internal events either before, during, or after the preparation of movement features could serve as a critical juncture at which Task 1 is declared to be done. This is an adjustable parameter in SRD model.

b. Task 2 Production Rules : Like Task 1 production rules Task production rules do task initiation, response selection, repetition bypass and task completion when a Task 2 stimulus is presented. Application of these rules proceeds as information passes through the components of the EPIC architecture, leading from stimulus to response. Specifically, the Task 2 rules are defined to deal with the stimulus modality, response modality, and S-R associations relevant in performing Task 2.

   Furthermore, in order that overt task 2 responses do not occur prematurely after they have been selected, the SRD model assumes that at short SOAs, selected task 2 responses are stored temporarily in working memory rather than being sent directly to their motor processor for immediate output. It is this optional strategic deferment of selected task 2 responses that gives the model its name. Response deferment is assumed to be supervised by an executive process that controls when selected task 2 responses are released after sufficient task 1 progress has occurred. Such control precludes conflicts over the use of the same motor processor, and it helps satisfy instructions about task priorities associated with the PRP procedure.

c. Executive Process Production Rules : The executive processes function somewhat like the allocation policies (Kahneman, 1973), Supervisory Attentional System (Norman & Shallice, 1986), and Central Controller (Schneider & Detweiler, 1988) introduced by previous theorists. The executive process has its own set of production rules which together help achieve three objectives : (a) task 1 responses always precede task 2 responses; (b) movement preparation and initiation for task 2 do not usurp the motor processor needed for task 1; and (c) subject to the preceding constraints, task 2 is completed as quickly as possible. These objectives are achieved through the strategy outlined in the diagrammatic representation of production rules of task 1 and task 2 in Figure 7.

Temporal arrangement and functions of several steps of executive processes are as follows :

a. Task-rule enablement : At the start of each trial under the PRP procedure, when an initial warning signal is detected, the executive processes enables both the Task 1 and Task 2 production rules for execution and then response selection may proceed for each task as soon as the identification of relevant stimuli has been completed by EPIC's perceptual processors. As implied by above diagram the executive process does not directly start and stop perceptual activities for Task 1 and 2. Rather, EPIC's perceptual processors operate in parallel with the cognitive processor. Thus, as soon as a test stimulus reaches an appropriate sensor (e.g. the eyes or ears), its perception proceeds autonomously, leading to stimulus identities being put in working memory. Nevertheless, perceptual activities can be controlled indirectly by the executive processes, depending on where it focuses

EPIC's peripheral sensors (e.g., the eyes).

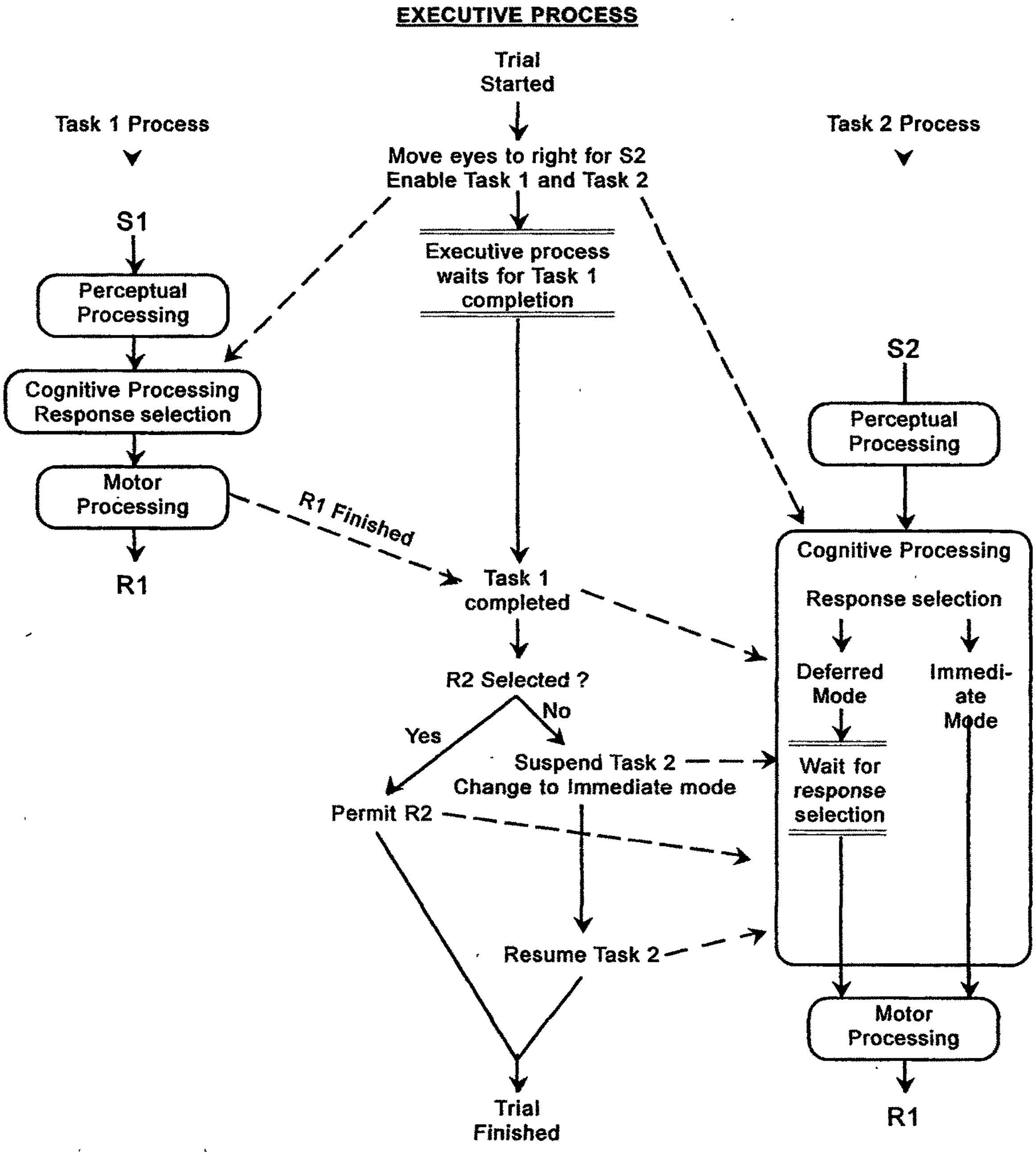

Fig. 7 The task scheduling strategy used by the executive processes for the PRP procedure

b. Transmission-mode initialization : Executive process also initializes the response-transmission mode to be used during response selection. along with enablement of production rules for each task. This involves putting the notes "STRATEGY TASK 1 IS IMMEDIATE" "STRATEGY TASK 2 IS DEFERRED" in working memory. Consequently, Task 2 responses that are selected during the early stages of Task 1 will be put in working memory temporarily rather than being sent directly to their motor processor, thus ensuring that overt Task 2 responses do not occur prematurely. After being placed in working memory, a pending Task 2 response must wait there until the executive process later permits the Task 2 production rules to send it to an appropriate motor processor.

c. Anticipatory eye movements : Executive processes while initializing task rule enablement and transmission-mode also make anticipatory eye movements when either Task 1 or Task 2 is visual. If both tasks involve visual stimuli, and if their stimuli have different spatial locations, then the eyes would first be positioned appropriately for Task 1 because of its higher priority. After perception of a visual Task 1 stimulus has progressed far enough, the eyes would later be repositioned for a visual Task 2 stimulus. Alternatively, if only the Task 2 stimuli are visual, then the eyes would be positioned for them at the start of each trial, thereby letting stimulus perception in Task 2 start sooner than might otherwise be the case. Because eye movements take significant amounts of time (e.g. approximately 200 ms or more for preparation and execution), overt Task 2 RTs can depend substantially on which tasks are visual.

d. Task-status monitoring : This is an intermediate stage of executive process that involves monitoring the status of Task 1 performance as well as progress on stimulus identification and response selection of Task 2. If the SOA is short and Task 1 takes a relatively long time, then a Task 2 response may be selected and put in working memory before intermediate task-status monitoring by the executive process ends. On the other hand if the SOA is long or Task 1 goes quickly, then no Task 2 response may be selected during this period. In any case, eventually a Task 1 production rule will put the note "TASK 1 DONE" in working memory, cuing the executive process to take its next step, an unlocking routine for Task 2.

e. Task 2 unlocking : The unlocking routine enables previously and subsequently selected Task 2 responses to reach their motor processor for final output. This entails dealing with various possible states of affairs that may arise because Task 2 starts and proceeds temporarily in the deferred response-transmission mode. For example, it is possible that by the time Task 1 finishes, either (a) a Task 2 response already has been selected and put in working memory, (b) response selection has started but not been completed for Task 2, or (c) response selection for Task 2 has not yet begun. To deal with the latter alternatives, the executive process takes one or more of several sub-steps, including response permission or task suspension, transmission-mode shifting, and task resumption. A flowchart of these sub-steps and their time course appears in Figure 7. Which of them is taken during a particular trial depends on exactly how much progress has been made on Task 2 by the time Task 1 is done. After the Task 1 production rules have put the note "TASK 1 DONE" in working memory, the executive process chooses between taking the response permission or task suspension sub-step of the unlocking routine. If Task 2 response selection is already done and stored in working memory than unlocking routine starts and response permission is granted for Task 2. If Task 2 response selection is not yet done, then unlocking routine starts and temporarily suspends Task 2 by deleting a note "GOAL DO TASK 2", replaces note "STRATEGY TASK 2 IS DEFERRED" to "STRATEGY TASK 2 IS IMMEDIATE", and resumes Task 2 by again putting a note "GOAL DO TASK 2" in working memory.

(f). Anticipatory response preparation : After the unlocking routine is done, the executive process also may take one more step; anticipatory preparation of a Task 2 response movement. This occurs if the SOA is long and response selection for Task 2 has not begun already. The additional preparation involves sending the features of anticipated Task 2 response movements to their motor processor, which then prepares them in advance, thereby reducing the time that will be taken for later feature preparation when the motor processor subsequently receives the full identity of the selected Task 2 response. For example, if all of the alternative Task 2 responses require finger presses by the right hand, the executive process may instruct the manual motor processor to prepare the right-hand feature without yet knowing which particular finger will ultimately be involved.

3.6 ALGEBRAIC DESCRIPTION OF THEORETICAL AND SIMULATED REACTION TIMES (RTS)

SRD model has many interesting implications about patterns of RTs in the PRP procedure. Some implications can be derived from simple mathematical analyses, whereas others are more easily demonstrated by computer simulation. Together, these two approaches - analysis and simulation - complement each other nicely for the present purposes. Simulations with the SRD model allows verifications as to whether its assumptions are well defined and logically sufficient for describing basic multiple-task performance. The simulation process also yields numerical predictions about theoretical mean RTs that would be difficult or impossible to obtain mathematically. Nevertheless, despite such difficulties, it is possible to formulate some algebraic equations for the mean RTs implied by the SRD model. With these equations, appropriate values of some parameters on which the model and its EPIC architecture rely could be estimated, and thus, the model's goodness of fit to empirical data in a principled fashion could be estimated. Just as important, the theoretical RT equations clarify why simulated RTs exhibit various quantitative patterns depending on details of the experimental conditions. Thus, through joint analysis and simulation, the SRD model promises to account precisely for RT data from a range of empirical studies.

a. *Architecture and Model Parameters :* Several types of parameter that modulate the dynamics of EPIC's perceptual, cognitive, and motor processors; they are "built in" the system components and do not depend on the particular sets of production rules used by the SRD model for performing individual tasks. Also included are other parameters that do depend on these rule sets and that emerge from the SRD model's task or executive process. Of these all parameters many of the SRD model's and EPIC's parameters are linearly or multiplicatively related to each other; they are listed here distinctly for the purpose of exposition. Furthermore, the mean numerical values assigned to some of these parameters stay fixed across all simulations. Thus, model actually has relatively few adjustable parameters and degrees of freedom with which to account for empirical data. Details of each parameter are as given below -

(1) Cycle duration (tc) : This is a cognitive-processor parameter. It is the duration of each cycle during which the cognitive processor tests the conditions and executes the actions of production rules in procedural memory. **tc** is unaffected by the number of production rules that have to be processed.

However, because individual task and executive processes typically take more than one cycle to be completed, their completion times and resulting RTs depend directly on tc.

(2) Working-memory gating time (tg) : This is a cognitive-processor parameter. It is the time between the moments when a new item of information (e.g., a stimulus identity) enters working memory and the cognitive processor can first use this item in subsequent operations. On average tg equals half of tc because the cognitive processor examines the contents of working memory at the start of each cycle but ignores any further items that enter during the remainder of the cycle.

$$tg = 0.5 \times tc$$

(3) Stimulus detection time (td) : This is a perceptual-processor parameter. This is a modality-specific parameter. It is the time from the external onset of a stimulus until the perceptual processor devoted to its sensory modality puts a detection symbol in working memory, indicating that the stimulus onset has occurred. During simple RT tasks, the sum of td and tg determines when response selection and transmission can begin.

(4) Stimulus identification time (ti) : This is a perceptual-processor parameter. It is the time from the onset of a presented stimulus until the perceptual processor for its modality puts the identity of the stimulus in working memory. During choice RT tasks, the sum of ti and tg determines when response selection can begin.

(5) Number of movement features (nf) : This is a motor-processor parameter. This is the number of movement features prepared by a motor processor when it converts a selected response symbol to an overt movement.

(6) Preparation time per feature (tf) : This is a motor-processor parameter. This is the time taken per movement feature to complete its conversion.

(7) Action-initiation time (ta) : This is a motor-processor parameter. It is the time taken to begin an overt movement after all of its requisite features have been presented.

(8) Movement production time (tm) : This is a motor-processor parameter. It is the total time that a motor processor takes to transform the identity of a selected response into the onset of physical motion, assuming the movement has not already been partially prepared in advance. By definition -

$$tm = (nf \times tf) + ta$$

(9) Preparation-benefit time (tp): This is a motor-processor parameter. It plays a role when some of the movement features for a response are prepared in advance, before the full identity of the response has been selected and sent to its motor processor. On such occasions, tp equals a product of the preparation time per feature (i.e. tf) and number of features prepared in advance. The preparation benefit is subtracted from the "normal" (unprepared) contribution of the movement-production time to the total RT.

(10) Number of response-selection cycles (ns) : This is a task-process parameter. It equals the total cycles taken by EPIC's cognitive processor in selecting the identity of a response to a stimulus once the stimulus is in working memory and the task's production rules have been enabled. The value of ns depends on the specific production rules used during response selection, which may change as a function of factors such as S-R compatibility and S-R numerosity.

(11) Response-selection time (ts) : This is a task-process parameter. It is the total time taken by the cognitive processor on each trial for response selection. It is a product of ns, and cycle duration, tc.

$$ts = ns \times tc$$

Thus ts depends on a task's production rules, just as ns does.

(12) Ocular orientation time (to) : This is an executive-process parameter. It is the time taken from the onset of a Task 1 stimulus until the executive process, using the ocular motor processor, has positioned EPIC's eyes at the spatial location of a visual Task 2 stimulus. Under the SRD model, the value of to is set by specifying trigger events that match the conditions of the executive-process production rules whose actions control the ocular motor processor. For example, suppose that the Task 1 stimulus is auditory, the Task 2 stimulus is visual, and a visual warning signal precedes the Task 1 stimulus. Detection

of the warning signal's onset then may trigger an immediate eye movement to the anticipated Task 2 stimulus location before the Task 1 stimulus starts, so to would be zero and not contribute to the subsequent Task 2 RT. However, if both the Task 1 and Task 2 stimuli are visual, or if looking at the Task 2 stimulus location is postponed temporarily for other reasons, then to could be substantially greater and dramatically increase the Task 2 RT.

(13) Unlocking onset latency (tu) : This is an executive-process parameter. It is the time between two intermediate events : (a) transmission of a selected Task 1 response to its motor processor and (b) initiation of the shift from deferred to immediate response-transmission mode for the Task 2 production rules. The value of tu is set by specifying what internal state during the production of an overt Task 1 response qualifies Task 1 to be declared done. This specification may depend on several factors, such as which motor processor is used for performing each task of the PRP procedure and how conservative the executive processes must be ensure that Task 1 responses always precede Task 2 responses. For example, if both tasks require using EPIC's manual motor processor, Task 1 may not be declared done until the manual motor processor has initiated an overt Task 1 response, so tu would include the entire movement-production time (i.e. tm). By contrast, if the two tasks require different motor processors (e.g. manual and vocal), and if some out-of-order responses are tolerated, Task 1 may be declared done as soon as its motor processor signals receipt of the Task 1 response identity, so tu could be much shorter.

(14) Minimum unlocking duration (tv) : This is an executive process parameter. Its values is set by specifying the production rules that unlock Task 2 after Task 1 has been declared done. If the Task 2 response has been selected already and put in working memory through the deferred response-transmission mode, tv is the time between the respective moments when Task 1 is declared to be done and the identity code for the selected Task 2 response reaches its motor processor. Alternatively, if the Task 2 response has not been put in working memory before Task 1 is done, tv is time taken by the executive process to suspend Task 2 temporarily and shift it from the deferred to the immediate response-transmission mode.

(15) Suspension waiting time (tw) : This is an executive process parameter. It is

an extra time during which the executive process keeps Task 2 suspended after the deferred-to-immediate mode shift has been completed. The value of tw is set by specifying how many additional cognitive-processor cycles the executive process waits during this period. In some cases, this specification can help avoid out-of-order responses, and it also accounts for interesting details of PRP curves that are otherwise difficult to explain.

(16) Preparation waiting time (ty) : This is an executive process parameter. It is an amount of time that the executive process waits before starting anticipatory preparation of Task 2 movement features after the Task 1 response movement has been initiated. The value of ty is set by specifying an event that triggers a production rule to start anticipatory movement-feature preparation during Task 2. For example, this event might correspond to EPIC's tactile perceptual processor detecting the end of the overt Task 1 response and putting a corresponding detection symbol in working memory. In turn ty would then depend on the tactile detection time. More generally, the length of ty may be related inversely to the amount of emphasis placed on completing Task 2 quickly at long SOAs.

(17) Response-transduction time (tr) : This is an apparatus parameter. It is an extra amount of time between the respective moments when an overt response movement begins and a movement-recording device would transduce the movement's physical onset. This time presumably depends on the response modality and recording device that are involved, thereby influencing predicted and observed RTs. For example, vocal RTs may involve greater values of tr than manual RTs do because the onsets of audible vocal sounds recorded with a voice key often are delayed substantially (e.g. approximately 100 ms or more) relative to the onsets of the articulatory movements that produce them, whereas manual keypresses can trigger corresponding switch closures almost instantaneously (e.g. approximately 10 ms or less).

A summary of all the parameters with the SRD model is presented in Table 2.

<u>*b.*</u> <u>*Task 1 RT :*</u>

Stages of Task 1 : Task 1 entails following sequence of stages :

(a) detection and, if need be, identification of the Task 1 stimulus by a

Table 2 shows parameters for simulations with the SRD model

System Component	Parameter Name	Symbol	Type	M	Source
Cognitive processor	Cycle duration	tc	S	50	G
	Working memory gating time	tg	S	25	G
Perceptual processor	Stimulus detection time	td	S	X	G, E
	Stimulus identification time	ti	S	X	G, E
Motor processor	Number of movement features	nf	C	2	G
	Preparation time per feature	tf	S	50	G
	Action-initiation time	ta	S	50	G
	Movement-production time	tm	S	150	G
	Preparation benefit	tp	S	X	G
Task processes	Number of selection cycles	ns	S	X	G, E
	Response-selection time	ts	S	X	G, E
Executive processes	Ocular orientation time	to	S	X	I
	Unlocking onset latency	tu	S	X	E
	Minimum unlocking duration	tv	S	100	G
	Suspension waiting time	tw	S	X	I
	Preparation waiting time	ty	S	X	I
Apparatus	Response-transduction time	tr	C	X	G, E

S = stochastic; C = constant; X = context-dependent parameters; G = informal guesstimation; I = iterative simulation; E = formal estimation

perceptual processor;

(b) selection of a Task 1 response by the cognitive processor and transmission of the response's identity to its motor processor;

(c) preparation of movement features and initiation of action by the motor processor; and

(d) transduction of the response movement.

Equations of Task 1 RTs :

When Task 1 involves simple reactions (i.e., only one possible S-R pair)

$$RT1 = td1 + tg + ts1 + tm1 + tr1$$

When Task 1 involves two or more alternative S-R pairs -

$$RT1 = ti1 + tg + ts1 + tm1 + tr1$$

Assumptions of Task 1 RT :

(a) SRD model involves discrete serial stage of processing.

(b) Above assumption facilitates estimation of parameter values for model.

(c) Task 1 RTs are independent of the SOA. When empirical Task 1 RTs do not depend on the SOA, the model's executive process - which can use alternative task-scheduling strategies - may be modified in a principled fashion to interpret and predict systematic SOA effects.

(d) Task 1 RTs are independent of Task 2 response-selection difficulty. However, the model's executive process also can mediate the effects of Task 2 difficulty on Task 1 RTs, which have been reported previously under some conditions.

c. *Task 2 RT equations :*

(a) Task 2 RTs incorporate the effects of both the SOA and Task 2 response-selection difficulty.

(b) Because of how the executive process works, information processing for Task 2 presumably involves a dynamic switching network whose properties generalize those of static program evaluation and review technique (PERT) networks. In static PERT networks, processing proceeds simultaneously along two or more distinct paths, and the time to produce an overt output depends on which path requires the most time to be completed; the structure of the network does not change dynamically within or between trials. On the other hand, under the SRD model, only one path of processing is taken for Task 2 during each stimulated test trial; the selection of this path stems from contingent switching operations (e.g. temporary suspension and resumption of Task 2 response selection) that coordinate Tasks 1 and 2 dynamically. Across trials, the set of possible paths from stimuli to responses may change depending on the SOA and other parameter values.

(c) Five alternative paths of processing may lead from Task 2 stimuli to Task 2 response under the SRD model. The path that is actually taken during an individual trial depends on the SOA, the stimulus identification times, and the response-selection times in Tasks 1 and 2. For each possible path, a distinct equation characterizes the theoretical Task 2 RT as a function of the SRD model's parameters and SOA. The SOA is especially important here because it determines whether the difficulty of response selection in Task 2 contributes additively or interactively to the Task 2 RT. Following table lists all five paths along with their characteristic, Task 2 RT equations and SOA constraints.

Table 3 shows reaction times and constraints on SOA for the five alternative paths of processing in task 2 under SRD model

PATH 1 : POSTSELECTION SLACK

RT2 = ti1 + tg + ts1 + tu + tv + tm2 + tr2 - SOA

SOA constraint
SOA $\leq$ ti1 + ts1 + tu - max (0, to2 - SOA) - ti2 - ts2

PATH 2 : MIDSELECTION SLACK

RT2 = max (0, to2 - SOA) + ti2 + tg + ts2 + tv + tw + tm2 + tr2

SOA constraint
ti1 + ts1 + tu - max (0, to2 - SOA) - ti2 - ts2 < SOA $\leq$ ti1 + ts1 + tu - max (0, to2 - SOA) - ti2

PATH 3 : PRESELECTION SLACK

RT2 = ti1 + tg + ts1 + tu + tv + tw + ts2 + tm2 + tr2 - SOA

SOA constraint
ti1 + ts1 + tu - max (0, t02 - SOA) - ti2 < SOA $\leq$ ti1 + ts1 + tu + tv + tw - max (0, to2 - SOA) - ti2

PATH 4 : NEUTRAL BASELINE

RT2 = max (0, to2 - SOA) + ti2 + tg + ts2 + tm2 + tr2

SOA constraint
ti1 + ts1 + tu + tv + tw - max (0, to2 - SOA) - ti2 < SOA < ti1 + ts1 + tm1 + tv - max (0, to2 - SOA) - ti2 - ts2

PATH 5 : MOTOR PREPARATION

RT2 = max (0, to2 - SOA) + ti2 + tg + ts2 + tm2 - tp2 + tr2

SOA constraint
SOA > ti1 + ts1 + tm1 + ty - max (0, to2 - SOA) - ti2 - ts2

3.7 THEORETICAL PRP CURVES

When RTs for the alternative paths of information processing in Task 2 are plotted graphically, one can see that the SRD model may produce several distinct families of theoretical PRP curves (Task 2 RT vs. SOA) whose shapes depend on the model's parameters. By examining each family in detail, one can better understand why PRP curves of both simulated and empirical mean Task 2 RTs appear as they do. This also helps in parameter estimation and goodness-of-fit assessment.

a. *Prototype PRP curve :* The families of PRP curves produced by the SRD model are based on a single underlying prototype PRP curve, which appear in Figure 8.

To depict the form of this curve clearly, it is assumed for the moment that the model's parameters are constants. Also, it is assumed that the parameter values allow each of the five possible paths of information processing between the Task

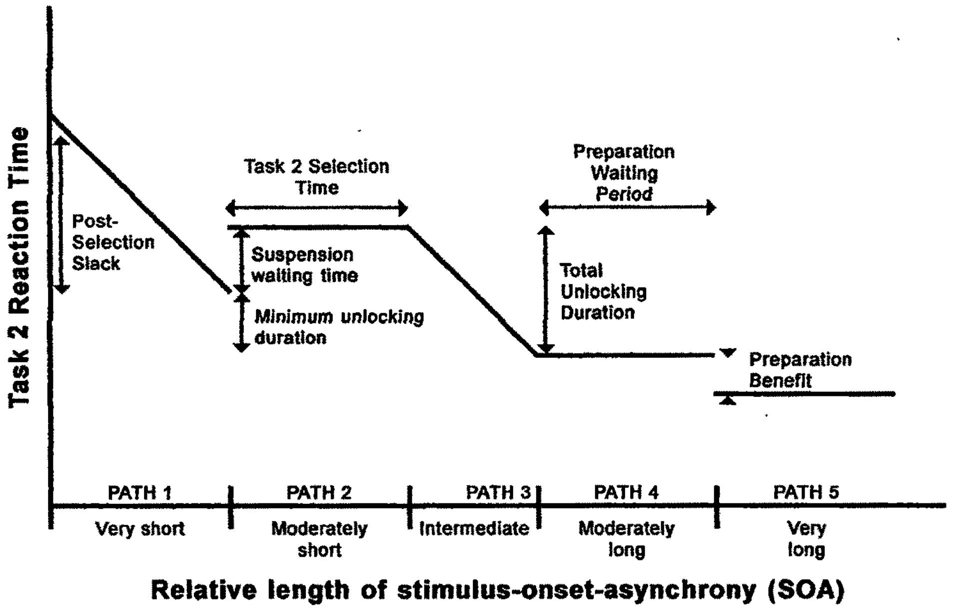

Fig 8 The prototype PRP curve implied by SRD model

2 stimuli and responses to be taken throughout some interval of positive SOAs. These assumptions constrain the prototype PRP curve to have five linear segments, corresponding respectively to contributions from the five Task 2 RT equations introduced previously. Details of each segment is as given below -

(1) First segment : The RT equation for Path 1, which entails postselection slack in Task 2, is the source of the prototype PRP curve's first segment. This segment extends over an interval of very short SOAs. Here, the Task 2 RT decreases linearly with a slope of -1 as the SOA increases and the postselection slack correspondingly decreases, terminating in an intermediate valley. By construction, the overall magnitude of this decrease equals the length of the postselection slack at an SOA of zero. Thus, to the extent that stimulus identification and response selection for Task 1 are slow or stimulus identification and response selection for Task 2 are fast, the initial Task 2 RT decrease will be large.

(2) Second segment : Next, however, the prototype PRP curve jumps abruptly upward because of a contribution from the RT equation for Path 2, which entails midselection slack in Task 2. The magnitude of this jump equals the suspension waiting time (tw) that delays the resumption of Task 2 after the SRD model's executive process starts unlocking it. Insofar as t2 is large, it may even raise the Task 2 RTs back up to where they are when the SOA equals zero. This would happen if the suspension waiting time has the same

magnitude as the postselection slack at zero SOA. Furthermore, after jumping upward, the Task 2 RTs are constant over an interval of moderately short SOAs, yielding the second (upper horizontal) segment of the prototype PRP curve. This segment is flat and forms a plateau because the midselection slack (i.e., tv + tw) stays the same for all moderately short SOAs. The plateau's extent equals the Task 2 response selection time (ts2). Therefore, if Task 2 response selection is difficulty, the second segment will be relatively long. As Welford (1967) noted, PRP curves may have relatively shallow (near zero) slopes at intermediate SOAs because there is variability in the time taken to complete Task 1, which in turn affects when a single-channel mechanism becomes available for Task 2. Without such variability, single-channel mechanisms and response-selection bottleneck models (Pashler, 1984, 1990, 1993) - in their simplest form - imply that PRP curves consist of two linear RT segments, with the first having a slope of -1 at relatively short SOAs and the second having a slope of zero at longer SOAs (Welford, 1959, 1967). By contrast, the SRD model implies shallow slopes at moderately short SOAs even when the underlying processes are entirely deterministic.

(3) Third segment : At the right end of the second segment, Path 3 and the RT equation for it lead the prototype PRP curve to descend again toward baseline. Associated with this next drop is preselection slack that decreases steadily as the SOA increases, yielding a third (middle diagonal) segment over an interval of intermediate SOAs. Because the third segment's slope is -1, the total decrease of the Task 2 RT that results from it equals tv + tw which also equals the magnitude of the midselection slack.

(4) Fourth segment : After the interval of intermediate SOAs, the prototype PRP curve reaches a neutral baseline corresponding to its fourth (next to lowest) segment in the figure. Here, the Task 2 RT has no temporal slack. The neutral baseline, which comes from the RT equation for Path 4, occurs over an interval of moderately long SOAs. The length of this interval is related linearly to the preparation waiting time of the SRD model's executive process. Thus, if tv is large, the prototype curve may remain at the neutral RT baseline for an extended period, until the SOA becomes very long.

(5) Fifth segment : Over the interval of very long SOAs, the prototype PRP curve falls to its lowest level, whose source is Path 5. Along this segment,

the Task 2 RTs are minimal because the preparation benefit time, tp2, is subtracted from the total movement-production time.

b. *Qualifications about the prototype curve :* Of course, the prototype PRP curve will never be observed directly in an experiment. Across experimental trials, real participant's performance - like the SRD model's parameters - may vary randomly, causing the prototype's individual segments to be smeared beyond recognition when viewed in terms of empirical mean Task 2 RTs. Nevertheless, some instructive insights are provided by examining the form of the prototype in the absence of such randomness. As a result, the contributions of underlying component processes to Task 2 RTs become more clearly visible at each SOA.

c. *PRP curve families :* On the basis of the prototype PRP curve the SRD model can produce several distinct families of theoretical PRP curves whose shapes are more or less similar to the prototype. For now, only four such families are considered here. They do not exhaust the entire range of possibilities, but they do constitute some especially instructive cases.

The PRP curve families shown in Figure 9 have several salient properties. Within each family, the only parameter that changes from one curve to the next is the Task 2 response-selection time (ts2), corresponding to systematic variations of response-selection difficulty; all the SRD model's other parameters are assumed to be constant for the different curves of a family. Consequently, all the depicted curves consist of concatenated linear segments. However, across families, other parameters besides the Task 2 response-selection time change systematically, causing the shapes of the curves in one family to differ from those in another.

Family 1 contains PRP curves such that each involves some postselection slack and has five segments like the prototype curve does. Family 2 contains PRP curves such that each involves a relatively long ocular orientation time, which introduces preidentification slack instead of postselection slack in Task 2 RTs at very short SOAs. By definition, the term preidentification slack is a period of time during which identification of the stimulus for a task has not yet begun even though the stimulus has been presented. Task 2 would include such slack if a visual stimulus for it occurs at a peripheral location to which the eyes are moved only after the stimulus's onset. This change again yields five segments per curve, but the left-most segments have somewhat different positions and extents than those of the

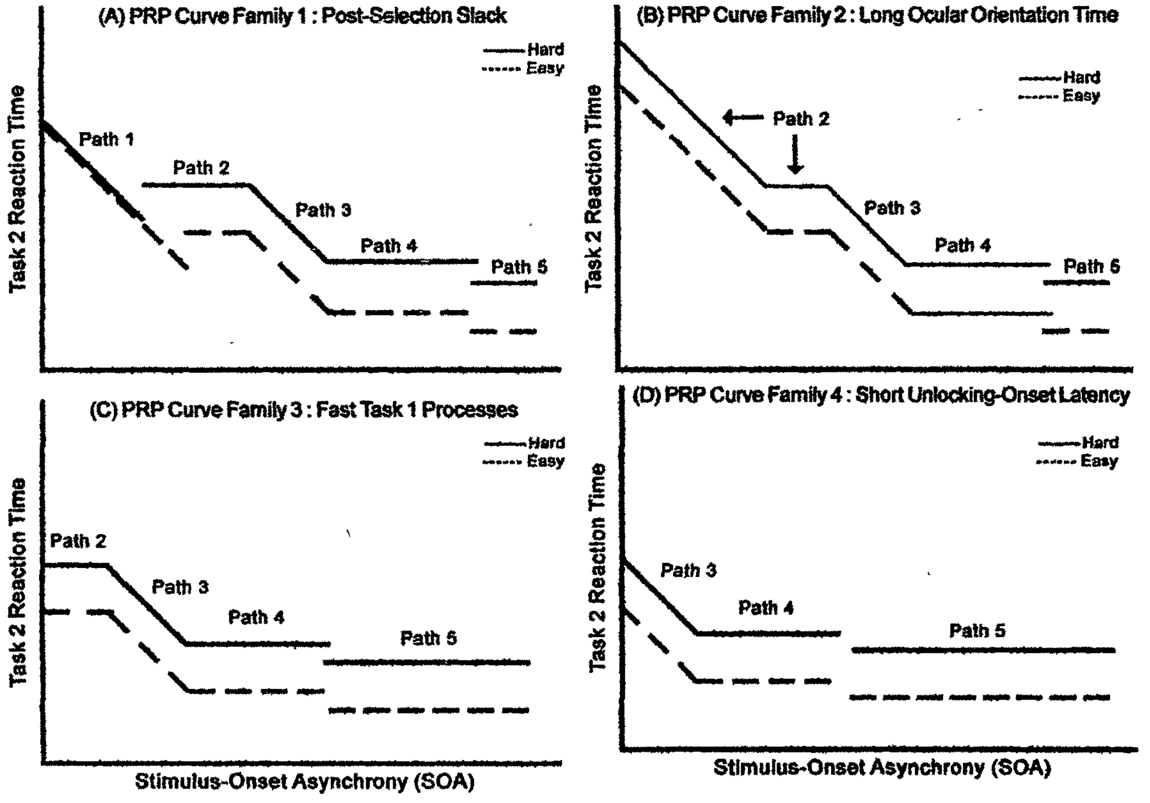

Fig 9 The prototype PRP curve implied by SRD model

curves in Family 1.

Family 3 contains PRP curves such that each involves relatively fast Task 1 processes, which introduce midselection instead of postselection slack at very short SOAs, yielding four rather than five segments per curve.

Family 4 contains PRP curves such that each involves a relatively short unlocking onset latency, which introduces preselection instead of postselection slack at very short SOAs, yielding only three segments per curve.

Viewed overall, these families of curves represent a range possibilities that may emerge from the SRD model depending on a particular values of its parameters. In some cases (e.g., Family 4), quantitative relations among the PRP curves of a family are similar to what a simple response-selection bottleneck model might imply. Testing the SRD model and evaluating it against other competitors therefore requires careful thought and control over the parameter values that an experiment entails.

3.8 PROTOCOL FOR SIMULATIONS WITH SRD MODEL

To demonstrate the applicability of the SRD model and its EPIC information-processing architecture, they are used in computer simulations of representative past studies with the PRP procedure. This allows detailed quantitative comparisons between simulated RTs produced by the model and empirical RTs obtained across various experimental contexts. Although good fits between the simulated and empirical RTs do not prove definitively that the model is correct, they at least establish it as a serious theoretical contender.

Before simulations began, software modules were programmed for each component of the EPIC architecture, including its perceptual processors, motor processors, cognitive processor and memory stores. These modules have been written in the LISP programming language and embody EPIC's basic assumptions in executable form. The functional properties of the architecture have remained the same throughout the simulations, just as real participants' underlying perceptual-motor and cognitive mechanisms presumably do during typical laboratory testing.

a. *Steps in each simulation :* Each simulation involves several steps. Together, these steps are analogous to ones that an experimenter would take in trying to replicate an actual empirical study using human participants.

1. Selection of empirical PRP study
2. Preparation of environment-simulation program
3. Preparation of executive and task production rules
4. Assignment of numerical parameter values
5. Execution of simulation programs
6. Data analysis

4.0 COGNITIVE AND AFFECTIVE STYLES

In fact while studying individual difference Meyer and Kieras (1997) found that "..Nevertheless, when task 1 is difficult, some people might still adopt a daring scheduling strategy. This prediction follows from several more considerations : (a) regardless of whether task 1 is easy or difficult, EPIC enable various task 2 lockout points and task 1 unlocking events to be used for task scheduling; (b) people differ in the extent to which their performance is routinely cautious or daring; (c) despite strong rewards for cautiousness, some individuals continue to perform daringly." Thus, individual differences may emerge which might be reflective of stylistic performance, which is discussed here below.

While proposing structural aspects of a multidimensional, system dynamic model of stylistic processing, Wardell Douglas M. and Royce Joseph R. (1978) stated that, "styles are distinguished as cognitive, affective and cognitive-affective constructs depending upon their association with either cognitive abilities, affective traits or both." Their taxonomy of styles has been shown in Table 4.

Table 4 shows classification of styles

Cognitive Styles	Affective Styles	Cognitive-Affective Styles
Cognitive styles	Tolerance for unconventional or unrealistic experiences	Field articulation
Cognitive complexity		Extensiveness of scanning
Cognitive differentiation	Constricted vs. flexible control	
Category width	Reflection vs. impulsivity	
Cognitive integration	Physiognomic vs. literal	
Analytical vs. relational categorizing		
Compartmentalization		
Abstract vs. concrete		
Levelling vs. sharpening		

Guralnik (1976), defined cognitive styles as "a subset of the general construct of style, which can be defined as a distinctive and characteristic manner....or method of acting or performing". Their classification of style has been as cognition centred, personality-centred and activity-centred as given in the Table 5.

Of interest here, are the two cognitive styles viz. Conceptual tempo, and Field dependence vs. independence.

1. Conceptual tempo : It is also referred as reflection-impulsivity polarity. Reflectivity

Table 5 Showing classification of styles

Cognition-Centred	Personality-Centred	Activity-Centred
Abstract vs. category width	Extraversion-introversion	Deep vs. elaborative
Cognitive complexity	Intuition-sensing	Environmental
Compartmentalization	Thinking-feeling	Emotional
Conceptual differentiation	Concrete-sequential	Sociological
Conceptual integration	Abstract-sequential	Physical
Conceptual style	Concrete-random	Realistic
Conceptual tempo	Abstract-random	Investigative
Constructed vs. flexible control		Artistic
		Social
Field independence vs. independence		Enterprising
Scanning		Conventional
Tolerance for unrealistic experiences		Wider vs. limited

is the tendency to consider and reflect on alternative solution, possibilities. Reflective individuals pause to think before beginning a task or making a decision and spend time evaluating their options. Conversely, impulsivity is the tendency to respond impulsively without sufficient forethought. Impulsive individuals quickly offers solutions to problems, without sufficient consideration of the probable accuracy of the solutions. Operationally, reflectivity-impulsivity typically has been measured by patterns of response latencies and errors on relatively simple, highly speeded tasks. In particular, a reflective person will have a longer response time with less errors. The instrument most frequently used to measure the construct has been the Matching Familiar Figure Test, in which a person is required to select from among several alternatives the one that exactly matches a standard. The number of errors and the time to complete the test are measured, and the median split is viewed as a cutoff for categorizing individuals. People with faster response times and relatively more errors are called impulsive; those with longer response times and few errors are called reflective.

2. Field dependence-independence : This polar construct is also known as psychological differentiation. It refers to the extent to which a person is dependent

versus independent of the organization of the surrounding perceptual field. The two principal measures of psychological differentiation are the Rod and Frame Test (RFT) and Embedded Figure Test (EFT). In the EFT individuals must locate a previously seen simple figure within the context of a larger, more complex figure that has been purposefully designed to embed and obscure the simple figure. Evidence suggests a close connection and perhaps an identity between field independence and aspects of intelligence.

Having covered relevant introduction in the field of PRP, EPIC and cognitive style, the discussion now proceeds to the current research.

5.0 PRESENT RESEARCH

Current research is intended to address following four sets of questions -

1. Real life situations actually demand task 2 priorities than task 1 as it is typically designed in PRP experiment. With this change in PRP experiment design -
   - What are the PRP effect and reaction time ?
   - What could be alternative production rules for the same ?
   - Which algebraic equation of SRD model fits in case of such a situation ?
2. Almost all multiple-task experiments generally follow dual-task procedures only.
   - What happens in case of 3 task experimental set up ?
   - How working memory shall become an important parameter in such cases ?
3. If experimental findings focuses on individual differences -
   - How stylistic differences (Field dependence-independence and Reflectivity-impulsivity cognitive-affective styles) shall be related with experimental findings ?
   - How cautious and daring styles shall relate with PRP findings ?
4. If data is analysed in terms of individual performance from trial to trial

- How much data shall actually fit with SRD model equations ?

- Can such data inform about executive processes ?

Study of this subject matter helps in understanding -

1. Architecture of human information processing system.

2. Structural interface of its components.

3. Capacities of these components.

4. Multiple Task Performance in the given contexts.

5. Principles to facilitate human performance in multiple task situations.

6. Interaction between cognitive and affective processes.

7. Individual differences in multiple-task performance.

8. Fundamental understanding of human information processing.

9. Possibility of construction of scales for selection, placement and training of individuals.

10. Task Designs in such a way so as to gain better performance especially in the context of human factors engineers.

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